“Studies on effects of plant growth regulators in polyhouse grown tomato (*Solanum lycopersicum* L.)”

THESIS

By

MUHAMMAD JUMA

(A-2019-30-054)

Submitted to

CHAUDHARY SARWAN KUMAR

HIMACHAL PRADESH KRISHI VISHVAVIDYALAYA

PALAMPUR – 176 062 (H.P.) INDIA

in

Partial fulfilment of the requirements for the degree

of

MASTER OF SCIENCE IN AGRICULTURE HORTICULTURE (VEGETABLE SCIENCE)

DEPARTMENT OF VEGETABLE SCIENCE AND FLORICULTURE

2021

Dr. Parveen Sharma
Professor

Department of Vegetable Science and Floriculture
CSK Himachal Pradesh Krishi Vishvavidyalaya
Palampur – 176062 (H.P.) India

CERTIFICATE – I

This is to certify that the thesis entitled **"Studies on effect of plant growth regulators in polyhouse grown tomato (*Solanum lycopersicum* L)"** submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Agriculture)** in the discipline of **Horticulture** (**Vegetable Science)** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Mr. Muhammad Juma (A-2015-30-054)** son of **Mr. Khudidust** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place : Palampur
Dated:

(Dr. Parveen Sharma)
Major Advisor

CERTIFICATE- II

This is to certify that the thesis entitled **“Studies on effect of plant growth regulators in polyhouse grown tomato (*Solanum lycopersicum* L)”** submitted by **Mr. Muhammad Juma (Admission No. A-2019-30-054)** son of **Mr. Khudidust** to the CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture)** in the discipline of **Horticulture (Vegetable Science)** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

(Dr. Parveen Sharma)
Chairperson Advisory Committee

(Dr. Pardeep Kumar)
Dean, Central University, Dharmshala
External Examiner

(Dr. Akhilesh Sharma) Member

(Dr. V.K. Sharma)
Member

(Dr. Shivani Katoch)
Dean’s Nominee

Head of the Department

Dean, Postgraduate Studies

ACKNOWLEDGEMENTS

A dream doesn't become reality through magic; it takes sweat, determination and hard work. I would like to thank "Allah", the merciful, who bestowed me with health, tenacity and courage enough to go through this crucial juncture. The work presented in this thesis would not have been possible without my close association with many people, who were always there when I needed them the most. I take this opportunity to extend my sincere gratitude and appreciation to all those who made this thesis possible.

I would like to thank my late father ***Mr. Khudidust**, **My Mother, family, Ali Dost & Sayed Faqir*** *for allowing me to realize my own potential. All the support they have provided me over the years was greatest gift anyone has ever given me. I am also thankful to my younger brothers* ***Abdul Malik, Muhammad Waez and Farmanullah*** *for being there with me from bits to colossal in every part of life.*

I would like to express my deep sense of gratitude, indebtness and personal regards to the chairperson of my advisory committee, ***Dr. Parveen Sharma**, Professor, Department of Vegetable Science and Floriculture for introducing me to this exciting field of science and for his dedicated help, advice, patience and continuous support. His constant guidance, cooperation and motivation have always kept me going ahead. I feel privileged to be associated with a person like him during my life.*

My special words of thanks should go to members of my advisory committee ***Dr. Akhilesh Sharma**, Professor, Department of Vegetable Science and Floriculture,* ***Dr. V.K Sharma**, Principal Scientist, Department of Agronomy, and* ***Dr. Shivani Katoch**, Professor, College of Veterinary and Animal science, for their valuable suggestions and guidance.*

I feel utmost duty to express my sincere thanks to Dean post graduate studies, Dean College of Agriculture and ***Prof. H. K. Chaudhary**, Honorable Vice Chancellor CSK HPKV Palampur and other university authorities for providing necessary facilities.*

I take this opportunity to convey my sincere thanks to ***Dr. Desh Raj Choudhary*** *Head department of Vegetable science and Floriculture,* ***Dr. Sanjay Chadha**, **Dr. Sonia Sood**, **Dr. Viveka Katoch**, **Dr. VIshal Dogra**, **Dr. Ravinder Singh*** *and other members of Department of Vegetable Science and Floriculture for providing me unconditional helping hand whenever needed at various stages of this investigation and my studies.*

I must also thank the academic staff of the department, for their whole hearted help and support. Thanks are due to Lab staff and Field staff Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya for their help extended for the field and lab. I have had great fortune during my post graduate studies and research of having the proper guidance and help of my seniors, friends and juniors who devotedly supported me over this thesis journey. I would like to thank my seniors Dr. Shilpa, Vandana, Manpreet Kaur and Payal for their support. A friend in need is a friend indeed, this proverb, seem to be absolutely true when I remember my friends Dr. Farhan Bhat, Nasratullah, Hazrat Mohammad, Abdul Ahad, Dr. Rafiullah, Abozar, Abdullah, Hasibullah, Tariq, Mohammad Ilyas, Saleman, Sachin, Ayush, Vikas, Rashmi, Shipra, Himani, Tejal, Sheetal, Shimalika, Nancy, Sinchana, Parul, Amita Naagar and Neeraj Gill for their cooperation, support and help during the course of investigation.

Acknowledgement is inherently endless & incomplete and I request indulgence from many friendly & helpful people whom I could not name here, due to paucity of space. It is worth mentioning the beautiful town Palampur and International Students Hostel for some unforgettable experience and memories.

Needless to mention, errors and omissions are mine.

Place : Palampur ***(Muhammad Juma)***

Dated :

TABLE OF CONTENTS

LIST OF ABBREVIATIONS USED

Sr. No.	Abbreviation	Meaning
1	et al.	Et alii (and others)
2	*viz.*	Vi delicet (namely)
3	p.	Page
4	pp.	Particular Page
5	^{o}C	Degree Celsius
6	g	Gram
7	Kg	Kilogram
8	mg	Milligram
9	%	Per cent
10	Fig.	Figure
11	cm	Centimeter
12	m	Meter
13	mm	Millimeter
14	m^2	Meter square
15	≤	Less than equal to
16	≥	More than equal to
17	@	At the rate
18	&	And
19	df	Degree of freedom
20	N	North
21	E	East
22	UV	Ultraviolet
23	No.	Number
24	GA_3	Gibberellic acid
25	NAA	Naphthalene acetic acid
26	ppm	Parts per million
27	RH	Relative humidity
28	TSS	Total soluble solids
29	NPK	Nitrogen, phosphorous and potassium
30	^{0}B	Degree Brix
31	ha	Hectare

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Department of Vegetable Science and Floriculture
CSK Himachal Pradesh Krishi Vishvavidyalaya
Palampur- 176062 (HP)

Title of the thesis	:	"Studies on effect of plant growth regulators in polyhouse grown tomato (*Solanum lycopersicum* L.)''
Name of the student	:	Muhammad juma
Admission number	:	A-2019-30-054
Major discipline	:	Vegetable Science
Minor discipline	:	Agronomy
Date of thesis submission	:	
Total pages of the thesis	:	78
Major Advisor	:	Dr. Parveen Sharma

ABSTRACT

The present investigation entitled "Studies on effect of plant growth regulators in polyhouse grown tomato (*Solanum lycopersicum* L.)" was carried out at Vegetable Research Farm of the Department of Vegetable Science and Floriculture, CSK HPKV Palampur, Himachal Pradesh during spring-summer and autumn-winter season with the objectives to study the effect of different plant growth regulators on yield, quality and to work out the economics of production under protected conditions. The experiment was laid out in a Factorial Randomized Block Design with three replications and data were recorded on horticultural and quality traits in tomato. The recommended package of practices and plant protection measures were followed from time to time to grow healthy crop. Among the different plant growth regulators GA_3 @75 ppm resulted maximum number of fruits per plant, fruit weight and marketable yield per plant, marketable yield per m^2 area, ascorbic acid content plant height and minimum number of days to 50 % flowering. Highest fruit yield (27.65 kg/m^2) with maximum net returns (394.00 $/m^2$) and higher benefit: cost ratio (2.48) was obtained with the treatment combination involving T_{16} (GA_3 @ 75ppm + All above three stages) during autumn-winter season. The combined effect of growth regulators at different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) and A_2B_1 (NAA @ 50 ppm sprayed at flowering stage) recorded maximum (27.40 and 30.97 mg/100 g) ascorbic acid content for first and second season. The combined effect of growth regulators at different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) recorded maximum (24.59 kg and 27.65 kg) marketable yield per m^2 during both the seasons which was significantly superior from all other two-way interactions. Therefore, it has been concluded that tomato plants sprayed with GA_3 @ 75ppm at flowering stage recorded maximum marketable yield and its contributing characters.

(Muhammad Juma)	**(Dr. Parveen Sharma)**
Student	Major Advisor
Date:	Date:

Head of the Department

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) (2n=2x=24) is one of the most important solanaceous vegetable crop cultivated throughout the world due to higher adaptability, yield and suitability for variety of uses in fresh as well as processed food industries. The crop is native to Central and South America (Vavilov 1951), It is popularly known as 'Love Apple', which is grown under kitchen garden (Kumar et al. 2013; Dhyani et al. 2018).

Tomato is regarded as nutritional vegetable crop and good source of Vitamin A (1000 IU), Vitamin C 22 mg), minerals like potassium, iron, calcium, soluble and insoluble dietary fibers, organic acids (malic and citric acid) and serve as a cheapest source to meet daily nutritional requirements (Saleem et al. 2013; Gupta et al. 2019). Lycopene, phenolics and ascorbic acid is the predominant antioxidant present in tomato fruits that reduces the risk of prostrate cancer (Hossain et al. 2004; Rai et al. 2012). Green unripe fruits are generally used for the preparation of chautney and pickles (Sharma et al. 2019). Ripe tomato fruit contains water (94.1%), energy (23calories), calcium (1.0 g), magnesium (7.0 mg), thiamine (0.09 mg), riboflavin (0.03 mg) and niacin (0.8 mg). It is also considered as a very good source of income for marginal and small-scale farmers as it contributes to the nutrition of the consumer (Singh et al. 2010).

In India, it covers an area of about 8.12 lakh hectares with a production of 20.57 million MT (NHB 2019). In India, tomato is mainly produced in Madhya Pradesh, West Bengal, Tamil Nadu, Bihar, Maharashtra, Andhra Pradesh, Karnataka, Gujarat, Odisha, Chhattisgarh, Uttar Pradesh, Telangana and Haryana. It is one of the most important off-season vegetable crop of mid and low hills of Himachal Pradesh and is grown in an area of about 11.06 thousand hectares with an annual production of 473.28 thousand MT, bulk of which is exported to adjoining plain markets (Anonymous 2017).

Tomato can be grown under diverse climatic conditions for various physiological activities but high altitudes and low humidity are best suitable conditions for tomato growth and yield. For summer and winter season, regions having altitude less than 300 and above 1200 m are most preferred, respectively (Fontes and Silva 2002). It is a warm season crop and optimum range of temperature is 20-24ºC. It requires 21-28 °C Day temperature and 15-20 °C cool night temperature for proper fruit setting. High temperature, humidity, rainfall and light intensity are the limiting factors of tomato production. High day and night temperature above

32 °C and 21 °C, respectively, was reported as limiting factor to fruit-set due to an impaired complex of physiological process in the pistil, which results in floral or fruit abscission.

Despite its economic importance, growers are not in position to produce good quality tomato with high productivity due to various biotic (pest and disease), abiotic (rainfall, temperature, relative humidity and light intensity) and crop factors (flower and fruit drop) (Dhillion et al. 2019). In open field conditions, year round production is not possible due to susceptibility to several biotic and abiotic stresses. Therefore, protected cultivation has been gaining importance in Himachal Pradesh on account of favourable growing conditions. Inside protected cultivation is the best substitute to overcome these stresses (Sinha et al. 2020). Protected cultivation offers several benefits like earliness, improved quality and productivity, pesticide residue free produce with higher returns to the growers. As per the crop species, the microclimate surrounding the crop is partially or fully controlled, so protected cultivation is a specialized and unique form of agriculture (Lekshmi and Celine 2015). Indeterminate varieties, under protected conditions are considered as best with higher yield and high returns due to their innate capacity of growing for longer period of time and utilize vertical space (Singh and Kumar 2017).

In tomato, growth, yield and quality of crop is affected by several factors particularly in adverse climatic conditions and plant growth regulators reported to play an important role in adverse climactic conditions. Plant growth regulators are a chemical substance with small concentration, which stimulate and regulate the physiological processes of the plants (Siwna et al. 2018). Among different growth regulators, gibberellic acid (GA), naphthalene acetic acid (NAA), 4-CPA and 2, 4-D is widely applied around the world. PGRs affect fruit set, fruit size, growth as well as yield and quality under low and high temperature. Use of plant growth regulators also contributes in enhancing the production of tomato and other vegetables in reverence of better growth and yield (Saha 2009).

GA_3 is a naturally occurring plant hormone that affects, cell enlargement and cell division which leads to inter node elongation in stem cells. Gibberellic acid enhances fruit setting, controls pre harvest fruit drop, increases fruit yield and extends shelf life (Pramanik et al. 2018).

NAA is commonly used in horticultural crops. It helps to stimulate different physiological activities of the plant including cell division, cell elongation, shoot elongation, photosynthesis, RNA synthesis membrane permeability and water uptake. It helps to prevent pre harvest fruit drop, higher fruit set, flower induction, leaf chlorophyll content, delayed senescence and prevent bud sprouting therefore improves yield (Razzak et al. 2011). It also affects the physiological processes, hasten maturity, produces better quality fruits and some other aspects such as increase the number of branches, increased fresh weight and yield (Pramanik et al. 2018). A large number of plant growth regulators are available in the market but their concentrations may vary from crop to crop, season to season and climate to climate. Thus, there is need to identify the most suitable plant growth regulators with their concentration to increase the yield as well the quality parameters of tomato under protected conditions.

Keeping in mind the limitations in production of the tomato crop and the importance of shift in human's approach towards increase in production of the crops around the world, it is imperative to work out possible solutions to increase production in response to the increasing population of the world. Therefore, the present study was formulated to know the effect of different plant growth regulators with different concentrations on yield and quality traits of tomato with the following objectives.

Objectives:

(1.) To study the effect of different plant growth regulators on yield and quality in tomato and

(2.) to work out the economics of production under protected conditions.

2. Review of Literature

Tomato is one of the most popular and most widely cultivated crop in the world. This crop is receiving much attention of the scientists to determine the effect of different plant growth regulators for successful cultivation. Plant growth regulators (PGRs) are used extensively in tomato to enhance plant growth and improve yield by increasing fruit number, fruit set and size (Batlang 2008; Serrani et al. 2007). These growth regulators play a pivotal role in germination, root development, branching, flower initiation, fruiting, lycopene development, synchronization, early maturation, parthenocarpic fruit development, ripening, TSS acidity and seed production (Pramanik and Mohapatra 2017). However, in this chapter, literature pertaining to effect of naphthalene acetic acid (NAA) and gibberellic acid (GA_3) on growth, yield and quality has been reviewed under the following heads.

2.1 Effect of Gibberellic Acid (GA_3) on growth, yield and quality

2.2 Effect of Naphthalene Acetic Acid (NAA) on growth, yield and quality

2.1 Effect of Gibberellic Acid (GA_3) on growth, yield and quality

Gibberellic acid is the most important growth stimulating commercially used in horticulture since long. It promotes cell elongation and division, enhance germination, flowering, pollination, fertilization, leaf expansion, increase fruit set, fruit size, improves quality of fruits, dormancy breaking and other aspects of growth and development of plant which ultimately leads to higher crop production. Gibberellic acid application controls flower and fruit drop, increases the yield if applied at right time with right concentration in tomato (Feofanova 1960).

GA_3 application helped in synthesis of protein including various enzymes, increased the rate of shoot elongation and photosynthetic capacity leading to higher total leaf area and leaf dry weight in tomato (Ballantyine 1995; Mostafa and Saleh 2006).

Gemici et al. (2000) reported that application of GA_3 at 10 ppm showed a 17% increase in stem length and fruit size. Meanwhile and year.2006, Bokade and his co-workers identified that plants treated with 50 ppm GA_3 gave maximum plant height and early flowering. In another study intiated by Pundir and Yadav in 2001, reported that the treatment of GA_3 at 50 ppm recorded the highest plant height.

Bhosle et al. (2002) conducted an experiment to study the effects of NAA (25, 50 and 75 ppm), gibberellic acid (15, 30 and 45 ppm) and 4-CPA (25, 50 and 75 ppm) on the growth and yield of tomato. GA_3 at 30 ppm resulted in maximum plant height while, 25 ppm 4-CPA and 45 ppm GA_3 resulted in maximum number of primary branches in varieties Dhanashree and Rajashree, respectively. Highest marketable yield was reported with use of 4-CPA at 75 ppm.

Khan et al. (2006) identified that application of GA_3 (10^{-8}M) gave best results in terms of number of fruits per plant, yield and higher lycopene content. The plants treated with GA_3 increased plant height, leaf area, leaf P content, fruit number, fruit yield and lycopene content of fruit as confirmed by Masoor et al. (2006). Whereas, in the same year Orzolek and Kaplan (2006) observed that the combination of GA_3 and Nutra-Phos 3-15 produced higher fruit yield as compared to the control. The concentration of GA_3 at 25 and 50 ppm increased plant height in tomato reported by Rai et al. (2006) and Nibhavanti et al. (2006).

Meena (2008) applied foliar spray of GA_3 at 50 ppm and 75 ppm and recorded significantly lower fruit drop (percentage). Application of GA_3 at 50 ppm showed higher TSS, ascorbic acid content, TSS per acid ratio and lower acidity percentage with maximum benefit-cost ratio (5.57).

Balaguera-Lopez and Hernandez (2009) reported that soaking of seeds in GA_3 (900 mg/l) showed maximum seed germination, root length, dry matter, stem and root fresh matter, leaf area, stem and total dry matter, leaf and root fresh matter along with assimilation rate. At the same time Uddain et al. (2009) revealed that GA_3 at 30 ppm was found superior for improvement of growth, yield and quality traits in tomato among different plant growth regulators. They recorded maximum plant height, number of leaves per plant, number of branches per plant, number of flower clusters, number of flower, cluster per plant, number of flowers per plant, number of fruit clusters, number of fruits per plant, average fruit weight, yield per plant and yield per ha.

Gelmesa et al. (2010) determined the effect of different concentrations and combinations of 2, 4-dichlorophenoxyacetic acid (2, 4-D) and gibberellic acid (GA_3) spray on fruit yield and quality of tomato. Increase in fruit length was observed with application of 10 mg/l of 2, 4-D combined with 10 mg/l GA_3 and increased fruit weight by 13% with 2,4-D spray. Titratable acidity, total soluble solids, lycopene content and fruit pericarp thickness (about 50%) were also increased due to combined application of 2,4-D and GA_3 spray. Final fruit yield was significantly improved with application of plant growth regulators. In Rome VF, GA_3 at concentration of 10 and 15 mg/l resulted in maximum fruit yield per hectare, respectively. Hence, yield increment of about 35% for Roma VF and 18% for Fetan were produced at 10 mg/l GA_3 and 10 + 15 mg/l 2, 4-D and GA_3, respectively. Significant increase in fruit size and weight due to 2,4-D and increased fruit number due to GA_3 spray contributed to increased fruit yield. The results indicated that both PGRs are important in tomato production to boost yield and improve fruit quality under unfavourable climatic conditions.

Desai et al. (2011a) conducted an experiment to study the role of plant growth regulators and micronutrient on growth and yield of tomato. GA_3 at 75 ppm showed maximum fruit length, girth and pulp-seed ratio while, naphthalene acetic acid at ppm displayed maximum fruit weight, yield per plant and yield per hectare. While in the year 2012, Gelmesa and his co-workers assessed the effects of foliar spray of 2, 4-D and GA_3 on fruit setting in tomato. Application of GA_3 increased fruit set percentage and marketable fruit number per plant.

Verma et al. (2011) conducted an experiment with the intention of investigating the influence of different concentrations of NAA, 2, 4-D and GA_3 on growth, quality and yield of tomato. They identified that GA_3 at 40 ppm displayed maximum plant height, minimum days of first flowering, maximum number of flowers per plant, number of fruit cluster, number of flower cluster per plant, number of fruits per plant, internodal length, fruit length, average fruit weight, TSS and minimum acidity in tomato.

Choudhury et al. (2013) reported that GA_3 at 20 ppm gave best results in tomato among all the plant regulators. Maximum plant height at 60 DAT, number of flower clusters per plant, number of flowers per plant, number of fruits per plant, average fruit weight and fruit yield with 20 ppm $GA_{3.}$ Whereas, in the same year Prasad et al. (2013) revealed that tomato plant sprayed with 80 ppm GA_3 showed maximum plant height and higher yield.

Sultana (2013) revealed that application of GA_3 at 50 ppm increased the plant height, number of leaves, number of flower clusters and plant, number of flowers per cluster, number of fruit clusters per plant, fruit diameter, weight of fruits per plant and yield of tomato.

Kumar et al. (2014) determined the effect of GA_3 (10 ppm, 20 ppm, 30 ppm, 40 ppm and 50 ppm) on growth and yield of tomato. Application of GA_3 at 50 ppm showed maximum plant height, number of leaves, and number of fruits fresh fruit weight, ascorbic acid, TSS and yield followed by 40 ppm $GA_{3.}$ Whereas in the same year another research was been conducted by Mazed et al. (2014) observed that GA_3 had significant influence on growth and yield contributing characters of tomato. GA_3 spray at 120 ppm recorded highest plant height, maximum number of leaves per plant and yield per hectare. In the same year Prajapati and Varma (2014) reported that application of GA_3 at 50 ppm developed maximum number of branches and minimum days for initiation of flowering in sweet pepper.

Ram et al. (2014) identified GA_3 superior among all treatments in terms of exhibiting maximum plant height (cm), number of branches, number of flowers per plant, number of clusters per plant, number of fruits per cluster, number of fruits per plant, average fruit length (cm), average fruit diameter (cm), average fruit weight (g), fruit yield per plant (kg), fruit yield per plot (kg), fruit yield per hectare (q), acidity (%) and TSS as compared to NAA in tomato.

Akand et al. (2015) determined the effect of different concentrations of Gibberellic acid (0, 75, 100 and 125 ppm) on growth, yield and quality in tomato genotype *viz*., golden. Application of GA_3 at 125 ppm resulted in maximum plant height, number of leaves per plant, dry matter content of leaves, dry matter content of stem, dry matter content of root, dry matter content of fruit, number of flowers per plant, number of fruit clusters per plant, number of fruits per plant, fruit length, fruit diameter, yield per plant and yield per hectare.

Begum et al. (2016) reported that application of GA_3 in winter tomato enhanced plant height, stem diameter, leaf number, leaf fresh weight, leaf dry weight, average weight of green fruit, ripened fruit per plant and yield per plant as compared to NAA. In continuous of research on growth regulators Chandiniraj et al. (2016) reported that application of GA_3 at 60 ppm gave maximum plant height, fruit diameter and minimum days to flowering in chilli.

Rahman et al. (2016) reported that application of GA_3 in tomato at 30 ppm showed minimum number of days to first flowering, maximum number of flowers per plant, number of fruits per plant, average fruit weight and fruit yield per hectare followed by NAA 30 ppm.

Saurabh et al. (2016) studied the effect of GA_3 (10, 20 and 30 ppm), NAA (20, 25 and 30 ppm) and 2, 4-D (5, 10 and 15 ppm) on growth and yield of tomato. They reported that as the concentration of GA_3 and NAA was increased, growth and yield was also increased. Among all the treatments, GA_3 at 30 ppm increased the plant height, number of flowers per plant, number of fruits per plant, number of primary branches, number of secondary branches, fruit diameter, fruit yield per plant and fruit yield / ha.

Ahmad et al. (2017) studied the influence of different plant growth regulators on growth, yield and quality in tomato. Application of GA_3 at 200 ppm was found best among all the treatments with maximum plant height, number of leaves, number of branches, minimum days to first flower, maximum number of flowers, number of fruits, fruit length, single fruit weight, yield per plant and yield / ha.

Shital et al. (2017) stated that the application of GA_3 at 50 ppm recorded significantly maximum plant height, number of branches per plant, number of fruits per plant, fruit length, fruit diameter, seed yield per plant, germination percentage, root length, shoot length, root fresh weight, shoot fresh weight, root dry weight and shoot dry weight in tomato.

Tomar et al. (2017) reported linear increase in growth parameters like plant height and number of branches per plant with increasing level of GA_3. GA_3 at 30 ppm showed maximum plant height, number of primary branches, number of secondary branches, number of flowers per plant, number of fruits per plant, fruit length, fruit weight and fruit diameter in tomato.

Gurjar et al. (2018) conducted an experiment to study the response of tomato varieties to different plant growth regulators. Four varieties (V1- J.T.-99, V2-Pusa Ruby, V3-Sel.-7, V4-DVRI-1) and 3 combinations of plant growth regulators at different concentrations (H1- 15 ppm GA_3 followed by 25 ppm NAA, H2- 30 ppm GA_3 followed by 50 ppm NAA, H3- 45 ppm GA_3 followed by 75 ppm NAA) were used in this study. Foliar application of 15 ppm GA_3 followed by 25 ppm NAA resulted in superior growth and yield attributing characters and lead to higher fruit yield in tomato. Combination of variety 'Sel.-7' and 15 ppm GA_3 and 25 ppm NAA was found best for increasing productivity of tomato crop. Variety 'Sel.-7' sprayed with 15 ppm GA_3 followed by 25 ppm NAA gave highest gross and net return along with B:C ratio followed by 'Pusa Ruby' sprayed with same concentration of plant growth regulators.

Hossain et al. (2018) recorded maximum plant height, shoot dry weight, cluster per plant, bud per cluster, flower per cluster, fruit per cluster with use of combination of 20 ppm NAA and 20 ppm GA_3 whereas, 20 ppm NAA showed maximum root dry weight in tomato crop.

Jakhar et al. (2018) studied the effect of plant growth regulators on growth and yield of tomato cultivar 'Shivaji'. Different concentrations of GA_3 (25, 50 and 75 ppm), NAA (25, 50 and 75 ppm) and Kinetin (25, 50 and 75 ppm) were sprayed at 7, 14 and 21 days after transplanting to study the growth behaviour and yield attributes of tomato. All growth, phenological as well as yield parameters was found to be significantly superior. Application of 50 ppm GA_3 gave maximum plant height, number of leaves per plant, number of branches per plant at 90 days after transplanting, minimum days to 50 % flowering, maximum numbers of flowers per plant, fruit length, fruit diameter, number of fruits per plant, fruit yield per plant and fruit yield per ha.

Kumar et al. (2018) studied the effect of plant growth regulators on growth, flowering, yield and quality of tomato. Among different concentrations of NAA (15, 30, 45 ppm), 2,4-D (5, 10, 15 ppm) and GA_3 (20, 30, 40 ppm), GA_3 at 40 ppm gave maximum plant height, flower cluster per plant, fruits per plant, internodal length, average fruit length, average fruit weight, titrable acidity, TSS and higher fruit set.

Rinchu et al. (2018) studied the effect of GA_3 and NAA on growth and fruit yield in tomato. Among all the treatments, application of GA_3 at 75 ppm gave maximum plant height, number of flowers per cluster, number of fruits per plant, fruit weight, fruit diameter and fruit yield per plant.

Siwna et al. (2018) reported that foliar application of GA_3 at 50 ppm gave maximum plant height, number of leaves per plant, number of branches per plant, fruit diameter, minimum days to first flowering, days to first fruiting, minimum days to maturity, highest TSS, acidity and ascorbic acid among GA_3, NAA and kinetin in tomato.

Gupta et al. (2019) determined the influence of different plant growth regulators including GA_3 (50 and 75 ppm), NAA (75 and 100 ppm), boron (75 ppm), combination of GA_3 and boron, NAA and boron. Application of combination of GA_3 and boron at 75 ppm showed highest plant height, number of primary branches, maximum number of flowers per plant and number of fruit clusters per plant.

Singh et al. (2019) reported that GA_3 at 30 ppm showed maximum plant height, number of primary branches, number of secondary branches, number of fruits per plant, number of flowers per plant and maximum fruit yield per plant in tomato.

Ali et al. (2020) conducted an experiment to study the effect of plant growth regulators on growth, yield and quality in tomato. They identified that application of 50 mg per liter of GA_3 and 20 mg per liter 4-CPA enhanced the fruit yield, early flowering and fruiting, TSS and vitamin C in tomato. Number of fruits per plant was increased with 50 ppm GA_3 application.

Mistry et al. (2020) reported that application of GA_3 at 100 ppm increased the plant height, number of leaves, number of fruits per plant, fruit weight, ascorbic acid and TSS among the different treatments of GA_3.

Naz et al. (2020) identified that GA_3 at 100 ppm exhibited maximum plant height, number of leaves per plant, larger leaf area, maximum fruit number, fruit length, fresh fruit weight, dry fruit weight, fruit yield, TSS, total acidity, vitamin, lycopene and carotenoids in tomato.

NAA

Naphthalene acetic acid is a synthetic plant hormone in the auxin family. It is known to stimulate cell division, cell elongation, shoot elongation, photosynthesis, RNA synthesis, membrane permeability and water uptake involved in many physiological processes. It reduces pre harvest fruit drop, increases flower induction, fruit set, delay senescence prevents bud sprouting, increase leaf chlorophyll content and fruit yield in vegetable crops (Razzak et al. 2011).

Mehta and Mathai (1976) observed that foliar spray of NAA at 0.2 ppm and 0.1 ppm gave significantly higher fruit set and minimum number of days to flowering in tomato, respectively. While in the year 1978, Kaushik and his co-workers showed that NAA at 1, 10 or 100 mg per liter increased fruit set per plant at lowest concentration, the highest concentration reduced fruit number when sprayed on tomato plants at the 2-leaf stage.

Sagar et al. (1978) reported that application of NAA 20 ppm at flowering stage significantly increased fruit number in tomato. They recorded higher yield with foliar application of NAA at 10 and 20 ppm at time of first flowering.

Gupta et al. (2000) identified that application of NAA at 75 ppm along with Humaur at 2000 ppm in tomato gave maximum plant height, minimum days to first flower initiation, minimum days to fruit setting, higher fruit yield with excellent shelf life of fruits.

Gupta et al. (2001) recorded minimum days for fruit setting in plant with the treatment of 25 ppm NAA in tomato. The foliar spray of 10 ppm NAA followed by pollination on initial trusses resulted in highest number of fruits and seed yield in tomato (Rodrigues et al. 2001). However, Alam and Khan (2002) reported that the fruit yield of tomato was affected by the NAA. NAA at 20 ppm increased the fruit weight, whereas, NAA at 25 ppm displayed maximum number of fruits per plant and fruit yield per plant.

Rai et al. (2002) reported maximum chlorophyll content, TSS, carotenoid content and titrable acidity with foliar use of NAA (75 ppm) and humaur (2000 ppm) while, IAA (25 ppm) and multiplex (2500 ppm) enhanced ascorbic acid content in tomato fruits. In another case study conducted by Olaiya et al. (2010) evaluated the effect of plant growth regulators (IAA, IBA and NAA) on biochemical parameters of tomato. Titratable acidity was increased with higher concentrations of IBA and NAA. NAA at 100 ppm increased the ash, crude fibre content, TSS, TSS to titrable acidity ratio.

Desai et al. (2011b) reported maximum acidity per cent and ascorbic acid with application of NAA at 75 ppm whereas, GA_3 at 75 ppm showed maximum reducing sugars, non-reducing sugars, total sugars and TSS. While, Patel et al. (2012) revealed that application of NAA increases the fruit diameter in tomato.

Abbasi et al. (2013) studied the effect of foliar application of naphthalene acetic acid (NAA) and calcium chloride ($CaCl_2$) on growth, yield and shelf life in tomato and reported that combination of calcium (1%) and NAA (0.02%) showed maximum number of flower clusters, highest fruit set percentage, minimum days to fruit maturity and maximum yield. NAA reduced pre-harvest fruit drop, which ultimately enhanced the yield in tomato.

Maurya et al. (2013) studied the effect of different concentrations of NAA (0, 20, 40, 60 and 80 ppm) on growth and yield in tomato. Application of NAA at 40 ppm increased the fruit yield by 30% in tomato. Whereas Rahman et al. (2013) studied the influence of ABT-6 hormone (10, 20, 30, 40 ppm) on growth and yield in tomato. Growth and yield traits were significantly affected with different levels of ABT-6 hormone. Application of 20 ppm ABT-6 hormone gave maximum plant height, number of leaves, number of branches fruit setting, number of flowers, number of fruits, fresh fruit weight and dry weight of fruits.

Moniruzzaman et al. (2014) reported that NAA at 40 ppm produced highest percentage of long and medium styled-flower, leaf photosynthesis, Fv/Fm (efficiency of photosystem II) and minimum days to flowering in BARI Begun-10. In the same year Pargi et al. (2014) determined the effect of NAA (10, 20, 30, 40 and 50 ppm) on biochemical parameters, growth and yield of tomato. Maximum plant height, number of leaves, number of fruits per plant, fruit weight, chlorophyll content, protein content and lycopene with application of 50 ppm NAA in tomato.

Tiwari and Singh (2014) conducted an experiment to find the most suitable plant growth regulator and their appropriate concentration to increase the production of tomato. Foliar spray of seven different plant growth regulators (Alar, Ethephon, Cipa, GA_3, 2,4-D, NAA, Paclobutrazol) with different concentrations were done at 30, 45 and 60 days after transplanting of the seedlings of the cultivar "Pant T-3". CIPA (20 ppm), paclobutrazol (10 ppm) reduced plant height significantly. Application of Alar (100 ppm), NAA (40 ppm) and Ethephon (100 ppm) increased number of branches whereas, early maturity of fruits was observed with 2, 4 D (10 and 5 ppm), CIPA (20 ppm) and Ethephon (100 ppm). Foliar spray of CIPA (20 ppm), 2-4 D (5 ppm) and NAA (40 ppm) showed more number of fruits per plant while, higher fruit set was observed in CIPA (20 ppm), 2, 4-D (5 ppm) and GA_3 (10 ppm). Application of NAA (40 ppm), 2, 4-D (10 ppm) and paclobutrazol (20 ppm) showed higher TSS and pericarp thickness were greater in Ethephon (50 ppm), NAA (40 ppm), 2, 4-D (5 ppm) and CIPA (20 ppm). Highest fruit yield pre plant was recorded in CIPA (20 ppm), 2 4-D (5 ppm) and Alar (50 ppm).

Verma et al. (2014) reported that fruit set in tomato was successfully improved with application of NAA. Mizan (2016) evaluated the effect of different concentrations of NAA on growth and yield of tomato. Application of 50 ppm NAA gave maximum plant height, dry matter of fruit and yield. They suggested that foliar spray of 50 ppm NAA was found best for better growth and yield of tomato.

Jahan and Anamika (2017) revealed significant positive effects of NAA on the yield, storage behaviour and quality of tomato fruits. Number of fruits per plant and yield pre plant were significantly increased with single spray of 400 ppm NAA and double spray of 200 ppm NAA, which were higher than control by 26.92% and 15.38%, respectively. Maximum fresh fruit weight and minimum fruit weight loss were recorded due to double spray of 400 ppm NAA.

Tomar et al. (2017) studied the effect of different levels of NAA (20, 25 and 30 ppm) on growth of tomato. They reported that application of NAA at 30 ppm displayed maximum plant height, number of primary branches, number of secondary branches, number of flowers per plant, number of fruits per plant, fruit length, fruit weight and fruit diameter.

Singh et al. (2018) studied the effect of different concentrations of NAA (25, 50, 75 and 100 ppm) and GA_3 (20, 40, 60 and 80 ppm) on growth and fruit quality of tomato. Among all, GA_3 at 80 ppm and NAA at 100 ppm showed maximum plant height, number of branches, number of fruits per plant, average fruit weight (g), average yield per plant

(g) and yield per ha (t/ha). GA_3 at 80 ppm and NAA at 100 ppm could be used to improve the quality and yield attributing characters of tomato.

Ujjwal et al. (2018) determined the effect of foliar application of different levels of GA_3 and NAA on reproductive and quality attributes of tomato *cv.* Pusa Rohini. The different treatment concentrations tested were NAA (15, 20, 25 and 30 ppm) and GA_3 (20, 30, 40 and 50 ppm). All parameters related to yield and quality parameters were significantly influenced by different concentrations of the plant bio-regulators. Foliar application of GA_3 at 50 ppm resulted in higher reproductive aspects *viz.*, number of clusters per plant, number of fruits per cluster, number of fruits per plant, fruit set, fruit length, fruit diameter, fruit weight, yield and maximum TSS, while minimum acidity percent in fruits was recorded with foliar spray of NAA at 25 ppm.

3. MATERIALS AND METHODS

The present experiment was carried out under the naturally ventilated polyhouses having 250m^2 area each at the vegetable farm of Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya (CSKHPKV), Palampur during spring-summer and autumn-winter seasons. Details of the present investigation are presented below:

3.1 Site:

3.1.1 Location

Vegetable farm of CSK HPKV, Palampur is situated at an elevation of 1,290.8 m above mean sea level with 32º 6' N latitude and 76º 3' E longitudes. Both the experimental polyhouses were installed in this particular location.

3.1.2 Climate

The climate of the area is characterized with high rainfall, heavy winters and mild summers. This location is categorized as humid and sub temperate region, where approximately eighty per cent rainfall is received during June- September. The mean monthly relative humidity (RH) ranges from 46-48 per cent over the year in this region. It is very difficult to grow tomato crop in open conditions in Palampur due to heavy rains after July onward. Meteorological data recorded during spring-summer and autumn-winter seasons are given in Appendix-I and figure 3.1.

3.2 Materials and layout of the experiment

3.2.1 Experimental material

Palam Tomato Hybrid-1was used to study the PGRs effect under the protected environment. Foliar application of two growth regulators Gibberellic Acid (@ 50& 75ppm) and Naphthalene Acetic Acid (@ 50 & 75 ppm) concentrations were applied at vegetative, flowering, fruiting and all the three stages to test their effect on tomato yield and its attributing traits. The following study was carried out under naturally ventilated polyhouse having 250 m^{2}area. The details of the materials used in the experiment are given in the table 1.

Fig. 3.1: Mean weekly meteorological data during the cropping season (April to July 2020) inside the polyhouse

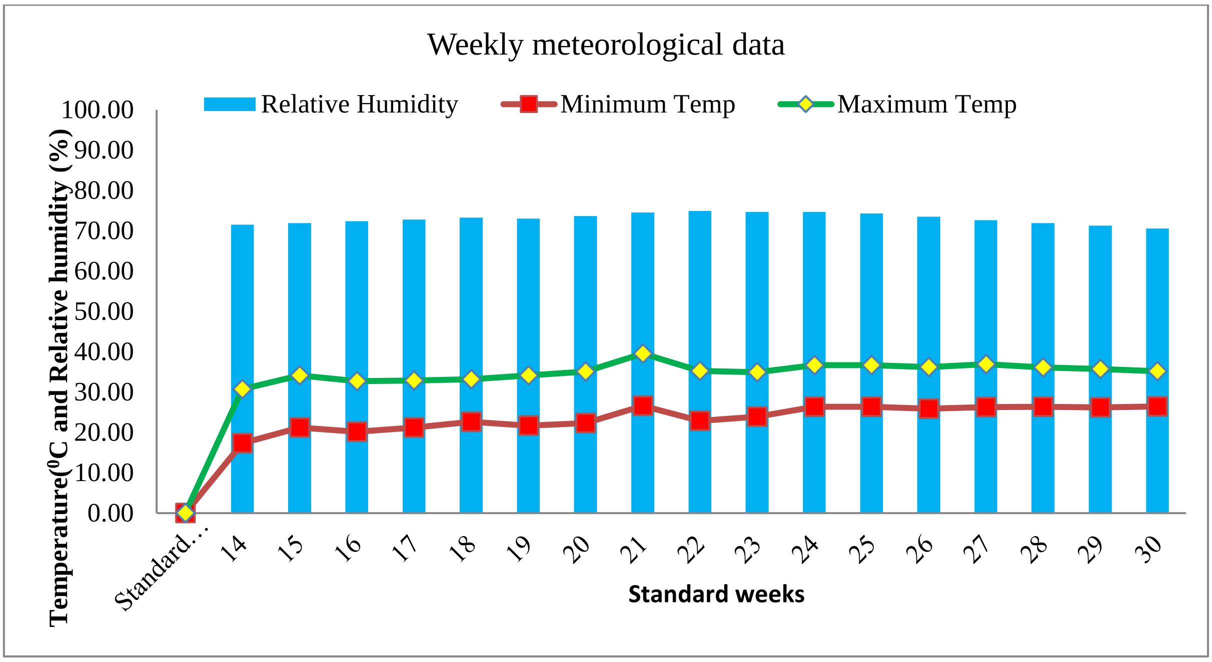


Fig. 3.2: Mean weekly meteorological data during the cropping season (September 2020 to February, 2021) inside the polyhouse

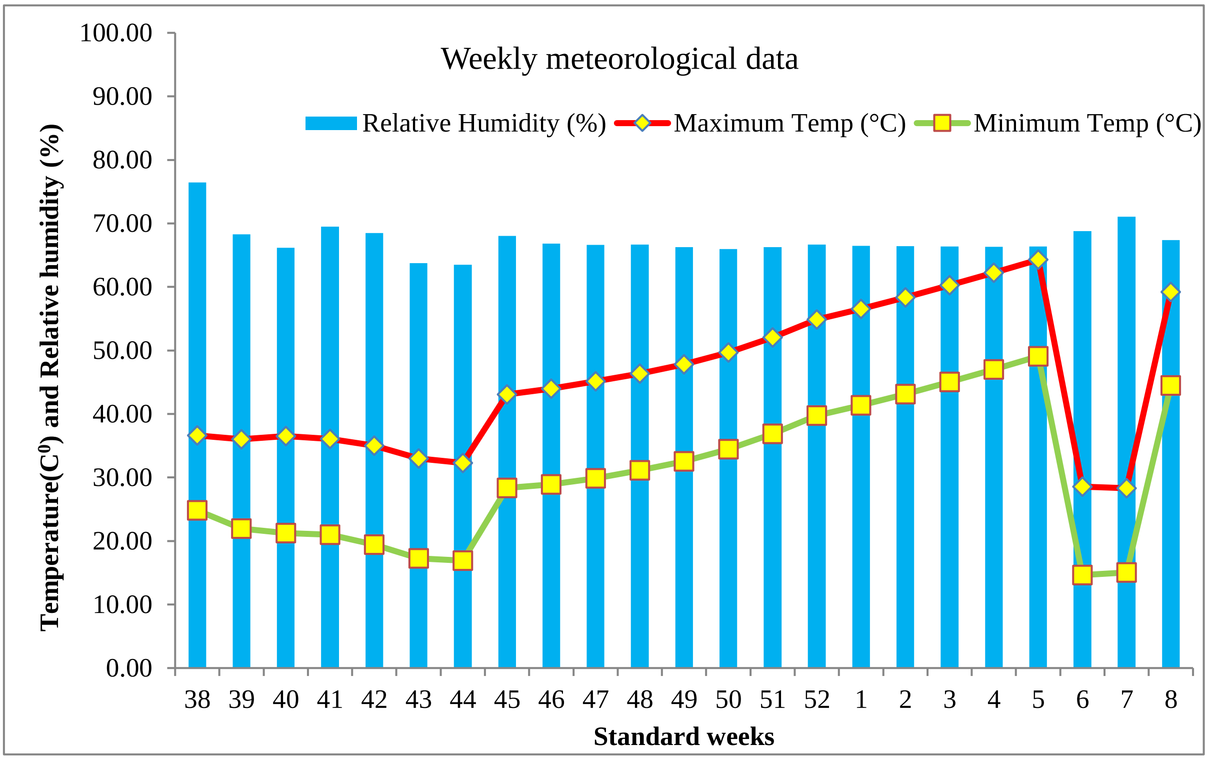


Table 1. Detail of experimental material

S.No.	Treatment code	Treatment details
1	T_1	GA_3 @ 50 ppm + Vegetative stage
2	T_2	GA_3 @ 50 ppm + Flowering stage
3	T_3	GA_3 @ 50 ppm + Fruiting stage
4	T_4	GA_3 @ 50 ppm + All above three stages
5	T_5	GA_3 @ 75ppm + Vegetative stage
6	T_6	GA_3 @ 75ppm + Flowering stage
7	T_7	GA_3 @ 75ppm + Fruiting stage
8	T_8	GA_3 @ 75ppm + All above three stages
9	T_9	NAA @ 50 ppm + Vegetative stage
10	T_{10}	NAA @ 50 ppm + Flowering stage
11	T_{11}	NAA @ 50 ppm + Fruiting stage
12	T_{12}	NAA @ 50 ppm + All above three stages
13	T_{13}	NAA @ 75ppm + Vegetative stage
14	T_{14}	NAA @ 75ppm + Flowering stage
15	T_{15}	NAA @ 75ppm + Fruiting stage
16	T_{16}	NAA @ 75ppm + All above three stages
17	T_{17}	Control (without any treatment)

3.2.2 Layout plan

The experiment was conducted in a factorial randomized block design with three replications inside the modified naturally ventilated polyhouse (25 m × 10 m). Sixteen plants of each treatment were planted at a spacing of 70 × 30 cm and trained on two stems in each replication.

3.2.3 Manure and fertilizer including fertigation

Before transplanting, vermicompost @ 1.0 kg/m^2 area and chemical fertilizers @ (50 kg each of N, P and K/ha) were applied. Fertigation was applied after three weeks of transplanting with water soluble fertilizers @ 150 kg each of N, P and K/ha twice a week and was stopped 15 days before final harvesting of the fruits.

3.2.4 Nursery sowing and transplanting

Seeds were sown in plug-trays on 3rd February, 2020 for spring-summer season and 23rd July, 2020 for autumn-winter season in soil-less media containing a mixture of coco peat: perlite: vermiculite (@ 3:1:1) in growth chamber to get healthy and disease free seedlings of tomato. The seedlings were transplanted at 3-4 leaf stage in the modified naturally ventilated polyhouse on 1st April, 2020 for spring-summer season and on 20th August 2020 for autumn-winter season.

3.2.5 Cultural practices

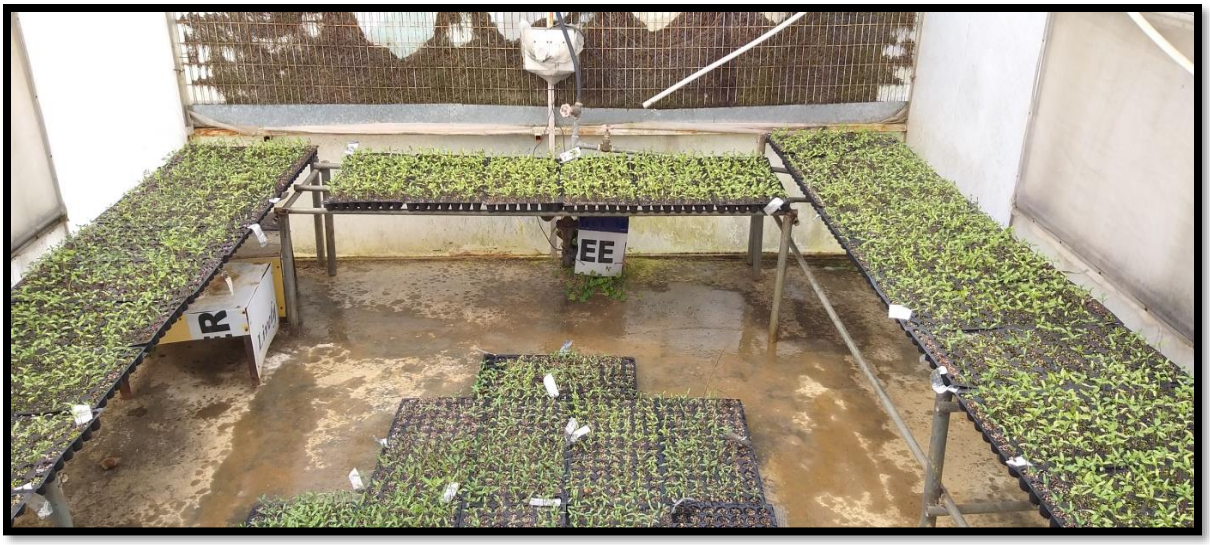
All the intercultural operations *viz*., hoeing, earthing up, irrigation, cutting, fertigation, training, pruning, staking and weeding were carried out in accordance with recommended package and practices of tomato. Irrigation was done through drip irrigation system three to four times a week as per the crop requirement. The plants were trained on two stems through jute and nylon twines.

3.2.6 Preparation of GA_3 and NAA

Spray solutions of GA_3 and NAA were prepared at the concentration of 50 & 75 ppm by dissolving 50 mg & 75 mg of GA_3 and NAA in 20 ml ethanol, respectively and then 1.0 litre volume was made with distilled water prior to application of plant growth regulators. These growth regulators were applied at vegetative, flowering, fruiting and all of the three stages of the plant in evening.

3.4 Recording of the data

For data recording, five plants in each entry were tagged randomly and following observations on different quantitative and quality traits were recorded.



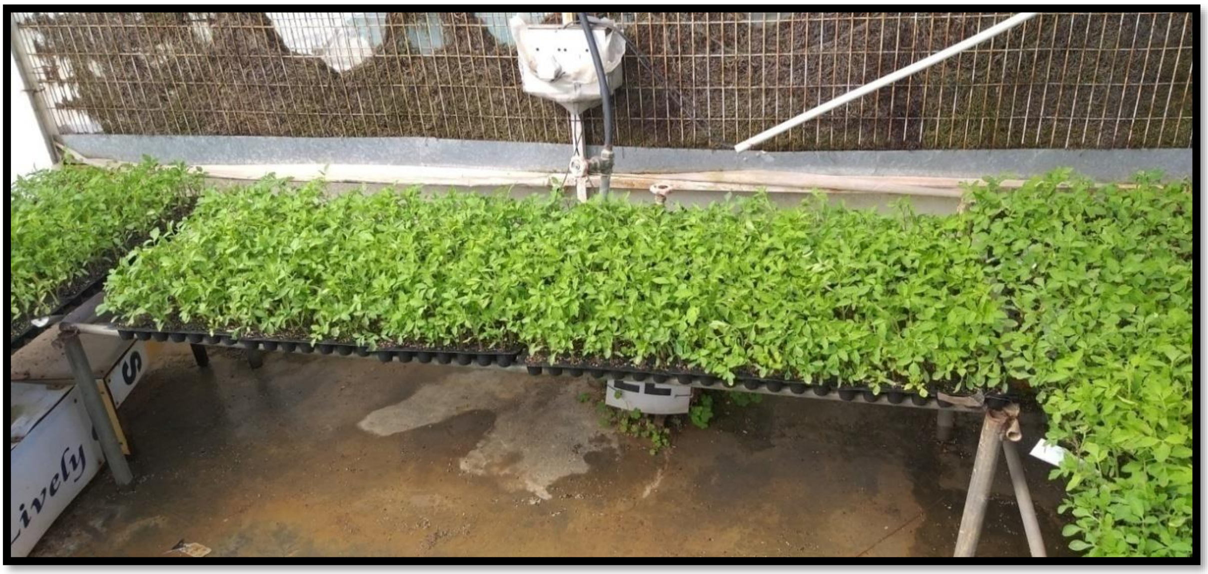


Plate 3.1: General view of seed sowing, different growth stages of tomato seedling.

Plate 3.2. General view of preparing growing beds and transplanting of plants in polyhouse.

Plate 3.3. General view of staking and different growth stages of tomato crop under protected condition.

Plate 3.4. General view of tomato crop maturity and harvesting.

3.4.1 Days to 50 per cent flowering

Numbers of days were counted from transplanting date to the opening of the flower on 50 per cent of the total plant population for each plot.

3.4.2 Days to first harvest

Numbers of days were counted from date of transplanting to the date when at least one ripe fruit was harvested and means values were calculated.

3.4.3 Number of fruits per cluster

Numbers of fruits per cluster were counted from randomly 3 clusters from five selected plants and their mean values were calculated.

3.4.4 Number of fruits per plant

Total numbers of fruits per plant were counted in the five selected plants by adding the number of marketable fruits harvested in each picking and their mean value was calculated.

3.4.5 Fruit weight (g)

It was calculated by dividing marketable yield with total number of fruits.

3.4.6 Marketable yield per plant (kg)

Fruit yield per plant was calculated by adding marketable yield of each picking and average values were calculated.

3.4.7 Marketable yield per m^2 area

Marketable yield per meter square was calculated by counting the number of plants per m^2 and multiplied by yield per plant.

3.4.8 Fruit shape index

The polar diameter of fruits was divided by equatorial diameter to estimate the fruit shape index (Roy and Choudhury, 1972).

The fruits were grouped as:

	Ratio	Shape
(i)	$\geq$1.00	Oval
(ii)	0.86-0.99	Spherical
(iii)	0.71-0.85	Intermediate (flat-round)
(iv)	$\leq$0.70	Flat

3.4.9 Internodal distance (cm)

Distance between two nodes was measured in a vine at different three nodes and averages were calculated.

3.4.10 Pericarp thickness (mm)

Pericarp thickness (mm) was measured from the equatorial section after cutting fruits transversely with the help of scale from five fruits from each entry and average values were calculated.

3.4.11 Plant height (cm)

The plant height was taken from ground level to the tip of the main shoot after the last fruit picking.

3.4.12 Total Soluble Solid (TSS)

The total soluble solids (TSS) content was estimated with the help of 'Erma Hand Refractometer under room temperature conditions (20^0 C) by putting a drop of juice on the prism and taking the reading. The values recorded were expressed as per cent of juice (AOAC 1970).

3.4.13 Ascorbic acid (mg/100g)

The ascorbic acid contents were estimated by 2,6-dichlorophenol Indophenol Visual Titration Method as described by Ranganna (1979). The standard ascorbic acid solution was prepared by dissolving 100 mg of L-ascorbic acid in 100 ml of metaphosphoric acid (3%). Ten milliliter of this solution was diluted to 100 ml with 3% metaphosphoric acid. The metaphosphoric acid (3%) solution was prepared by dissolving 15 grams of metaphosphoric acid in 500 ml distilled water. For the preparation of dye, 50 mg of sodium salt of 2,6-dichlorophenol indophenol was dissolved in about 150 ml distilled water containing 42 mg of sodium bicarbonate. This was cooled and 200 ml volume was made. To determine the dye factor, 5 ml each of standard ascorbic acid and metaphosphoric acid (3%) solution was taken in a flask and titrated against the dye to a pink colour, which persisted for at least 15 seconds. Dye factor (mg of ascorbic acid per ml of dye) was calculated by using the following formula: Dye factor = 0.5/titre 10 g of macerated sample was blended with 3% metaphosphoric acid to make up the volume to 100 ml. Out of this 100 ml solution, 10 ml solution was taken and titrated against 2, 6-dichlorophenol indophenol dye. The end point was determined by the appearance of rose pink colour which persisted for at least 15 seconds. The results thus obtained were expressed in terms of mg of ascorbic acid/100 g of pulp. The ascorbic acid content was calculated by using the following formula:

$$\text{Ascorbic Acid (mg/100g)} = \frac{\text{Titre} \times \text{Dye factor} \times \text{Volume made up}}{\text{Aliquot of extract Taken for estimation} \times \text{Weight of sample taken for estimation}} \times 100$$

3.5 Economic Studies

In order to evaluate most profitable treatment, the economics of individual treatment was worked out at prevailing and output rates in the market.

3.5.1 Cost of cultivation

The cost of the cultivation includes the expenditure incurred on various inputs including manpower.

3.5.2 Gross return

Gross return implies the value of output and was worked out by multiplying total output with average price.

3.5.3 Net return

Net return = Gross return – Cost of cultivation

3.5.4 Output: Input ratio

This ratio shows the value of output per rupee of expenditure on input used.

$$\text{Output: Input ratio} = \frac{\text{Gross return (Rs.)}}{\text{Cost of cultivation (Rs.)}}$$

3.6 Statistical analysis

The recorded data on various parameters were statistically analyzed using OPSTAT. The mean for all the treatments was calculated and analysis of variance for all the characters was performed by Gomez and Gomez (1984) using Factorial RBD. The calculated F values were compared with the tabulated F- values at 5% level of significance. When the calculated F-values were higher than the tabulated, it was considered to be significant.

4. RESULTS AND DISCUSSION

Plant growth regulators (PGRs) play important role in growth, development, yield and quality of tomato. PGRs are either natural or synthetic chemical that are applied to plant in order to alter its desirable characteristics. The results obtained from this experiment have been presented through tables with reasons and scientific support. Attempt has been made to establish the cause-and-effect relationship of our findings justifying by giving supportive evidences based on the literature. The results have been discussed under following heads:

4.1 Quantitative and qualitative characters

i. Days to 50% flowering
ii. Days to first harvest
iii. Number of fruits per cluster
iv. Number of fruits per plant
v. Fruit weight (g)
vi. Marketable yield per plant (kg)
vii. Marketable yield per m^2 area (kg)
viii. Fruit shape index
ix. Internodal distance (cm)
x. Pericarp thickness (mm)
xi. Total soluble solids (°Brix)
xii. Ascorbic acid (mg/100g)
xiii. Plant height (cm)

4.2 Economic Studies

i. Returns
ii. Output: Input ratio

4.1 Days to 50 % flowering

This an important character from earliness point of view because early maturity is desirable since it fetches good returns to the growers. During the spring-summer season the mean values for the growth regulators were non-significant (table 4.1) whereas, were significant for different stages of the plant growth. The interactions of the plant growth regulators and different stages of plant exhibited (A×B) significant results. Among the application of PGRs GA_3 @ 75 ppm took minimum (27.58) number of days to 50 per cent flowering. Whereas, from the different stage of plant growth the flowering stage (A_2) took minimum (27.41) numbers of days for 50 per cent flowering. The combined effect of growth regulators with the different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) took least (26.33 days) number of days to 50 per cent flowering which were significantly at par with A_4B_4 (GA_3 @ 75 ppm sprayed at all above three stages). During the autumn -winter season the mean values for the individual effect of growth regulators at different stages of the plant growth were significant. The interactions of the plant growth regulators and different stages of plant (A×B) exhibited significant results for number of days to 50 per cent flowering. Among the application of growth regulators GA_3 @ 75 ppm took minimum (27.25) number of days to 50 per cent flowering. Whereas, from the different stage of plant growth the flowering stage (A_2) took minimum (27.25) numbers of days for 50 per cent flowering. The combined effect of growth regulators with the different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) took least (25.33 days) number of days to 50 per cent flowering which were significantly at par with A_4B_2 (NAA @ 75 ppm sprayed at all above three stages of plant). In general, the minimum number of days to 50 per cent flowering was observed during the autumn-winter as compared to the spring-summer season. Interaction effects of plant growth regulators and different stages of plant growth (A×B) for both the seasons showed that minimum number of days for 50 per cent flowering in the autumn-winter season. Application of GA_3 at 75 ppm was found to be more effective in earliness. This might be attributed to that GA_3 application in tomato plants helped in synthesis of protein including various enzymes which resulted the increased rate of shoot elongation and photosynthetic capacity leading to increased physiological activities profuse flowering and chlorophyll content increased with increased concentrations of GA_3 (Mostafa and Saleh, 2006). Chaudhary et al. (2006), also found that gibberellins induced cell division, cell elongation and cell enlargement. Foliar application of GA_3 also reduced days for first flowering in cherry tomato as observed by Mehraj et al. (2014).

Another possible reason for the earliness in this may be because of GA_3 treatments which increased the number of leaves and promoted vegetative growth and thus there was translocation of more photosynthates to other plants parts which might have facilitated early flowering. The results are in conformity with the findings of Verma et al. (2014) and Ujjawal et al. (2018) in tomato.

Table 4.1: Effect of GA_3 and NAA on days to 50% flowering at different growth stages of tomato plant

Growth regulators / Different stages of plant	Spring-Summer: Naphthalene Acetic Acid 50ppm B_1	Spring-Summer: Naphthalene Acetic Acid 75ppm B_2	Spring-Summer: Gibberellic Acid 50ppm B_3	Spring-Summer: Gibberellic Acid 75ppm B_4	Spring-Summer: Mean A	Autumn-Winter: Naphthalene Acetic Acid 50ppm B_1	Autumn-Winter: Naphthalene Acetic Acid 75ppm B_2	Autumn-Winter: Gibberellic Acid 50ppm B_3	Autumn-Winter: Gibberellic Acid 75ppm B_4	Autumn-Winter: Mean A
Vegetative stage (A_1)	28.67	28.00	28.00	28.67	**28.33**	26.33	28.00	28.33	28.67	**27.83**
Flowering stage (A_2)	27.33	28.33	27.67	26.33	**27.41**	27.33	28.33	28.00	25.33	**27.25**
Fruiting stage (A_3)	29.33	29.00	28.67	28.33	**28.83**	29.33	29.00	28.67	28.33	**28.83**
All above three (A_4)	27.66	27.00	28.67	27.00	**27.58**	27.67	27.00	28.67	26.67	**27.50**
Mean B	**28.25**	**28.08**	**28.25**	**27.58**		**27.67**	**28.08**	**28.42**	**27.25**	
$CD_{0.05}$										
Factor (A)	**0.60**					**0.84**				
Factor (B)	**N/S**					**0.84**				
Factor (A×B)	**1.20**					**1.67**				

4.2 Days to first harvest

This character has utmost importance because any technique that can improve fruit quality and early yield is the need of the hour. Earliness leads to early supply of the produce in the market and enable it to fetch remunerative prices. GA_3 is one of the most important growth stimulating substances used in agriculture since long. It may promote cell elongation, cell division and thus helps in growth and development of tomato plant but its applications extended maturity time and harvest. In our study the results with respect to days to first harvest were non-significant (table 4.2) and are in support with the results of Islam et al. (2020) in tomato.

Table 4.2: Effect of GA_3 and NAA on days to first harvest at different growth stages of tomato plant

Growth regulators / Different stages of plant	Seasons									
	Spring-Summer					Autumn-Winter				
	Naphthalene Acetic Acid		Gibberellic Acid		Mean A	Naphthalene Acetic Acid		Gibberellic Acid		Mean A
	50ppm	75ppm	50ppm	75ppm		50ppm	75ppm	50ppm	75ppm	
	B_1	B_2	B_3	B_4		B_1	B_2	B_3	B_4	
Vegetative stage (A_1)	71.00	69.00	69.67	70.00	**69.92**	77.67	78.13	78.27	78.43	**78.13**
Flowering stage (A_2)	68.67	69.33	68.67	66.67	**68.33**	78.23	77.17	75.85	73.23	**76.12**
Fruiting stage (A_3)	67.33	69.33	67.00	69.00	**68.17**	79.22	301.17	75.97	78.55	**133.73**
All above three (A_4)	67.33	69.00	67.00	68.00	**67.83**	79.13	78.33	79.67	78.60	**78.93**
Mean B	**68.58**	**69.17**	**68.08**	**68.42**		**78.56**	**133.70**	**77.44**	**77.20**	
CD $_{0.05}$										
Factor (A)	**1.28**					**N/S**				
Factor(B)	**N/S**					**N/S**				
Factor (A×B)	**N/S**					**N/S**				

4.3 Number of fruits per cluster

Number of fruits per cluster is an indication of more yield per plant and is generally dependent on better fruit set. Fruit setting in tomato is optimum, if agro techniques are employed effectively. During spring-summer season it is clear from the data represented in the table 4.3 that the mean values for the growth regulators and different stages of plant growth were non-significant and also non-significant for the individual effects of the different stages of the plant growth and growth regulators. The interactions of the plant growth regulators and different stages of plant exhibited (A×B) also non-significant. During the autumn winter season grown crop it is clear from the data represented in the table 4.3 that the mean values for the individual effect of growth regulators at different stages of the plant growth were significant whereas, the interactions of the plant growth regulators and different stages of plant (A×B) exhibited non-significant results for number of fruits per cluster. Among the application of growth regulators, NAA @ 75 ppm when sprayed on tomato crop produced maximum (6.38) number of fruits per cluster. Whereas, from the different stage of plant growth at fruiting stage (A_3) maximum number of fruits per cluster were produced.

In general, it is clear from the mean values of the individual factor the maximum (6.77) number of fruits per cluster were produced during the autumn-winter grown crop. This might be due to the fact that NAA promoted flower primodia production in tomato plant therefore controlling the number of fruits per cluster.

Table 4.3: Effect of GA_3 and NAA on number of fruits per cluster at different growth stages of tomato plant

Growth regulators / Different stages of plant	Seasons									
	Spring-Summer					Autumn-Winter				
	Naphthalene Acetic Acid		Gibberellic Acid		Mean A	Naphthalene Acetic Acid		Gibberellic Acid		Mean A
	50ppm	75ppm	50ppm	75ppm		50ppm	75ppm	50ppm	75ppm	
	B_1	B_2	B_3	B_4		B_1	B_2	B_3	B_4	
Vegetative stage (A_1)	5.07	5.15	5.24	5.54	**5.25**	6.27	5.63	6.03	5.40	**5.83**
Flowering stage (A_2)	5.65	6.10	5.82	6.13	**5.92**	6.07	5.77	5.70	5.00	**5.63**
Fruiting stage (A_3)	5.09	5.26	6.05	5.71	**5.53**	7.20	7.47	6.27	6.13	**6.77**
All above three (A_4)	5.47	4.61	5.97	5.43	**5.37**	5.53	6.63	5.90	5.83	**5.98**
Mean B	**5.32**	**5.28**	**5.77**	**5.70**		**6.27**	**6.38**	**5.98**	**5.59**	
CD $_{0.05}$										
Factor (A)	**N/S**					**0.56**				
Factor(B)	**N/S**					**0.56**				
Factor (A×B)	**N/S**					**N/S**				

The result revealed that GA_3 also increased the number of flower cluster plant. (Ranjeet et al. 2014). Applications of NAA and GA3 compounds causes increased synthesis of cytokinin, auxins and transport them to auxiliary buds that help boost transformation from vegetative phase to reproductive phase (Kannan et al. 2009). Our findings are in agreement with those of Gemmici et al. (2006), Uddain et al. (2009), Verma et al. (2014), Ujjawal et al. (2018) and Islam et al. (2020) in tomato in tomato.

4.4 Number of fruits per plant

Number of fruits per plant is an important character since it directly influences yield per unit area. More the number of marketable fruits per plant, more will be the yield and hence, give better returns. Therefore, higher number of fruits per plant and optimum size are desirable. During the spring-summer season it is evident from the data represented in the table 4.4 that the mean values for the growth regulators and different stages of plant growth are significant also the interactions of the plant growth regulators and different stages of plant exhibited (A×B) significant results. Among the application of growth regulators GA_3 @ 75 ppm when sprayed produced maximum (52.75) number of fruits per plant. Whereas, from the different stage of plant growth the flowering stage (A_2) produced maximum (54.67) numbers of fruits per plant. The combined effect of growth regulators with the different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) produced higher (57.00) number of fruits per plant which were significantly at par with the A_2B_2, A_2B_3, and A_1B_4 interactions which produced 55.00 number of fruits per plant. During the autumn -winter season interactions effect of the plant growth regulators and different stages of plant exhibited (A×B) significant results for number of fruits per plant. Among the application of growth regulators GA_3 @ 75 ppm when sprayed produced maximum (57.25) number of fruits per plant. Whereas, from the different stage of plant growth the flowering stage (A_2) produced maximum (60.17) numbers of fruits per plant. The combined effect of growth regulators with the different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) produced maximum (66.33) number of fruits per plant which were significantly superior from all the two-way interactions. In general, the maximum number of fruits per plant was observed during the autumn-winter season. This increase in fruit set by GA_3 is possibly due to the ability of the growth regulators to increase the functional male and female organs and their compatibility thus lessens the reduction of embryo abortion in plants and therefore increased tomato fruit number, fruit length and fruit diameter (Prasad et al. 2013). GA_3 produces higher number of fruits plant and this might be due to that gibberellic acid enhanced fruit setting percentage and total yield in tomato (Verma et al. 2014). The improvement in fruit formation due to the foliar spray of GA_3 in our study might be because of the fact that GA_3 increases the metabolic activity in plant, which resulted in enhancement of reproductive phase in tomato. Another reason supported by Chovatia et al. (2010) that application of growth regulators at the time of flowering prevents pre-harvest flower abscission by increasing the available plant hormone concentration at this critical phase of reproductive development in tomato plants which ultimately increases the number of fruits per plant. Baliyan et al. (2013) also reported that the plant sprayed with the growth regulator GA_3 remained physiologically more active to build up sufficient food stocks for developing flowers, fruit and resulted in increased fruit set, which ultimately lead to higher yields. The increasing number of fruits per plant by GA_3 and NAA treatment might be due to rapid and better nutrient translocation from roots to apical parts of the plant (Prasad et al. 2013). GA_3 significantly responded in promoting vegetative growth characters conductive to food manufacturing mechanism.

Table 4.4 Effect of GA_3 and NAA on number of fruits per plant at different growth stages of tomato plant

Growth regulators / Different stages of plant	Seasons									
	Spring-Summer					Autumn-Winter				
	Naphthalene Acetic Acid		Gibberellic Acid		Mean A	Naphthalene Acetic Acid		Gibberellic Acid		Mean A
	50ppm	75ppm	50ppm	75ppm		50ppm	75ppm	50ppm	75ppm	
	B_1	B_2	B_3	B_4		B_1	B_2	B_3	B_4	
Vegetative stage (A_1)	50.00	47.00	49.67	55.00	**50.42**	52.33	49.00	46.67	53.67	**50.42**
Flowering stage (A_2)	51.67	55.00	55.00	57.00	**54.67**	56.33	58.00	60.00	66.33	**60.17**
Fruiting stage (A_3)	49.00	48.00	49.67	46.00	**48.17**	48.67	50.67	53.00	52.00	**51.08**
All above three (A_4)	46.00	44.33	50.00	53.00	**48.33**	47.67	51.33	49.33	57.00	**51.33**
Mean B	**49.17**	**48.58**	**51.08**	**52.75**		**51.25**	**52.25**	**52.25**	**57.25**	
$CD_{0.05}$										
Factor (A)	**1.01**					**1.40**				
Factor(B)	**1.01**					**1.40**				
Factor (A×B)	**2.03**					**2.79**				

hence the treated plants had comparatively more food stocks. GA_3 level in treated plants was naturally more, which, itself has a property of increasing fruiting. GA_3 become more active in presence of extra plant food and hence the number of fruits seems to have increased.

Gibberellic acid (GA_3) at low concentration was reported to promote fruit setting in tomato (Sasaki et al. 2005). Another possible reason could be that GA_3 causes significant vegetative growth that culminates to higher photosynthesis manufacturing and in presence of this food stock, GA_3 leads to produce more fruit. Exogenous supply of growth regulators at critical stages of flowering and fertilization, ovary formation, fruit and seed development period etc. may enhance source to sink relationship, accumulation of photosynthesis and efficient utilization of food reserves for the development of fruit. The results are in conformity with the finding of Alam and Khan (2002) in tomato, Rai et al. (2002) in tomato, Nibhavanti et al. (2004) in tomato, Naz et al. (2020), Prasad et al. (2013), Choudhury et al. (2013) in tomato, Verma et al. (2014), Tomar et al. (2017), Ahmad et al. (2017) in tomato, Singh et al. (2018), Ujjawal et al. (2018) in tomato, Islam et al. (2020) and Mistry et al. (2020) in tomato also.

4.5Fruit weight

Average fruit weight is the most important yield contributing character which has a key role in the acceptance of the produce for fresh market tomato. During the spring-summer season it is clear from the data represented in the table 4.5 that the mean values of fruit weight for the growth regulators and different stages of plant growth are significant and also interactions between plant growth regulators and different stages of plant exhibited (A×B) significant results. Application of growth regulator GA_3 @ 75 ppm when sprayed produced maximum (65.17 g) fruit weight whereas, from the different stages of plant growth the fruiting stage (A_2) produced maximum (66.27 g) fruit weight. The combined effect of growth regulators with the different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) produced maximum (71.90 g) fruit weight which were significantly at par with the A_3B_4 which produced fruits of having weight 69.80 g. During the autumn -winter interactions effect of the plant growth regulators and different stages of plant also exhibited (A×B) significant results. Among the application of growth regulators GA_3 @ 75 ppm sprayed plants produced fruits with maximum (64.62 g) fruit weight. Whereas, from the different stage of plant growth the all the above three stages (A_4) produced fruits with maximum (66.94 g) fruit weight. The combined effect of growth regulators with the different stages of plant growth showed that the interaction A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) recorded maximum fruit weight i.e. 69.50 g number of fruits per plant which were significantly at par with the two way interactions i.e. A_2B_2, A_3B_2, A_4B_2, A_3B_3, A_4B_4 and A_4B_4. In general, the highest fruit weight (66.27 g) was observed during the spring-summer season as compared to the autumn-winter season which recorded 66.94 g fruit weight. Interaction effects of plant growth regulators and different stages of plant growth (A×B) for both the seasons showed maximum (71.90 g) fruit weight for the spring-summer season grown crop whereas, 69.50 g fruit weight for autumn-winter season grown crop.

Table4.5: Effect of GA_3 and NAA on Fruit weight (g) at different growth stages of tomato plant

Growth regulators / Different stage of plant	Seasons									
	Spring-Summer					Autumn-Winter				
	Naphthalene Acetic Acid		Gibberellic Acid		Mean A	Naphthalene Acetic Acid		Gibberellic Acid		Mean A
	50ppm	75ppm	50ppm	75ppm		50ppm	75ppm	50ppm	75ppm	
	B_1	B_2	B_3	B_4		B_1	B_2	B_3	B_4	
Vegetative stage (A_1)	59.13	56.80	61.80	59.40	**59.28**	55.87	56.30	59.20	60.47	**57.96**
Flowering stage (A_2)	56.67	68.47	65.87	71.90	**65.73**	48.87	66.37	59.67	69.50	**61.10**
Fruiting stage (A_3)	69.80	68.67	64.00	62.60	**66.27**	68.43	67.27	68.07	61.03	**66.20**
All above three (A_4)	71.07	66.73	67.93	56.80	**65.63**	66.30	66.00	68.00	67.47	**66.94**
Mean B	**64.17**	**65.17**	**64.90**	**62.68**		**59.87**	**63.98**	**63.73**	**64.62**	
$CD_{0.05}$										
Factor (A)	**1.51**					**1.90**				
Factor(B)	**1.51**					**1.90**				
Factor (A×B)	**3.01**					**3.79**				

The increased weight of the fruits for the treatments sprayed with GA_3 due to the fact that gibberellins application increases membrane permeability (Aloni et al. 1968) that facilitate absorption and utilization of mineral nutrients (Khan et al. 1998) and transport of assimilates (Mulligan and Patrick, 1973) which may result in higher weight of fruits. Another reason could be the increased individual fruit weight of tomato due to that the GA_3 treated plants having maximum fruit length and diameter, which are directly responsible for the higher fruit weight. Our results are similar with the results of Uddain et al. (2009) in tomato, Prasad et al. (2013), Naz et al. (2020), Verma et al. (2014), Ahmad et al. (2017) in cherry tomato, Singh et al. (2018), Singh et al. (2019), Ali et al. (2020) and Mistry et al. (2020) in tomato crop.

4.6Marketable yield per plant

The ultimate objective of the study was to have maximum yield for better returns. Yield is responsible for commercial viability of a variety and is one of the important characters attaining highest consideration in the entire research programme. During the spring-summer season it is clear from the data represented in the table 4.6 that the mean values of marketable yield per plant for the growth regulators and different stages of plant were significant and their interactions were also significant.

Table 4.6: Effect of GA_3 and NAA on marketable yield per plant (kg) at different growth stages of tomato plant

Growth regulators / Different stages of plant	Seasons									
	Spring-Summer					Autumn-Winter				
	Naphthalene Acetic Acid		Gibberellic Acid		Mean A	Naphthalene Acetic Acid		Gibberellic Acid		Mean A
	50ppm	75ppm	50ppm	75ppm		50ppm	75ppm	50ppm	75ppm	
	B_1	**B_2**	**B_3**	**B_4**		**B_1**	**B_2**	**B_3**	**B_4**	
Vegetative stage (A_1)	2.96	2.67	3.07	3.27	**2.99**	2.91	2.76	2.76	3.24	**2.92**
Flowering stage (A_2)	2.93	3.77	3.62	4.10	**3.60**	2.75	3.85	3.58	4.61	**3.70**
Fruiting stage (A_3)	3.42	3.29	3.18	2.88	**3.19**	3.33	3.41	3.61	3.17	**3.38**
All above three (A_4)	3.27	2.96	3.39	3.01	**3.16**	3.16	3.39	3.35	3.85	**3.44**
Mean B	**3.14**	**3.17**	**3.32**	**3.31**		**3.04**	**3.35**	**3.33**	**3.72**	
CD $_{0.05}$										
Factor (A)	**0.03**					**0.04**				
Factor(B)	**0.03**					**0.04**				
Factor (A×B)	**0.07**					**0.07**				

Among the application of growth regulators GA_3 @ 50 ppm when sprayed produced maximum (3.32 kg) marketable yield per plant whereas, from the different stage of plant growth the flowering stage (A_2) recorded maximum (3.60 kg) marketable yield per plant. The combined effect of growth regulators at different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) recorded maximum (4.10 kg) marketable yield per plant which was significantly superior from all other two way interactions. During the autumn- winter season interaction effects were also significant. Among the application of growth regulators GA_3 @ 75 ppm when sprayed produced maximum (3.72 kg) marketable yield per plant. Whereas, from the different stage of plant growth the flowering stage (A_2) recorded maximum (3.70 kg) marketable yield per plant. The combined effect of growth regulators at different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) recorded maximum (4.61 kg) marketable yield per plant which was significantly superior from all other two way interactions. According to Gelmesa et al. (2012) applications of GA_3 helped in improvement in number of fruits per cluster, fruit set, and marketable fruit number per plant. Hasanuzzaman et al. (2015) revealed that application of GA_3 at higher concentration showed increased fruit number, fruit clusters, length and diameter of fruit, yield per plant, yield per plot and yield per hectare

4.7Marketable yield per m^2 area

Similar trend was observed for this trait and the interactions of the plant growth regulators and different stages of plant exhibited (A×B) significant results for marketable yield per m^2 area for both the seasons (Table 4.7). Among the application of growth regulators GA_3 @ 75ppm when sprayed produced maximum (19.89 kg) marketable yield per m^2 and this was at par with the treatment B_3 (GA_3 @ 50 ppm) which calculated 19.88 kg marketable yield per m^2 area whereas, from the different stages of plant growth the flowering stage (A_2) recorded maximum (21.62 kg) marketable yield per m^2 area. The combined effect of growth regulators at different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) recorded maximum (24.59 kg) marketable yield per m^2 which was significantly superior from all other two way interactions. The interactions of the plant growth regulators and different stages of plant represented (A×B) significant results for marketable yield per m^2during autumn-winter. Among the application of growth regulators GA_3 @ 75 ppm when sprayed calculated maximum (22.31 kg) marketable yield per m^2 area whereas, different stage of plant growth the flowering stage (A_2) recorded maximum (22.17 kg) marketable yield. The combined effects of growth regulators at different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) calculated maximum (27.65 kg) marketable yield per m^2 which was significantly superior from all two way interactions. This might be attributed to the fact that GA_3 playsan important role in cell division and elongation which ultimately have positive effect on plant growth (Batlang et al. 2006).

Table 4.7: Effect of GA_3 and NAA on marketable yield per m^2 area at different growth stages of tomato plant

Growth regulators / Different stages of plant	Seasons									
	Spring-Summer					**Autumn-Winter**				
	Naphthalene Acetic Acid		**Gibberellic Acid**		**Mean A**	**Naphthalene Acetic Acid**		**Gibberellic Acid**		**Mean A**
	50ppm	**75ppm**	**50ppm**	**75ppm**		**50ppm**	**75ppm**	**50ppm**	**75ppm**	
	B_1	**B_2**	**B_3**	**B_4**		**B_1**	**B_2**	**B_3**	**B_4**	
Vegetative stage (A_1)	17.74	16.01	18.41	19.60	**17.94**	17.49	16.53	16.56	19.46	**17.51**
Flowering stage (A_2)	17.56	22.59	21.73	24.59	**21.62**	16.50	23.09	21.45	27.65	**22.17**
Fruiting stage (A_3)	20.52	19.77	19.05	17.27	**19.15**	19.97	20.44	21.63	19.04	**20.27**
All above three (A_4)	19.61	17.74	20.36	18.06	**18.94**	18.94	20.32	20.12	23.07	**20.62**
Mean B	**18.86**	**19.03**	**19.88**	**19.89**		**18.23**	**20.10**	**19.94**	**22.31**	
CD $_{0.05}$										
Factor (A)	**0.20**					**0.22**				
Factor(B)	**0.20**					**0.22**				
Factor (A×B)	**0.40**					**0.44**				

It helps in controlling the pre harvest fruit drop which is a major problem and also increases fruit setting percentage, fruit yield and extend shelf life and could be a suitable reason for highest marketable yield per plant and per m^2. Patel et al. (2012) also observed that application plant growth regulator increased the diameter of fruit and thus marketable yield per plant and per m^2 in tomato. Another possible reason for increased yield of tomato is due to enhanced plant growth and faster rate of plant development which is promoted by cell elongation and thereby increased cell enlargement, cell division and differentiation which in turn resulted into increase in number of flowers, fruit set size and fruit weight. The results are in line with those of Uddain et al. (2009) in tomato, Prasad et al. (2013), Verma et al. (2014), Ahmad et al. (2017) in cherry tomato, Singh et al. (2018) in tomato, Islam et al. (2020) in tomato and Ali et al. (2020) in tomato crop. According to them GA_3 has promoting effect on DNA, RNA, protein, ribose and polyribosome multiplication that contributes towards increased biomass production of vegetative parts as well as fruits that enhanced yield.

4.8 Fruit shape index

The shape of fruit are important cultivar traits of any vegetable crop which are predominantly determined by genetic character, but can be greatly influenced by different crop improvement practices Data enumerated in table 4.8 showed that during both the seasons (spring-summer and autumn-winter) the two-way interaction and individual effects were non-significant. Hence, there was no effect of growth regulators on the shape of the fruit because this is genetically controlled trait. Similar findings for tomato fruit growth are described by various researchers (Gupta and Gupta, 2000; Rai et al. 2006; Uddain et al. 2009).

Table 4.8: Effect of GA_3 and NAA on fruit shape index at different growth stage of tomato plant

Growth regulators / Different stages of plant	. Seasons									
	Spring –Summer					Autumn –Winter				
	Naphthalene Acetic Acid		Gibberellic Acid		Mean A	Naphthalene Acetic Acid		Gibberellic Acid		Mean A
	50ppm	75ppm	50ppm	75ppm		50ppm	75ppm	50ppm	75ppm	
	B_1	B_2	B_3	B_4		B_1	B_2	B_3	B_4	
Vegetative stage (A_1)	0.90	0.87	0.87	0.80	**0.86**	0.97	0.97	0.87	0.93	**0.93**
Flowering stage (A_2)	0.87	0.80	0.77	0.80	**0.81**	0.93	0.80	0.83	1.07	**0.91**
Fruiting stage (A_3)	0.90	0.80	0.87	0.80	**0.84**	0.87	0.90	0.83	0.90	**0.88**
All above three (A_4)	0.77	0.80	0.80	0.87	**0.81**	0.87	0.87	0.87	0.90	**0.88**
Mean B	**0.86**	**0.82**	**0.83**	**0.82**		**0.91**	**0.88**	**0.85**	**0.95**	
$CD_{0.05}$										
Factor (A)	**N/S**					**N/S**				
Factor(B)	**N/S**					**0.07**				
Factor (A×B)	**N/S**					**N/S**				

Whereas, the results were contradictory with the findings of Naz et al. (2020) who revealed that foliar spraying of PGRs and antioxidants was effectual as it might be contributed to more supply and accumulation of food materials in plants and its efficient mobility in plants resulting in increased growth stimulation, ultimately helped in earlier flower initiation, increased fruit set, rapid fruit development, fruit number, fruit length, fruit diameter and weight of fruits which all together enhanced fruit shape index and yield.

4.9 Inter nodal length (cm)

Data presented in table 4.9 for the two-way interaction indicated that the individual effects of different stages of plant growth and interaction of A×B was significant for the spring-summer transplanted tomato crop. It is custom clear that the maximum internodal length was measured during the flowering stage of plant growth (A_2) and for the combined effects of two way interactions (A×B) maximum (9.71 cm) internodal length was reported for A_3B_3 (GA_3 @ 50 ppm at fruiting stage) combination.

Table 4.9: Effect of GA_3 and NAA on inter nodal distance (cm) at different growth stages of tomato plant

Growth regulators / Different stages of plant	Seasons									
	Spring-Summer					Autumn-Winter				
	Naphthalene Acetic Acid		Gibberellic Acid		Mean A	Naphthalene Acetic Acid		Gibberellic Acid		Mean A
	50ppm	75ppm	50ppm	75ppm		50ppm	75ppm	50ppm	75ppm	
	B_1	B_2	B_3	B_4		B_1	B_2	B_3	B_4	
Vegetative stage (A_1)	6.67	8.29	9.27	9.11	**8.34**	9.03	9.30	9.80	8.47	**9.15**
Flowering stage (A_2)	8.77	9.29	8.43	9.05	**8.89**	10.17	9.23	8.50	9.63	**9.38**
Fruiting stage (A_3)	9.31	9.35	9.71	9.69	**9.52**	9.40	8.07	9.67	9.53	**9.17**
All above three (A_4)	9.70	8.37	9.30	8.34	**8.93**	10.23	10.07	10.37	10.00	**10.17**
Mean B	**8.62**	**8.83**	**9.18**	**9.05**		**9.71**	**9.17**	**9.58**	**9.41**	
$CD_{0.05}$										
Factor (A)	**0.68**					**N/S**				
Factor(B)	**N/S**					**N/S**				
Factor (A×B)	**1.35**					**N/S**				

It is due to the stimulatory effect of GA_3 on plant growth due to cell elongation especially of internodal stem cells and rapid cell division in growing portion. These findings are very close with the earlier findings of Uddain et al. (2009), Chovatia et al. (2010), Naz et al. (2020), Verma et al. (2014) and Ujjawal et al. (2018) in tomato.

4.10 Pericarp thickness (mm)

Data presented in table 4.10 depicts that there was non-significant effect for pericarp thickness except for stages of plant growth in autumn-winter season. Earlier researchers reported that GA_3 plays important role in pericarp thickness of tomato fruits. This may be attributed to the increased supply of photosynthetic materials and its efficient mobilization in plants giving rise to increased stimulation of fruit growth ultimately influenced the pericarp thickness (Bhosle et al. 2002; Pundir and Yadav 2001).

Table4.10: Effect of GA_3 and NAA on Pericarp thickness (mm) at different growth stages of tomato plant

Growth regulators / Different stages of plant	Seasons									
	Spring –Summer					Autumn-Winter				
	Naphthalene Acetic Acid		Gibberellic Acid		Mean A	Naphthalene Acetic Acid		Gibberellic Acid		Mean A
	50ppm	75ppm	50ppm	75ppm		50ppm	75ppm	50ppm	75ppm	
	B_1	B_2	B_3	B_4		B_1	B_2	B_3	B_4	
Vegetative stage (A_1)	0.06	0.04	0.05	0.05	**0.05**	0.63	0.50	0.50	0.53	**0.54**
Flowering stage (A_2)	0.05	0.06	0.05	0.05	**0.05**	0.57	0.57	0.63	0.73	**0.63**
Fruiting stage (A_3)	0.05	0.06	0.06	0.06	**0.06**	0.67	0.63	0.63	0.70	**0.66**
All above three (A_4)	0.05	0.06	0.06	0.05	**0.05**	0.70	0.63	0.67	0.67	**0.67**
Mean B	**0.05**	**0.06**	**0.05**	**0.05**		**0.64**	**0.58**	**0.61**	**0.66**	
CD $_{0.05}$										
Factor (A)	**N/S**					**0.08**				
Factor(B)	**N/S**					**N/S**				
Factor (A×B)	**N/S**					**N/S**				

4.11 Total Soluble Solids (^{0} Brix)

Data presented in mean table 4.11 depicts non-significant effect for total soluble solids. Our results are similar with the results of Prasad et al. (2013), Kumar et al. (2014), Ranjeet et al. (2014), Verma et al. (2014), Rahman et al. (2019), Singh et al. (2019), Ali et al. (2020), Mistry et al. (2020) in tomato crop. Growth and quality of tomato has been improved with use of PGRs (Gelmesa et al. 2012; Saha, 2009).

Table 4.11: Effect of GA_3 and NAA on Total Soluble Solids (° Brix) at different growth stages of tomato plant

Growth regulators / Different stages of plant	Seasons									
	Spring-Summer					Autumn-Winter				
	Naphthalene Acetic Acid		Gibberellic Acid		Mean A	Naphthalene Acetic Acid		Gibberellic Acid		Mean A
	50ppm	75ppm	50ppm	75ppm		50ppm	75ppm	50ppm	75ppm	
	B_1	B_2	B_3	B_4		B_1	B_2	B_3	B_4	
Vegetative stage (A_1)	6.83	6.43	6.67	6.80	**6.43**	6.73	6.30	6.20	6.07	**6.33**
Flowering stage (A_2)	6.70	6.17	6.17	6.67	**6.43**	6.70	6.00	6.17	6.33	**6.30**
Fruiting stage (A_3)	6.20	6.23	6.97	6.60	**6.25**	6.30	6.60	6.70	5.63	**6.31**
All above three (A_4)	6.37	6.37	6.43	6.17	**6.33**	5.63	5.97	5.97	6.17	**5.93**
Mean B	**6.53**	**6.30**	**6.31**	**6.31**		**6.34**	**6.22**	**6.26**	**6.05**	
CD $_{0.05}$										
Factor (A)	**N/S**					**N/S**				
Factor(B)	**N/S**					**N/S**				
Factor (A×B)	**N/S**					**N/S**				

4.12 Ascorbic Acid content (mg/100 g)

Ascorbic acid content (Vitamin C) is one of the major quality components in tomato as it improves the nutritional value of fruit. Ascorbic acid content varied significantly for both the seasons. Among the application of growth regulators GA_3 @ 75 ppm produced maximum ascorbic acid content i.e. 26.62 mg/100 g and this was significantly at par with the B_3 (GA_3 @ 50 ppm) which calculated 26.07 mg/100 g. Whereas, from the different stages of plant growth the flowering stage (A_2) recorded maximum (26.63 mg/100) vitamin C content.

The combined effect of growth regulators with different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) recorded maximum (27.40 mg/100 g) ascorbic acid content which was significantly at par A_3B_4 and A_1B_4. In the second cropping-season GA_3 @ 75 ppm improved the quality in terms of vitamin C content and the value is 29.80 mg/100 g and this was significantly at par with the treatment A_3 and A_4 which calculated 28.89, 29.11 mg/100 g ascorbic acid content. The flowering stage (A_2) recorded maximum (30.12 mg/100) vitamin C content. The combined effect of growth regulators with different stages of plant growth showed that A_2B_1 (NAA @ 50 ppm sprayed at flowering stage) recorded maximum (30.97 mg/100 g) ascorbic acid content which was statistically at par with the various two way interactions i.e. A_4B_1, A_2B_2, A_3B_2, A_4B_2, A_3B_4, A_1B_3, A_2B_3, A_3B_3, A_1B_4, A_2B_4, A_3B_4 and A_4B_4.

Table 4.12: Effect of GA_3 and NAA on Ascorbic acid content (mg/100g) at different growth stages of tomato plant

Growth regulators / Different stages of plant	Seasons									
	Spring –Summer					Autumn –Winter				
	Naphthalene Acetic Acid		Gibberellic Acid		Mean A	Naphthalene Acetic Acid		Gibberellic Acid		Mean A
	50ppm	75ppm	50ppm	75ppm		50ppm	75ppm	50ppm	75ppm	
	B_1	B_2	B_3	B_4		B_1	B_2	B_3	B_4	
Vegetative stage (A_1)	21.11	22.08	25.07	26.32	**23.65**	24.61	25.58	28.57	29.82	**27.15**
Flowering stage (A_2)	28.80	25.67	24.66	27.40	**26.63**	30.97	29.17	28.16	30.90	**29.80**
Fruiting stage (A_3)	21.88	25.42	30.23	27.33	**26.22**	25.38	28.92	30.40	30.83	**28.89**
All above three (A_4)	25.97	26.67	24.34	25.44	**25.61**	29.47	30.17	27.84	28.94	**29.11**
Mean B	**24.44**	**24.96**	**26.07**	**26.62**		**27.61**	**28.46**	**28.74**	**30.12**	
$CD_{0.05}$										
Factor (A)	**0.87**					**1.08**				
Factor(B)	**0.87**					**1.08**				
Factor (A×B)	**1.74**					**2.16**				

The augment of ascorbic acid with GA_3 treatment might be either due to encouragement of biosynthesis of ascorbic acid or protection of synthesized ascorbic acid from oxidation through the enzyme ascorbic acid oxidise and gibberellins may promote the activity of acid invertase which causing an increase in hexose level in plant tissue. The results are similar with the findings of Verma et al. (2014) and Mistry et al. (2020) in tomato.

4.13 Plant height (cm)

Height of the plant is one of the important factor determining yield and harvest duration especially in plants with indeterminate type of growth habit under the protected structures. Taller plants are considered to be more desirable because they lead to more number of branches which ultimately bear more number of fruits and result in increased productivity.

GA_3 @ 50 ppm produced maximum (196.38 cm) plant height and this was statistically at par with B_4 (GA_3 @ 75 ppm) which recorded plant height of 194.33 cm (table 4.13). Among plant growth stages, flowering stage (A_2) recorded maximum (202.80 cm) plant height. The combined effect of growth regulators at different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) recorded maximum (215.00 cm) plant height which was significantly at par with A_1B_4 (GA_3 @ 75 ppm sprayed at vegetative stage) and superior from all other two way interactions. During autumn-winter NAA @ 50 ppm produced maximum (213.18 cm) plant height and this was significantly superior from other whereas, from the different stages of plant growth the flowering stage (A_2) recorded maximum (223.50 cm) plant height. The combined effect of growth regulators at different stages of plant growth showed that A_1B_1 (NAA @ 50 ppm sprayed at vegetative stage) recorded maximum (252.47 cm) plant height which was significantly superior from all the other two way interactions. This might be due to the influence of plant growth regulators on the expansion and enlargement of meristematic cells. PGRs promote vegetative growth by active cell division and elongation especially in the apical portion of the plants. Taiz and Zeiger (2009) reported that by promoting cell growth and division, the gibberellins stimulate elongation of internodes. Another reason could be due to cell elongation and rapid cell division in growing portion, stimulated RNA and there by leading to enhanced growth and development. Our findings are in agreement with those of Pundir and Yadav (2001), Nibhavanti et al. (2004), Bokode et al. (2006), Naz et al. (2020), Kumar et al. (2014), Verma et al. (2014) Maity et al. (2016), Tomar et al. (2017), Siwna et al. (2018) in tomato.

Table 4.13: Effect of GA_3 and NAA on plant height (cm) at different growth stages of tomato plant

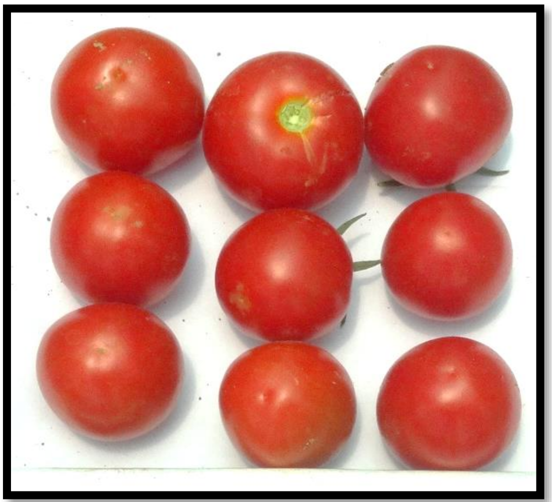
Growth regulators / Different stages of plant	Seasons									
	Spring –Summer					Autumn-Winter				
	Naphthalene Acetic Acid		Gibberellic Acid		Mean A	Naphthalene Acetic Acid		Gibberellic Acid		Mean A
	50ppm	75ppm	50ppm	75ppm		50ppm	75ppm	50ppm	75ppm	
	B_1	B_2	B_3	B_4		B_1	B_2	B_3	B_4	
Vegetative stage (A_1)	175.87	195.60	209.00	212.33	**198.20**	252.47	213.40	203.00	197.27	**216.53**
Flowering stage (A_2)	197.33	195.33	203.53	215.00	**202.80**	218.80	220.00	243.67	211.53	**223.50**
Fruiting stage (A_3)	185.33	155.33	182.67	191.67	**178.75**	196.73	189.07	194.00	204.07	**195.97**
All above three (A_4)	167.67	158.33	190.33	158.33	**168.67**	184.73	193.73	189.00	181.20	**187.17**
Mean B	**181.55**	**176.15**	**196.38**	**194.33**		**213.18**	**204.05**	**207.42**	**198.52**	

$CD_{0.05}$	Spring –Summer	Autumn-Winter
Factor (A)	**2.03**	**4.13**
Factor (B)	**2.03**	**4.13**
Factor (A×B)	**4.07**	**8.25**

All above three stages

Fruiting stage

Flowering stage



Vegetative Stage

Plate 4.1: General view of fruits in different plant stage after application of GA_3 @ 75 ppm

All above three Stages

Fruiting Stage

Flowering Stage

Vegetative Stage

Plate 4.2: General view of fruits in different plant stage after application of GA_3 @ 50 ppm

All above three Stages

Fruiting Stage

Flowering stage

Vegetative stage

Plate 4.3: General view of fruits in different plant stage after application of NAA @ 75 ppm

Al above three Stage

Fruiting Stage

Flowering Stage

Vegetative Stage

Plate 4.4: General view of fruits in different plant stage after application of NAA @ 50 ppm

Control (without any treatment

Plate 4.5: Fruit without any treatment (Control)

4.14 Effect of different treatment modules on economics of tomato production

Input cost for land preparation, seed cost, fertilizer and manure cost, plant protection measures cost and man power required for all the operations from transplanting of seedling to harvesting of tomato were recorded per treatment and converted into unit plot and then converted into cost per m^2. Prices of tomato were considered according to university rate basis. The economic analysis was carried out to find the gross and net return and the benefit cost ratio in the current research work. The relevant treatment-wise cost of cultivation, gross returns, net returns and benefit: cost ratio (B: C ratio) of tomato has been worked out for and depicted in Table 4.14, 4.15 and Appendix-III, respectively.

Perusal of data for spring-summer revealed that highest cost of cultivation (Rs. 159.42 /m^2) was incurred in T_{16} i.e. GA_3 @ 75ppm + All above three stage (Rs. 158.98 /m^2) followed by T_8 i.e. NAA @ 75ppm + All above three stage, whereas lowest cost of cultivation (Rs. 135.62/m^2) was observed in T_3 i.e. NAA @ 50ppm + Fruiting stage. The economic analysis showed that the highest net return of Rs.332.82 /m^2 by incurring Rs.158.98/- towards cost of cultivation per m^2 was obtained from treatment combination T_{16} (GA_3 @ 75ppm + All above three stage) on account of highest yield (24.59 kg/m^2) with the second highest benefit: cost ratio of 2.09. However, the highest benefit: cost ratio was 2.19 obtained in treatment combination T_{14} (GA_3 @ 75ppm + Flowering stage) which otherwise recorded second highest yield (22.59 kg/m^2) as well as net returns (Rs. 309.96/-) as compared to the former treatment combination i.e. T_{16}. This was 'in fact' on account of additional cost incurred for the treatment combination T_{16} (GA_3 @ 75ppm + All above three stage). Similarly, for Autumn-Winter season data revealed that highest cost of cultivation (Rs. 159.42 /m^2) was incurred in T_8i.e. NAA @ 75ppm + All above three stage which was followed by T_{16} i.e. GA_3 @ 75ppm + All above three stage (Rs. 159.00 /m^2), whereas lowest cost of cultivation (Rs. 135.62/m^2) was observed in T_3 i.e. NAA @ 50ppm + Fruiting stage. The economic analysis showed that the highest net return of Rs.394.00 /m^2 by incurring Rs.159.00/- towards cost of cultivation per m^2 was obtained from treatment combination T_{16} (GA_3 @ 75ppm + All above three stages) on account of highest yield (27.65 kg/m^2) with a highest benefit: cost ratio of 2.48. However, the second highest benefit: cost ratio was 2.19 obtained in treatment combination T_3 (NAA @ 50ppm + Fruiting stage) which otherwise recorded yield (21.64kg/m^2) as well as net returns (Rs. 394.00/-) as compared to the former treatment combination that isT_{16}. Based on the results obtained in this experiment, it is concluded that the treatment modules T_{14} (GA_3 @ 75ppm + Flowering stages) and T_{16} (GA_3 @ 75ppm + All above three stages) were found to be superior over all other treatments in relation to growth and yield parameters for Spring-Summer and Autumn-Winter season in tomato crop under the agro-climatic conditions of Palampur.

However, since these results are based on two seasons experiment; further trials may be needed to substantiate the results. The present results are in line with the findings of

Singh et al. (2017) in capsicum, Muhammad et al. (2019) in tomato in which GA_3 (75ppm) was the most profitable than rest of the treatments under the study and Ali et al. (2020) in tomato.

Table 4.14: Effect of different treatment combinations on economics (Spring-Summer Season) of tomato plant

Treatment code	Treatment details	Marketable yield per m^2 area (kg)	Cost of cultivation (Rs)/m^2 area	Gross return (Rs)/m^2 area	Net return (Rs) /m^2 area	Output: input ratio /m^2 area
T_1	NAA @ 50ppm + Vegetative stage	20.52	141.68	410.40	268.72	1.90
T_2	NAA@ 50ppm + Flowering stage	19.77	137.74	395.40	257.66	1.87
T_3	NAA @ 50ppm + Fruiting stage	19.05	135.62	381.00	245.38	1.81
T_4	NAA @ 50ppm + All above three stage	17.27	150.34	345.40	195.06	1.30
T_5	NAA @ 75ppm + Vegetative stage	19.61	152.91	392.20	239.29	1.56
T_6	NAA @ 75ppm + Flowering stage	17.74	149.83	354.80	204.97	1.37
T_7	NAA @ 75ppm + Fruiting stage	20.36	146.77	407.20	260.43	1.77
T_8	NAA @ 75ppm + All above three stage	18.06	159.42	361.20	201.78	1.27
T_9	GA_3 @ 50ppm + Vegetative stage	17.73	140.84	354.60	213.76	1.52
T_{10}	GA_3 @ 50ppm + Flowering stage	16.01	137.76	320.20	182.44	1.32
T_{11}	GA_3 @ 50ppm + Fruiting stage	18.41	139.94	368.20	228.26	1.63
T_{12}	GA_3 @ 50ppm + All above three stage	19.60	152. 84	392.00	239.52	1.57
T_{13}	GA_3 @ 75ppm + Vegetative stage	17.56	149.90	351.20	201.90	1.35
T_{14}	GA_3 @ 75ppm + Flowering stage	22.59	141.84	451.80	309.96	2.19
T_{15}	GA_3 @ 75ppm + Fruiting stage	21.73	145.84	434.60	288.76	1.98
T_{16}	GA_3 @ 75ppm + All above three stage	24.59	158.98	491.80	332.82	2.09
T_{17}	Control (without any treatment)	16.52	139.48	330.40	190.92	1.37

Table 4.15 Effect of different treatment combinations on economics (Autumn-Winter Season) of tomato plant

Treatment code	Treatment details	Marketable yield per m^2 area (kg)	Cost of cultivation (Rs)/m^2 area	Gross return (Rs)/m^2 area	Net return (Rs) /m^2 area	Output: input ratio /m^2 area
T_1	NAA @ 50ppm + Vegetative stage	19.97	141.68	395.80	254.12	1.79
T_2	NAA @ 50ppm + Flowering stage	20.44	137.74	408.80	271.06	1.98
T_3	NAA @ 50ppm + Fruiting stage	21.64	135.62	432.80	297.18	2.19
T_4	NAA @ 50ppm + All above three stage	19.04	150.34	380.80	230.46	1.53
T_5	NAA @ 75ppm + Vegetative stage	18.94	152.91	378.80	225.89	1.48
T_6	NAA @ 75ppm + Flowering stage	20.33	149.83	406.60	256.77	1.71
T_7	NAA @ 75ppm + Fruiting stage	20.12	146.77	402.40	255.63	1.74
T_8	NAA @ 75ppm + All above three stage	23.07	159.42	461.40	301.98	1.89
T_9	GA_3 @ 50ppm + Vegetative stage	17.49	140.80	349.80	209.00	1.48
T_{10}	GA_3 @ 50ppm + Flowering stage	16.54	137.80	330.80	193.00	1.41
T_{11}	GA_3 @ 50ppm + Fruiting stage	16.56	139.90	331.20	191.30	1.37
T_{12}	GA_3 @ 50ppm + All above three stage	19.46	152. 84	389.20	236.40	1.55
T_{13}	GA_3 @ 75ppm + Vegetative stage	16.50	149.90	330.00	180.10	1.21
T_{14}	GA_3 @ 75ppm + Flowering stage	23.09	141.80	461.80	320.00	2.26
T_{15}	GA_3 @ 75ppm + Fruiting stage	21.45	145.80	429.00	283.20	1.94
T_{16}	GA3 @ 75ppm + All above three stage	27.65	159.00	553.00	394.00	2.48
T_{17}	Control (without any treatment)	17.51	139.48	350.20	210.72	1.51

5. SUMMARY AND CONCLUSIONS

The experiment entitled, "Studies on effect of plant growth regulators in polyhouse grown tomato (*Solanum lycopersicum* L.)'' was conducted in a modified naturally ventilated polyhouses at the Experimental Farm of Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur during spring-summer and autumn-winter season with the following objectives in view:

I. To study the effect of different plant growth regulators on yield and quality of tomato and
II. to work out the economics of tomato production under protected conditions.

The experiment was laid out in a factorial randomized block design with three replications, consisting of seventeen treatments having combinations of two plant growth regulators i.e. (GA_3 @ 50ppm, GA_3 @ 75ppm and NAA @ 50 ppm, NAA @ 75ppm) and four growth stages of tomato plant *viz*., Vegetative stage, flowering stage, fruiting stage and all above three stages.

Genotype Palam Tomato Hybrid-1 were used for the study and sowing was done in plastic plug trays by using soilless media having, coco peat, perlite and vermiculite in the ratio of 3:1:1, respectively inside the growth chamber on 3rd February, 2020 for spring-summer and 23rd July, 2020 for autumn-winter season to get healthy and disease-free seedlings of tomato. The seedlings of spring-summer tomato crop were ready for transplanting after 25 days and subsequently transplanted on 1st March, 2020 whereas, the seedlings of autumn-winter season were ready for transplanting after 28 days and transplanted on 20th August, 2020 inside the modified naturally ventilated polyhouse having 250 m^2 area. The crops were raised following all the package and practices for protected cultivation of tomato.

The interactions of the plant growth regulators with growth stages of plant exhibited significant results for day to 50 per cent flowering in both the seasons and indicated that when growth regulator GA_3 @ 75ppm sprayed at flowering stage took minimum number of days (27.58) for harvesting. The effect of plant growth regulators was non-significant for number of fruits per cluster in both the seasons. Growth regulator GA_3 @ 75 ppm when sprayed produced maximum number of fruits per plant i.e. 52.75 and 57.25, respectively in both the seasons. Whereas from the different stage of plant growth the flowering stage (A_2)

produced (54.67 and 60.17) numbers of fruits per plant. The combined effect of growth regulators with the different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) produced (57.00 and 66.33) number of fruits per plant during both the seasons, which were significantly at par with the A_2B_2, A_2B_3, and A_1B_4interactions which produced 55.00 number of fruits per plant. GA_3 plays important role on controlling pre harvest fruit drop and increases fruit setting percentage. Studies showed that fruit weight of tomato significantly varied with the application of plant growth regulators during both the seasons. The interactions of the plant growth regulators and different stages of plant exhibited (A×B) significant results for fruit weight. Among the application of PGRs, GA_3@ 75 ppm when sprayed produced maximum (65.17 g and 64.62 g) fruit weight in both the seasons whereas, during different stages of plant growth when this GA_3 sprayed at fruiting stage (A_2) plants produced fruits having maximum (66.27 g and 66.14 g) fruit weight. The combined effect of growth regulators with the different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) produced maximum fruit weight (71.90 g and 69.50 g) which were significantly at par with the A_3B_4.

The present study summarized that marketable yield per plant varied significantly with the application of plant growth regulators at different growth stages of the plant. The interactions of the plant growth regulators with different stages of plant also exhibited significant results for marketable yield per plant for both the seasons.GA_3 @ 50 ppm and @ 75 ppm when sprayed produced maximum (3.32 kg and 3.72 kg) marketable yield per plant for spring-summer and autumn-winter season, respectively. Whereas, from the different stage of plant growth the flowering stage (A_2) recorded maximum (3.60 kg and 3.70 kg) marketable yield per plant for first and second season. The combined effect of growth regulators at different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) recorded maximum (4.10 kg and 4.61 kg) marketable yield per plant which was significantly superior from all two-way interactions. Similar trend was recorded in marketable yield per m^2. Application of growth regulators GA_3 @ 50 ppm and 75 ppm when sprayed produced maximum (19.89 kg and 22.31 kg) for both the seasons. Whereas, from the different stages of plant growth the flowering stage (A_2) recorded maximum (21.62 kg and 22.17 kg) marketable yield per m^2. The combined effect of growth regulators at different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) recorded maximum (24.59 kg and 27.65 kg) marketable yield per m^2 during both the seasons which was significantly superior from all other two-way interactions. Plant height also varied significantly with the application of PGRs on different stages of the plant. The combined effect of growth regulators at different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) and A_1B_1 (NAA @ 50 ppm sprayed at vegetative stage) recorded maximum (252.47 cm and 215.00 cm) plant height in both seasons. The use of GA_3 considerably increase the number of fruits per plant, fruit settings, the weight of fruits and significantly increases the total yield per plant and per m^2 area. In many cases GA_3 promote vegetative growth i.e. height of the plant because it also promotes cell division and elongation.

Regarding the quality parameter PGRs have significant role & in the present study ascorbic acid content varied significantly with the application of plant growth regulators at different stages of plant growth in both the seasons. Application of growth regulators GA_3 @ 75 ppm when sprayed improved the quality in terms of vitamin C content and the value is 26.62 and 29.80 mg/100 g. Whereas, for the different stages of plant growth the flowering stage (A_2) recorded maximum (26.63 and 30.12 mg/100) vitamin C content. The combined effect of growth regulators at different stages of plant growth showed that A_2B_4 (GA_3 @ 75 ppm sprayed at flowering stage) and A_2B_1 (NAA @ 50 ppm sprayed at flowering stage) recorded maximum (27.40 and 30.97 mg/100 g) ascorbic acid content for first and second season. The economic analysis showed that the highest net return of Rs. 394.00 /m^2 by incurring Rs. 159.00/- towards cost of cultivation per m^2 was obtained from treatment combination T_{16} (GA_3 @ 75ppm + All above three stages) on account of highest yield (27.65 kg/m^2) with a highest benefit: cost ratio of 2.48.

Conclusions:

From the present experiment, it has been concluded that tomato plants sprayed with GA_3 @ 75ppm at flowering stage recorded maximum marketable yield and its contributing characters.

LITERATURE CITED

Abbasi NA, Zafar L, Khan HA and Qureshi AA. 2013. Effects of naphthalene Acetic Acid and calcium chloride application on nutrient uptake, growth, yield and post-harvest performance of tomato fruit. *Pakistan Journal of Botany* 45: 1581-1587

Ahmad H, Hassan MR, Laila B, Mahbuba S and Uddin AFMJ. 2017. Plant growth promoters on growth and yield of summer cherry tomato line (JP-27). *Journal of Bioscience and Agriculture Research* 12: 1041-1047

Akand H, Khairul Mazed HEM, Pulok AI, Chowdhury SN and Moonmoon JF. 2015. Growth and yield of tomato (*Lycopersicon esculentum* Mill.) as influenced by different level of gibberellic acid application *International Journal of Applied Research* 1: 71-74

Alam SM and Khan MA. 2002. Fruit yield of tomato as affected by NAA spray. *Asian journal of plant science* 1: 24

Ali MR, Quddus MA, Trina TN, Salim MMR and Asaduzzaman M. 2020. Influence of plant growth regulators on growth, yield, and quality of tomato grown under high temperature in the tropics in the summer, *International Journal of Vegetable Science* pp 1-18

Aloni B, Daie J and Wyse RE. 1968. Enhancement of (14C)-sucrose export from source leaves of *Vicia faba* by gibberellic acid. *Plant Physiology* 82: 962-966

Anonymous. 2017. Department of Agriculture, Shimla-5

AOAC. 1970. Official Methods of Analysis of the Association of Official Analytical Chemists. (Ed. Wiliam Horwitz). Benjamin Franklin Station, Washington, D.C., USA

Balagura-Lopez HE and Hernandez CJF. 2009. Effect of gibberellic acid (GA_3) on seed germination and growth of tomato (*Solanum lycopersicum* L.) *Acta Horticultura*821:141-147

Baliyan SP, Madhava Rao KS, Baliyan PS and Mahabile M. 2013. The effects of 4-Chlorophenoxy acetic acid plant growth regulator on the fruit set, yield 42 and economic benefit of growing tomatoes in high temperatures. *International Journal of Agricultural Science and Research* 3: 29-36

Ballantyine DJ. 1995. Cultivar, photoperiod and gibberellin influence shoot elongation and photosynthetic capacity of *Hardy Azaleas*.*Horticultural Science* 2: 257-259

Batlang U. 2008. Benzyladenine plus gibberellins (GA4+7) increase fruit size and yield in greenhouse-grown hot pepper (*Capsicum annuum* L.). *Journal of Biological Science* 8: 659-662

Batlang V, Emongor VE and Pule-Meulenburg F. 2006. Effect of benzyladenine and gibberellic acid on yield and yield components of cucumber (*Cucumis sativus* L. cv. tempo). *Journal of Agronomy* 5: 418-423.11

Begum MM, Karim MM, Hossain MA, Rahman MM and Islam MO. 2016. Morphological characters and dry mass production in winter tomato as affected by foliar application of plant growth regulators. *Asian-Australasian Journal of Bioscience and Biotechnology* 1:514-520

Bhosle AB, Khorbhade SB, Sanap PB and Gorad MJ. 2002. Effect of plant hormones on growth and yield of summer tomato. (*Lycopersicon esculentum* Mill.). *Orissa Journal of Horticulture* 30: 63-65

Bokade N, Bhalekar MN, Gupta NS, Deshpande A. 2006. Effect of growth regulators on growth and yield of tomato in summer. *Journal of Maharashtra agricultural universities* 31:64- 65

Chandiniraj A, Holebasappa K, Hore JK and Chattopadyay N. 2016. Growth and yield of chilli (*Capsicum annuum* L.) as influenced by different growth regulators. *The Journal an International Quarterly Journal of life sciences* 11: 385-388

Chaudhary BR, Sharma MD, Shakya SM and Gautam DM. 2006. Effect of plant growth regulators on growth, yield and quality of chilli (*Capsicum annum* L.) at Rampur, Chitwan. *Journal of Institute of Agriculture and Animal Science* 27: 65-68

Choudhury S, Islam N, Sarkar MD and Ali MA. 2013. Growth and yield of summer tomato as influenced by plant growth regulators. *International Journal of Sustainable Agriculture* 5: 25-28

Chovatia RS, Ahlawat TR, Kavathia YA, Jivani LL and Kaila DC. 2010.Effect of plant growth regulators on vegetative, flowering, and yield of bitter gourd. cv. Priya. *Indian Journal of Horticulture* 67: 254-256

Desai SS, Chovatia RS and Singh V. 2011a. Effect of different plant growth regulators and micronutrients on fruit characters and yield of tomato cv.Gujarat Tomato-3 (GT3). *The Asian journal of horticulture* 7: 546-549

Desai SS, Chovatia RS and Singh V. 2011b. Effect of different plant growth regulators and micronutrients on fruit quality and plant micronutrient content of tomato. *International journal of agriculture sciences* 10: 130-133

Dhillon NS, Sharma P, Kumar P and Sharma V. 2019. Comparative performance of tomato genotypes for yield and quality characters under protected environment. *International Journal of Chemical Studies* 7: 1678-1680

Dhyani S, Misra CA and Verma P. 2018. Assessment of tomato (*Solanum lycopersicon* L.) hybrids for fruit quality and yield characters in the hill region of Utttarkhand. *International Journal of Science and Research* 7: 2319-7064

Feofanova ND. 1960. The effect of giberellin on fruit development in tomatoes. *Botanical journal* 45: 1781-1786

Fontes PCR and Silva DJH. 2002. Producao de tomate de mesa. Vicosa, MG: Aprenda Facil pp195.

Gelmesa D, Abebie B and Desalegn L. 2010. Effects of gibberellic acid and 2, 4-dichlorophenoxyacetic acid spray on fruit yield and quality of tomato (*Lycopersicon esculentum* Mill.). *Journal of Plant Breeding and Crop Science* 2: 316-324

Gelmesa D, Abebie B and Desalegn L. 2012. Regulation of tomato (*Lycopersicon esculentum* Mill.) fruit setting and earliness by gibberellic acid and 2, 4-dichlorophenoxy acetic acid application. *African journal of biotechnology* 11: 11200-11206

Gemici M, Güve A and Yürekli AK. 2000. Effect of some growth regulators and commercial preparations on the chlorophyll content and mineral nutrition of (*Lycopersicon esculentum* Mill.) *Turkish Journal of Botany* 24: 215-219

Gemici M, Türkyilmaz B and Tan K. 2006. Effect of 2, 4-D and 4-CPA on yield and quality of the tomato (*Lycopersicon esculentum* Mill.). *Journal of Food Science* 29: 24-32

Gomez KA and Gomez AA. 1984. Statistical procedures for agricultural research. John Wiley and Sons, New York pp 680

Gupta PK and Gupta AK. 2000. Efficacy of plant growth regulators (IAA and NAA) and micronutrient mixtures on growth, flowering, fruiting and shelf life of tomato (*Lycopersicon esculentum* Mill.). *Bioved Research Society* 11: 25-29

Gupta PK, Gupta NK and Reddy S. 2001. Efficiency for plant growth regulators and micronutrient mixture on growth and shelf life of tomato (*Lycopersicon esculentum* Mill.) fruit. *Indian Journal of Agricultural Biochemistry* 14:63- 65

Gupta S, Jha MK and Sahu MR. 2019. Study on effect of plant growth regulators and boron on growth attributes of tomato (*Solanum lycopersicum* Mill.). *Journal of Pharmacognosy and Phytochemistry* 8: 2024-2027

Gurjar JS, Banafar RN, Gupta NK, Gurjar PK, Singh L. 2018. Effect of NAA, GA_3 on growth and yield of tomato varieties. *Journal of Pharmacognosy and Phytochemistry* 7: 3157-3160

Hossain ME, Amin R, Sani MNH, Ahamed KU, Hosain MT and Nizam R. 2018. Impact of exogenous application of plant growth regulators on growth and yield contributing attributes of summer tomato. *Journal of Plant and Soil Science* 24: 1-14

Hasanuzzaman, Akand HEM, Mazed K, Pulok AI, Chowdhury SN and Moonmoon JF.2015. Growth and yield of tomato (*Lycopersicon esculentum* Mill.) as influenced by different level of gibberellic acid application *International Journal of Applied Research* 1: 71-74

Hossain MM, Khalequzzaman KM, Hossain MA, Mollah MRA and Siddique MA. 2004. Influence of planting time on the extension of picking period of four tomato varieties. *Journal of Biological Science* 4: 616-619

Islam MS,Hoque MA, Sumiz SA, Jony M, Ranu K and Shamsuzzaman M. 2020. Effects of foliar application of indol butyric acid (IBA), gibberellic acid (GA_3) and zinc (Zn) on yield and quality of tomato. *International Journal of Plant & Soil Science* 16: 19-30

Jahan N and Anamika WJ. 2017. Effects of two growth regulators on yield, storage behaviour and quality of tomato (*Lycopersicon esculentum* mill.) *Bangladesh journal of Botany* 46: 709-715

Jakhar D, Thaneshwari, Nain S and Jakhar N. 2018.Effect of plant growth regulator on growth, yield & quality of tomato (*Solanum lycopericum*) Cultivar 'Shivaji' under Punjab Condition. *International Journal of Current Microbiology and Applied Sciences* 7: 2630-2636

Kannan K. Jawaharlal M and Prabhu M. 2009. Effect of plant growth regulators on growth and yield parameters of paprika cv. KtPl-19. *Agricultural Science Digest* 29: 157-162

Kaushik MP, Sharma JK and Singh I. 1978. Effect of alpha naphthalene acetic acid, gibberellic acid, kinetin and norphactin on yield of tomato. *Plant Science* 6: 51-53

Khan MMA, Gautam AC, Mohammad F, Siddiqui MH, Naeem M and Khan MN. 2006. Effect of gibberellic acid spray on performance of tomato. *Turkish Journal of Biology* 30:11-16

Khan NA, Ansari HR and Samiullah. 1998. Effect of gibberellic acid spray during ontogeny of mustard on growth, nutrient uptake and yield characteristics. *Journal of Agronomy and Crop Science* 181: 61-73

Kumar A, Biswas TK, Tarun KB, Singh N and Lal DEP. 2014. Effect of gibberellic acid on growth, quality and yield of tomato (*Lycopersicon esculentum* Mill.). *Journal of Agriculture and Veterinary Science* 7: 28-30

Kumar D, Kumar R, Kumar S, Bhardwaj ML, Thakur MC, Kumar R, Thakur KS, Dogra BS, Vikram A, Thakur A and Kumar P. 2013. Genetic variability, correlation and path coefficient analysis in tomato. *International Journal of Vegetable Science* 19: 313- 323

Kumar S, Singh R, Singh V, Singh MK and Singh AK. 2018. Effect of plant growth regulators on growth, flowering, yield and quality of tomato (*Solanum lycopersicum* L.). *Journal of Pharmacognosy and Phytochemistry* 7: 41-44

Lekshmi SL and Celine AV. 2015. Evaluation of tomato hybrids for fruit, yield and quality traits under polyhouse conditions. *International Journal of Applied and Pure Science and Agriculture* 5:58-68

Masroor A, Khan C, Gautam C, Mohammad F, Manzer H, Siddiqui M, Naeem M and Khan N. 2006. Effect of gibberellic acid spray on performance of tomato. *Turkish Journal of Biology* 30: 11-16

Maurya SK, Singh BK, Singh AK, Vani VM and Singh B. 2013. Impact of NAA on yield and quality of tomato (*Lycopersicon esculentum* Mill.). *Environment and Ecology* 31: 190-192

Mazed KHEM, Akand MH, Haque MN, Pulok MAI and Moonmoon JF. 2014. Growth and yield of tomato as influenced by GA3 and pruning. *International Journal of Current Research* 6:10464-10469

Meena RS. 2008. Effect of GA_3 and NAA on growth, yield and quality of tomato (*Lycopersicon esculentum* Mill.) cv. Pusa Ruby grown under semi-arid conditions. *Current Agriculture* 32:83-86

Mehraj H, Sadia AA, Taufique T, Rashid M and Jamal Uddin AFM. 2014. Influence of foliar application of gibberellic acid on cherry tomato (*Lycopersicon esculentum* Mill. var. *Cerasiforme*). *Journal of Experimental Bioscience* 5: 27-30

Mehta AK and Mathi DJ. 1976. Effects of growth regulators on summer tomato (*Lycopersicon esculentum* Mill.) *Haryana Horticultural Science* 4: 167-176

Mistry KK, Iqubal KF and Bapari SP. 2020. The Application Effect of GA_3 on plant growth, yield and quality attributes of tomato (*Lycopersicom esculentum* Mill.) *Syrian Journal of Agricultural Research* 7: 441-448

Mizan MMH. 2016. Effect of NAA and GA_3 on growth and yield of tomato. M.Sc. Thesis, p 1-100. Department of Horticulture, Sher-E-Bangla Agricultural University, Dhaka

Moniruzzaman M, Khatoon R, Hossain MFB, Jamil MK and Islam MN. 2014. Effect of GA_3 and NAA on physio-morphological characters, yield and yield components of brinjal (*Solanum melongena* L.). *Bangladesh Journal of Agricultural Research* 39: 397-405

Mostafa EAM and Saleh MMS. 2006. Influence of spraying with gibberellic acid on behavior of anna apple trees. *Journal of Applied Sciences Research* 2: 477-483

Muhammad W, Khan NM, Ilyas M, Hissam M, Khan W, Ali B, Khan RM and Hilal M. 2019. Influence of Calcium chloride and Gibberellic acid levels on the growth, yield and quality of tomato in the agro-climatic conditions of Mardan-Pakistan. *Pure Applied Biology* 8: 1191-1205

Mulligan DR and Patrick JW.1973. Gibberellic-acid-promoted transport of assimilates in stems of (*Phaseolus vulgaris* L.). Localised versus remote site (S) of action. *Planta* 145: 233-238

National Horticulture Board. 2019. Area and production statistics of tomato http://nhb.gov.in.

Naz S, Naqvi SAH, Siddique B, Zulfiqar MA and Rehman A. 2020. Exogenous application of selected antioxidants and phyto-development directors influenced the development, output and biochemical attributes of tomato (*Lycopersicum esculentum* Mill.). *Pakistan Journal of Agricultural Research* 33: 789-797

Nibhavanti B, Bhalekar MN, Gupta NS and Deshpande A. 2006. Effect of growth regulators on growth and yield of tomato in summer. *Journal of Maharashtra Agricultural Universities* 31:64-65

Nibhavanti BK, Bhalekar MN, Gupta NS and Deshpande AN. 2004. Effect of growth regulators on growth and yield of tomato. *Journal of Maharashtra Agricultural University* 31: 64-65

Olaiya CO, Soetan KO and Ogunkolade NS. 2010. Evaluation of the biochemical effects of auxins on nutritional quality of tomato (*Solanum lycopersicon*) 4: 041-045

Orzolek MD and Kaplan RC.2006. Effect of the addition of growth regulators in gel on growth and yield of tomatoes. *Acta Horticulture* 198: 135-140

Pargi SC, Lal EP, Singh N and Biswas TK. 2014. Effect of naphthalene acetic acid on biochemical parameters, growth and yield of tomato (*Lycopersicon esculentum* L. Mill*).* *Journal of Agriculture and Veterinary Science* **7**:16-18

Patel JS, Sitapara HH and Patel KA. 2012. Influence of plant growth regulators on growth, yield and quality of tomato and brinjal, *International Journal of Forestry & Crop Improvement* 3: 116-118

Prajapati VP and Varma LR. 2014. Effect of spray treatment of plant growth substances at different stages on growth and yield of sweet pepper (*Capsicum annum* L.) cv. Indra under green house. *International Journal of Life Sciences Research* 2: 235-240

Pramanik K and Mohapatra PP. 2017. Role of auxin on growth, yield and quality of tomato – A Review. *International Journal of Current Microbiology and Applied Science* 6: 1624-1636

Pramanik K, Das SP, Acharya LK and Jayapuria D. 2017. Role of gibberellic acid on growth, yield and quality of tomato: A Review. *International journal of conservation science* 5: 826-830

Pramanik K, Pradhan J and Sahoo SK. 2018. Role of auxin and gibberellins growth, yield and quality of tomato: A review. *The Pharma Innovation Journal* 7: 301-305

Prasad RN, Singh SK, Yadava RB and Chaurasia SNS. 2013. Effect of GA_3 and NAA on growth and yield of tomato. *Vegetable Science* 40: 195-197

Pundir JPS and Yadav PK. 2001. On effect of GA_3, NAA and 2, 4-D on growth, yield and quality of tomato var. Punjab Chhuhara. *Current Agriculture* 25: 137-138

Rahman MH, Khan MA and Islam MR. 2013. Effect of ABT-6 hormone on growth and yield of BINA tomato-5. *Journal of Natural Products* 6: 103-108

Rahman MM, Haque ME, Parveen K, Tipua MMH and Islam MS. 2016. Effect of different sources of nutrient and hormones on growth and yield of tomato. *Journal of Bioscience and Agriculture Research* 11: 936-941

Rahman MS, Saki MJ, Hosain MT and Rashid S. 2019. Cumulative effect of zinc and gibberellic acid on yield and quality of tomato. *International Journal of Biosciences* 14: 350-360

Rai AC, Singh M and Shah K. 2012. Effect of water withdrawal on formation of free radical, proline accumulation and activities of antioxidant enzymes in ZAT12- transformed transgenic tomato plants. *Plant Physiology and Biochemistry* 61: 108-114

Rai GK, Singh J, Singh S, Gupta AK. 2002. Effect of plant growth regulators (IAA and NAA) and micronutrient mixtures (Humaur and Multiplex) on growth, yield and quality of tomato (*Solanum esculentum* Mill.). *Annals of Biology* 18:13-17

Rai N, Yadav DS, Patel KK, Yadav RK, Asati BS and Chaubey T. 2006. Effect of plant growth regulators on growth, yield and quality of tomato, *Solanum lycopersicon* Mill. grown under mid hill of Meghalaya. *Vegetable Science* 33:180-182

Ram RB, Prakash J and Meena ML. 2014. Growth, flowering, fruiting, yield and quality of tomato (*Lycopersicon esculentum* Mill.) as influenced plant bio regulators. *International Journal of Plant Sciences* 9:67-71

Ranjeet, Ram RB, Jay P and Meena ML. 2014. Growth, flowering, fruiting, yield and quality of tomato (*Lycopersicon esculentum* Mill.) as influenced plant bio regulators. *International Journal of Plant Science* 9: 67-71

Razzak MA, Sattar MA, Amin MS, Kyum MA and Alam MS. 2011. Krishi Projukti Hatboi (5th edn.). Bangladesh Agricultural Research Institute (BARI), Gazipur 1701, Bangladesh, p. 384

Rinchu B, Saravanan S, Prasad VM, Baby S and Geethu BL. 2018. Effect of GA_3 and NAA on plant growth and yield of cherry tomato (*Lycopersicon esculentum* var. *cerasiforme*) under polyhouse condition. *The Pharma Innovation Journal* 7: 79-82

Rodrigues MJ, Warade SD and Patil SD. 2001. Effect of growth regulators and truss sequence on hybrid seed yield of tomato hybrid. *Advances in Plant Sciences* 14:495-499

Roy SK and Choudhary B. 1972. Studies on physiochemical characteristics of few varieties in relation to processing. *Journal of Food Science Tech* 9:151-153

Sagar V, Saini SS and Rattan RS. 1978. Effect of plant growth regulators on yield and number of fruits in tomato (*Lycopersion esculentum* Mill.). *Seeds and Farms* IV: 22-24

Saha P. 2009. Effect of NAA and GA_3 on yield and quality of tomato (*Lycopersicon esculentum* Mill). *Environmental Ecology* 27: 1048-1050

Saleem MY, Asghar M, Iqbal Q, Rahman A and Akram M. 2013. Diallel analysis of yield and some yield components in tomato (*Solanum lycopersicum* L.). *Pakistan Journal of Botany* 45: 1247-1250

Sasaki H, Yano T and Yamasaki A. 2005. Reduction of high temperature inhibition in tomato fruit set by plant growth regulators. *JARQ Japan International Research Centre for Agriculture* 39: 1-7

Saurabh T, Dubey AK, Singh SK and Ujjwal V. 2016. Effect of Different Levels of NAA, GA_3 and 2, 4-D on growth and yield of tomato *(Lycopersicon Esculentum* Mill.). *Annals of Horticulture* 9: 97-100

Serrani JC, Fos M, Atares A and Garcıa Martınez JL. 2007. Effect of gibberellin and auxin on parthenocarpic fruit growth induction in the cv. Micro Tom of tomato. *Journal of Plant Growth Regulation* 26: 211-221

Sharma P, Dhillon NS, Kumar V and Kumar P. 2019. Correlation and path analysis for yield and its contributing traits in tomato (*Solanum lycopersicum*) under the protected environment. *Journal of Pharmacognosy and Phytochemistry* 1: 447-450

Shital CA, Patel NB, Mehta DR, Patel JB, Ishita ZM and Vaja AD. 2017. Effect of plant growth regulators on seed yield and Its parameters in tomato (*Solanum lycopersicon* L.). *International Journal of Agriculture Sciences* 9: 3906-3909

Singh J, Dwivedi AK, Devi P, Bajeli J, Tripathi A and Maurya SK. 2019. Effect of plant growth regulators on growth and yield attributes of tomato (*Solanum lycopersicom* Mill.). *International Journal of Current Microbiology and Applied Sciences* 8: 1635-1641

Singh R and Kumar J. 2017. Off- season performance of tomato hybrids cultivation under natural ventilated polyhouse conditions in north plains of India. *International Journal of Agricultural Science and Research* 8: 635-640

Singh RK, Rai N and Singh SN. 2010. Response of tomato genotypes to tomato leaf curl virus. *Indian Journal of Agricultural Science* 80:755-758

Singh SK, Kumar A, Beer K, Singh VP and Patel SK. 2018. Effect of naphthalene acetic acid (NAA) and gibberellic acid (GA3) on growth and fruit quality of tomato (*Lycopersicon* *esculentum* Mill.) *International Journal of Current Microbiology and Applied Science* 7: 306-311

Sinha A, Singh P, Bhardwaj A and Kumar R. 2020. Evaluation of tomato (*Solanum lycopersicum L.*) genotypes for morphological, qualitative and biochemical traits for protected cultivation. *Current Journal of Applied Science and Technology* 39: 105- 111

Siwna Y, Dixit A, Sahu TK. 2018. Studies on the effect of different plant growth regulators on growth and quality attributes of tomato (*Solanum lycopersicum* L.) Cv. Kashi Amrit. *International Journal of Science and Research* 8: 1222-1226

Sultana M. 2013. Effect of nitrogen and gibberellic acid on growth and yield of tomato, M. Sc. Thesis p1-86, Department of Horticulture, Sher-e-Bangla Agricultural University, Dhaka

Taiz, L and Zeiger, E. (2009). Fisiologia vegetal (4th ed., p. 819). Porto Alegre: Artmed

Tiwari AK and Singh DK. 2014. Use of plant growth regulators in tomato (*Solanum lycopersicum* L.) under tarai conditions of Uttarkhand. *Indian Journal of Hill Farming* 27: 38-40

Tomar S, Sanjive KR, Singh AK, Dubey, Singh JP and Abhishek .2017. Role of plant hormones on vegetative growth of tomato (*Lycopersicon esculentum* Mill.) *International Journal of Current Microbiology and Applied Sciences*) 6: 3319-3323

Uddain J, Akhter HK, Mostafa MG and Rahman MJ. 2009. Effect of different plant growth regulators on growth and yield of tomato. *International Journal of Sustainable Agriculture* 1: 58-63

Ujjwal V, Singh MK, Dev P, Chaudhary M, Kumar A and Maurya RL. 2018. Impact of foliar application of different levels of GA3 and NAA on reproductive and quality parameters of tomato (*Solanum Lycopersicum* L.). *Journal of Pharmacognosy and Phytochemistry* 1: 84-86

Vavilov NI. 1951. The origin variation immunity and breeding of cultivated plant. *Chronical Botanica* 13: 364

Verma PPS, Meena M and Meena SK. 2014. Influence of plant growth regulators on growth, flowering and quality of tomato (*Lycopersicon Esculentum* Mill). *Indian Journal of Hill Farming* 27:19-22

Verma PPS, Meena ML and Meena SK. 2011. Influence of plant growth regulators on growth, flowering and quality of Tomato (*Lycopersicon Esculentum* Mill), cv. H-86. *Indian Journal of Hill Farming* 27: 19-22

APPENDICES-I

Mean weekly meteorological data recorded inside modified naturally ventilated polyhouse during 02-Apr-20to 23-Jul-20

Standard week	Dates	Temperature (°C)		Relative Humidity
		Maximum Temp	Minimum Temp	
		(°C)	(°C)	(%)
14	02-Apr-20	30.70	17.36	71.53
15	09-Apr-20	34.14	21.20	71.95
16	16-Apr-20	32.71	20.14	72.36
17	23-Apr-20	32.86	21.21	72.76
18	30-Apr-20	33.21	22.64	73.28
19	07-May-20	34.13	21.69	73.06
20	14-May-20	35.07	22.31	73.64
21	21-May-20	39.57	26.60	74.54
22	28-May-20	35.24	22.86	74.97
23	04-Jun-20	34.93	23.89	74.72
24	11-Jun-20	36.71	26.36	74.69
25	18-Jun-20	36.71	26.36	74.26
26	25-Jun-20	36.21	25.86	73.52
27	02-Jul-20	36.91	26.31	72.62
28	09-Jul-20	36.14	26.36	71.91
29	16-Jul-20	35.71	26.21	71.26
30	23-Jul-20	35.14	26.43	70.60

APPENDICES-II

Mean weekly meteorological data recorded inside modified naturally ventilated polyhouse during17-Sep-2020 to 19-Feb-2021

Standard week	Dates	Temperature (°C)		Relative Humidity
		Maximum Temp (°C)	Minimum Temp (°C)	(%)
38	17-Sep-20	36.64	24.81	76.43
39	24-Sep-20	36.00	21.93	68.29
40	01-Oct-20	36.50	21.24	66.14
41	08-Oct-20	36.07	21.00	69.50
42	15-Oct-20	35.00	19.44	68.50
43	22-Oct-20	33.00	17.29	63.75
44	29-Oct-20	32.29	16.93	63.50
45	05-Nov-20	43.07	28.38	68.02
46	12-Nov-20	43.99	28.89	66.81
47	19-Nov-20	45.13	29.88	66.60
48	26-Nov-20	46.36	31.11	66.67
49	03-Dec-20	47.83	32.56	66.26
50	10-Dec-20	49.67	34.43	65.95
51	17-Dec-20	52.05	36.88	66.26
52	25-Dec-20	54.87	39.73	66.65
1	01-Jan-21	56.56	41.36	66.46
2	08-Jan-21	58.35	43.14	66.41
3	15-Jan-21	60.24	45.03	66.38
4	22-Jan-21	62.23	47.02	66.34
5	29-Jan-21	64.28	49.08	66.35
6	05-Feb-21	28.58	14.65	68.80
7	12-Feb-21	28.31	15.06	71.04
8	19-Feb-21	59.22	44.48	67.40

Brief Bio data of student

Name	:	Muhammad Juma
Father's Name	:	Mr. Khudidust
Date of Birth	:	September06,1986
Permanent Address	:	House no. 15 Lane No4 Jalalabad City Nangarhar, District No 8

Academic Qualifications:

Examination passed	Year	School/Board/ University	Marks (%)	Major Subjects
High School	2008	S. Muly Habiburrhman (Nangarhar)	71.6%	Chemistry, Physics, History, Islamic, English, Science, Mathematics, computer, Home Economics, Agriculture.
B.Sc. (Horticulture)	2013	Nangarhar Agriculture university	65%	Fundamental of Horticulture, Plant Taxonomy, Floriculture, Agric. Extension, Microbiology, Field Crops, Soil sciences, Pathology, Weed Control, Every Green Fruit, Ecology, Plant Physiology, Seed Production, Vegetable Production, Vegetable and Fruit diseases, Deciduous Fruits, Nute Crops, Process & Storage of Agric. Products.
M. Sc. (Agriculture)	2021	CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur	6.97	Major Discipline: Vegetable Science Minor Discipline: Agronomy