International Journal of Agricultural Sciences ISSN: 2167-0447 Vol. 5 (3), pp. 551-558, May, 2015. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Impact of Gibberellic acid and 2, 4 - dichlorophenoxyacetic acid spray on fruit yield and quality of tomato (*Lycopersicon esculentum* Mill.)

***Hailu Dinka Kidan, Aklilu M. Makonnen and Mikael T. Yimenu**

Department of Agronomy, Faculty of Agriculture, Arba Minch University, Arba Minch, Ethiopia.

Accepted 20 March, 2015

Experiment was conducted at Melkassa Agricultural Research Center, centeral rift valley of Ethiopia from September 2008 to January 2009 with the objective to determine the effects 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. The experiment consisted of two tomato varieties-one processing (Roma VF) and one fresh market (Fetan), three levels of 2,4-dichlorophenoxyacetic acid (2,4-D) (0, 5 and 10 mg l^{-1}) and four levels of gibberellic acid (GA_3) (0, 10, 15 and 20 mg l^{-1}) arranged in 2 × 3 × 4 factorial combinations, in randomized completed block design with three replications. The result showed increase in fruit length from 5.44 to 6.72 cm at 10 mg l^{-1} 2,4-D combined with 10 mg l^{-1} GA_3 above the control, increased fruit weight by 13% due to 2,4-D and reduced fruit weight in single or combined application of GA_3 with 2,4-D. Fruit pericarp thickness was increased by about 50% due to 2,4-D and GA_3 application above the control. Titratable acidity, total soluble solids and lycopene content were also increased due to combined application of 2,4-D and GA_3 spray. Lower fruit pH is another quality attributes of tomato affected by 2,4-D application while that of GA_3 has no effect. Final fruit yield were significantly improved above the control even though both varieties responded differently. For Roma VF, GA_3 at concentration of 10 and 15 mg l^{-1} resulted in maximum fruit yield of 69.50 and 67.92 ton ha^{-1}, respectively in the absence of 2,4-D. For Fetan, maximum marketable fruit yield of 74.39 and 74.20 ton ha^{-1} was obtained from treatment combinations of 10 + 15 and 5 + 0 2,4-D and GA_3, respectively. Hence, yield increment of about 35% for Roma VF and 18% for Fetan were produced at 10 mg l^{-1} GA_3 and 10 + 15 mg l^{-1} 2,4-D and GA_3, respectively over the control. 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 unfavorable climatic conditions of high temperature. Therefore, it is important to further investigate application methods and concentrations of the PGRs under concern in different growing conditions on different tomato cultivars.

Key words: Gibberellic acid, 2,4-dichlorophenoxy acetic acid, tomato, *Lycopersicon esculentum* Mill, fruit yield, quality.

INTRODUCTION

In Ethiopia, tomato (*Lycopersicon esculentum* Mill.) is an important cash crop and widely cultivated both under irrigation and rain fed throughout the year (Lemma, 2002). Tomato has a significant role in human nutrition because of its rich source of lycopene, minerals and vitamins such as ascorbic acid and β-carotene which are anti-oxidants and promote good health (Wilcox et al., 2003). The general dietary deficiencies of vitamins in Ethiopian

*Corresponding author. Email: dr.dinkakidan@amu.edu.et

population could be alleviated by a liberal consumption of many vegetables including tomato (Fekadu et al., 2004). Considering the significant value of the crop emphasis has been given by the national vegetable crops research program in the country to improve yield and quality of fresh market and processing tomato in order to satisfy the demands of both local and export markets (Lemma, 2002). A number of improved varieties and other agronomic packages have been recommended to the users to overcome the low productivity and quality of tomato in the country. However, the average national yield still remains very low which is around 7 ton/ha (CSA, 2009) and less than 50% of the current world average yield of about 27 ton/ha (FAOSTAT, 2007). Increasing temperature, viral diseases and salinity are the major limiting factors in sustaining and increasing tomato productivity (Fekadu and Dandena, 2006). Lack of adabtive cultivars and poor fruit setting of existing varieties especially during the hot/dry season where the demand for tomato is very high is one challenge farmers are facing in tomato production even though there is potential land for cultivation. Breeding for heat tolerance in tomato crop has been difficult due to many factors like moderate heritability inheritance being complex or the cultivars becoming lower in yield (George et al., 1984). For good fruit set and better yield, pollination, germination of pollen grains, pollen tubes growth, fertilization and fruit initiation must take place successfully (Kinet and Peet, 1997). The author further explained that, high relative humidity of the air, low light intensity and extreme low and high temperature, and improper mineral nutrition seems to be involved in the control of those phenomena and result in low fruit set and quality.

Induction of artificial parthenocarpy through application of PGRs enables fertilization-independent fruit development that can reduce yield fluctuation in crops like tomato, pepper and likes (Heuvelink and Korner, 2001). This could be possible by application of certain PGRs like auxin and GA_3 that bring the possibility of tomato production under adverse environmental conditions. Gemici et al. (2006) reported that application of synthetic auxin and gibberellins (GAs) are effective in increasing both yield and quality of tomato. Those PGRs are used extensively in tomato to enhance yield by improving fruit set, size and number (Batlang, 2008; Serrani et al., 2007a) and could have practical application for tomato growers. Tomato fruit setting was promoted by gibberellic acid (GA_3) at low concentration (Sasaki et al., 2005; Khan et al., 2006) and reduced pre-harvest fruit drop with increased number of fruits per plant and yield was observed due to Naphthalene Acetic Acid (NAA) or β-NAA spray (Alam and Khan, 2002). Additionally, the report of Anwar (2010) indicated that application of 2, 4-D at 5 mg l^{-1} significantly improved growth attributes and fruit yield of tomato plant but those attributes decreased beyond this concentration. Furthermore, Bensen and Zeevaart (1990) reported that GA_3 is more effective on tomato stem growth at concentration of 10 ppm (10 mg l^{-1}) or below.

However, information regarding the practical use of 2,4-D and GA_3 their combined application, rate and concentration in crop production in general and tomato in particular is lacking in Ethiopia under condition where tomato production is affected due to adverse environmental conditions. On the other hand, most report indicated that synthetic auxin like 2,4-D has herbicidal or ephinastic effect (Pandolfini et al., 2002) which lead to flower bud abscission, poor fruit set, fruit defects and puffiness beyond certain concentrations. Contrary to this, GA_3 seems to have opposite effect to 2,4-D and promote vegetative growth and reproductive organ formation (Gemici et al., 2000) with extended flowering, maturity period and less fruit size formation (Graham and Ballesteros, 2006). If 2,4-D combined with GA_3 it may have not express such effects and resulted in intermediate result for better fruit setting, yield and quality (Serrani et al., 2007a). Hence, coordinated action of the two PGRs may be important to overcome the side effects of their single application and enhance fruit yield and quality in addition to the possibility of tomato production under adverse conditions in Ethiopia. This study was therefore initiated to investigate the best dose of the PGRs under consideration in single or combined application that improve tomato fruit yield and quality.

MATERIALS AND METHODS

The experiment was conducted at Melkassa Agricultural Research Center, Ethiopia which is located at 8°24′ N latitude, 39°21′ E longitude and at an altitude of 1550 m above sea level, in the middle rift valley of Ethiopia. The center is characterized by low and erratic rainfall with mean annual rainfall of 796 mm with peaks in July and August. The dominant soil type of the center is Andosol of volcanic origin with pH that ranges from 7 to 8.2. The mean annual temperature is 21.2°C with a minimum of 14°C and maximum of 28.4°C (MARC, 2008).

Two improved tomato varieties Roma VF and Fetan were obtained from Melkassa Agricultural Research Center and used as a test material. Roma VF is processing type, compact and strong stem with determinate growth habit while Fetan is fresh market type with strong stem having determinate growth habit. Commercial tissue culture grade of GA_3 ($C_{19}H_{22}O_6$) powder with 95% purity and 2,4-D ($C_8H_6Cl_2O_3$- CSA No 94-75) powder (salt formulation) were obtained from Sigma Chemical Co Ltd, Germany used for the experiment.

The two tomato varieties with three levels of 2,4-D (0, 5 and 10 mg l^{-1}) and four levels of GA_3 (0, 10, 15 and 20 mg l^{-1}) are arranged in a 2 × 3 × 4 factorial combinations, in RCB design with three replications. Seedlings were raised in mid September in an open nursery bed and transplanted to the experimental field after 35 days at a spacing of 30 cm between plants on ridges having 100 cm width. A net plot size of 12 m^2 (4 × 3 m) having 40 plants/plot was used. A total of 20 plants per plot were considered for data collection from the two middle rows. The field was irrigated using furrow irrigation when rainfall was not sufficient for plant growth. Urea as a source of nitrogen fertilizer was applied at a rate of 46 kg/ha in split form, half at transplanting and half at first flowering as a side dress. Phosphorous fertilizer was applied at a rate of 40

Table 1. Interaction effects of 2,4-D and GA_3 on fruit set percentage of tomato plants grown at Melkassa, Ethiopia.

2,4-D (mg l^{-1})	GA_3 (mg l^{-1})				Mean
	0	10	15	20	
0	54.75f	71.10b	75.43a	70.50b	67.95
5	60.86e	66.31c	66.06cd	63.49de	64.18
10	60.79e	63.68de	63.27de	62.04e	62.44
Mean	58.80	67.03	68.25	65.34	
CV (%)			9.94		

Means followed by the same letter within the table are not significantly different from each other according to DMRT at 5% probability level.

Table 2. Interaction effects of variety, 2,4-D and GA_3 on marketable fruit number per plant of tomato plants grown at Melkassa, Ethiopia.

2,4-D (mg l^{-1})	GA_3 (mg l^{-1}) Roma VF				Mean	GA_3 (mg l^{-1}) Fetan				Mean
	0	10	15	20		0	10	15	20	
0	41ef	62a	55b	55b	53	28c	35g	33gh	33g	32
5	47cd	49c	48c	40f	46	21j	21j	20j	22j	21
10	39f	34g	44de	30hi	37	19j	14k	15k	20j	17
Mean	42	48	49	42		23	24	23	25	
CV (%)					10.97					

Means followed by the same letter within the table are not significantly different from each other according to DMRT at 5% probability level.

kg/ha all at transplanting using di-ammonium phosphate as a side dress. Weeding, cultivation and pest control were done following previous recommendations (Lemma, 2002).

The required weight of the PGRs was taken using electronic sensitive balance (model BOSCH SAE200) and a stock solution was prepared by dissolving in 1 ml of 97% ethanol. Latter the stock solution was diluted in distilled water (dH_2O) to prepare the working solutions, just before application. Tween- 20 at the rate of 0.05% (v/v) was added before spray and mixed well to act as cohesive agent. The solution was poured into hand-held atomizer sprayer and was directly sprayed on the plants at early flowering (42 days after transplanting). Spraying was performed early in the morning to avoid rapid drying of the spray solution, due to transpiration.

Data were collected from randomly selected plants in the two middle rows except for fruit yield where the two middle rows were considered. The collected data includes fruit set percentage marketable fruit number per plant, fruit yield (marketable, unmarketable and total) (ton/ha), fruit length (cm), pericarp thickness (mm), total soluble solids (°Brix), pH, titratable acidity and lycopene content (mg/100 g). The data was analyzed using analysis of variance (ANOVA) by SAS (2002) software and mean separation was carried out by DMRT at 5% probability level.

RESULTS

Fruit set and number per plant

Percent fruit set was significantly affected by PGRs in both in single and combined application. Fruit set was increased from 54.75 to 75.43 (about 21%) when GA_3 concentration increased from 0 to 15 mg l^{-1} while the concentration of 2,4-D was kept at 0 mg l^{-1} and decreased in the presence of 2,4-D with or without GA_3 (Table 1). Hence, increased concentration of 2,4-D application resulted in low fruit set percentage compared to GA_3 and control treatment. On the other hand, GA_3 both in single and combined application with 2,4-D improved fruit set even though more increments was observed in increased concentration of GA_3 alone. Variation in percent fruit set observed subsequently lead to the variation in marketable fruit number (MFN) per plant (Table 2) due to the effects of PGRs under concern. The result indicated that combined and single application of 2,4-D and GA_3 significantly ($P < 0.001$) affected MFN per plant of both varieties. For instance, increased concentration of 2,4-D from 0 to 5 mg l^{-1} resulted in decreased MFN per plant from 42.79 to 33.42 by about 22% and further increase of 2,4-D concentration to 10 mg l^{-1} decreased MFN per plant to 26.92 by about 37% (data not shown). The data also indicated that MFN per plant significantly reduced by half from 62 to 30 for Roma VF and from 35.33 to 15 for Fetan depending on increased 2,4-D of concentration. However, MFN per plant was increased significantly when GA_3 concentration increased having an opposite effect with that of GA_3 in MFN per

Table 3. Interaction effects of variety, 2,4-D and GA_3 spray on marketable and total fruit yield of tomato plants grown at Melkassa, Ethiopia.

2,4-D (mg l^{-1})	GA_3 (mg l^{-1})	Marketable yield (ton/ha)		Total yield (ton/ha)	
		Roma VF	Fetan	Roma VF	Fetan
0	0	51.20d	62.90cd	59.68d	73.44c
	10	69.50a	66.78c	83.05a	83.08ab
	15	67.91ab	71.23b	79.96ab	83.34ab
	20	57.08cd	72.51ab	65.72cd	75.04c
5	0	57.14cd	74.20ab	64.24cd	85.23a
	10	62.54bc	72.10ab	72.61bc	84.14a
	15	66.40ab	73.67ab	75.44b	84.54a
	20	59.96c	66.47c	66.09cd	75.34c
10	0	55.59c	62.44d	74.31b	72.52c
	10	62.27c	73.93ab	67.87c	84.68a
	15	66.52ab	74.39a	76.98ab	84.52a
	20	56.18cd	66.73c	64.33cd	77.22bc
Mean		65.82		75.56	
CV (%)		7.54		8.33	

Means followed by the same letter within the column are not significantly different from each other according to DMRT at 5% probability level.

plant. Hence, the more the plants were exposed to high dose of 2,4-D spray resulted in low percent fruit set and succeeding MFN per plant due to high rate of flower bud abscission and subsequent fruit drop.

Fruit yield (total, marketable and unmarketable)

Significantly highest total and marketable fruit yield of 83.05 and 69.50 ton ha^{-1} were obtained at 0 mg l^{-1} of 2,4-D and 10 mg l^{-1} GA_3 and 0 and 15 mg l^{-1} 2,4- D and GA_3 combination, respectively in Roma VF (Table 3). Variety Fetan gave highest marketable fruit yield of 74.39 and 74.20 ton ha^{-1} at treatment combinations of 10 + 15 and 5 + 0 mg l^{-1} 2,4-D and GA_3, respectively. Lowest marketable and total fruit yield was obtained from control treatments for variety Roma VF and from 10 mg l^{-1} 2,4-D and control for variety Fetan. Hence, both PGRs at higher concentration in single and/or combined application resulted in lower fruit yield compared to the single or combined application at lower concentration.

Fruit length and percarp thickness

Significant variation in fruit length between the two varieties ($P < 0.001$), 2,4- D ($P < 0.001$), GA_3 ($P < 0.05$) and their interactions ($P < 0.05$) were observed. In variety Roma VF, interaction between 2,4-D and GA_3 significantly increased fruit length in almost all combinations tested except at higher level of GA_3 compared to the control (Table 4) . Maximum fruit length (6.72 cm) was recorded when the concentrations of both PGRs were at 10 mg l^{-1} in variety Roma VF and significantly started to decline for all concentration of 2,4-D when concentration of GA_3 was beyond 15 mg l^{-1}. Lowest fruit length of 5.34 cm and 5.44 cm were recorded from Fetan and Roma VF, respectively from the control treatmets. Hence, the interaction effects of 2,4-D and GA_3 indicated the possibility of increasing tomato fruit length with a combined application of the two PGRs than when each of them were applied independently. In addition to fruit length, fruit pericarp thickness (PT) was also significantly affected by 2,4- D ($P < 0.01$), GA_3 ($P < 0.05$) and interaction of 2,4-D with variety ($P < 0.05$) and 2,4-D with GA_3 ($P < 0.01$). The interaction effect of varieties and 2,4-D showed an increase in fruit PT for Roma VF from 4.06 to 5.03 mm and Fetan from 4.79 to 5.29 mm when the concentrations of 2,4-D increased to 10 mg l^{-1} (Table 5). Similarly, 2,4-D and GA_3 in combined applications showed increasing trend in fruit PT than the control (Table 6) even though it is significant only at 5 mg l^{-1} 2,4-D with 50.64% increment above the control.

Total soluble solids and titratable acidity

Fruit total soluble solids (TSS) (°Brix) was significantly affected due to 2,4-D alone and when combined with GA_3 while other treatment effects were not significant. The

Table 4. Interaction effects of variety, 2,4-D and GA_3 on fruit length (cm) of tomato plants of tomato plants grown at Melkassa, Ethiopia.

2,4-D (mg l^{-1})	GA₃ (mg l^{-1})							
	Roma VF				Fetan			
	0	10	15	20	0	10	15	20
0	5.44fg	6.02a-g	6.20a-e	5.88c-g	5.34g	5.49e-g	5.69d-g	5.47e-g
5	6.22a-e	6.49a-c	6.23a-e	6.29a-d	5.62d-g	5.97b-g	5.69d-g	5.67d-g
10	6.66a-c	6.72a	6.36a-d	5.96b-g	5.49e-g	5.70d-g	5.63d-g	5.86c-g
Mean	6.11	6.41	6.26	6.04	5.48	5.72	5.67	5.67
CV (%)					3.74			

Means followed by the same letter in the table are not significantly different from each other according to DMRT at 5% probability level.

Table 5. Interaction effects of variety and 2,4-D on fruit pericarp thickness (mm) of tomato plants grown at Melkassa, Ethiopia.

Variety	2,4-D (mg l^{-1})			Mean
	0	5	10	
Roma VF	4.06b	5.11ab	5.03ab	4.90
Fetan	4.79ab	4.87ab	5.29a	4.98
Mean	4.72	4.95	5.16	
CV (%)		8.93		

Means followed by the same letter in the table are not significantly different from each other according to DMRT at 5% probability level.

data (Table 6) indicated that, increased in TSS content up to 10% above the control at 10 + 0 and 10 + 20 mg l^{-1} 2,4-D and GA_3 treatment combinations were observed. Variation on fruit TA content due to varietal difference and combined application of the PGRs with increasing trends either due to increased concentration in single or combined application of the two PGRs under concern were another atiribute of the PGRs observed in this experiment. However, highest TA values of the two varieties were attained at different concentration and combination of the PGRs under concern. Hence, highest TA value of 0.76 was observed for variety Roma VF at 10 + 20 mg l^{-1} 2,4-D and GA_3 and for variety Fetan at 10 + 0 mg l^{-1} 2,4-D and GA_3, respectively (Figure 1).

Lycopene content

Lycopene content of the varieties were significantly affected by GA_3 in both single and combined application with 2,4-D (Tables 6 and 7). Variety and GA_3 interaction indicated that lowest lycopene content of 12.75 mg/100 g was obtained from the control (0 mg l^{-1} GA_3) and the highest (13.72 mg/100 g) from 10 mg l^{-1} GA_3 for Roma VF. In the case of Fetan, lowest lycopene contents (12.76 mg/100 g) was obtained at 10 mg l^{-1} and the highest (15.93 mg/100 g) at 20 mg l^{-1} GA_3 (Table 7). Combined application of GA_3 and 2,4- D also indicated that highest lycopene content of 16.03 and 15.33 mg/100 g were obtained at 20 + 0 and 5 + 10 mg l^{-1} GA_3 and 2,4-D respectively while the lowest (12.33 mg/100 g) lycopene content was from the control treatment.

DISCUSSION

Fruit set and number per plant

The present result indicated that, 2,4-D beyond certain concentration leads to flower bud abscission and fruit drop due to its herbicidal effect. Our result also support the findings of Gimici et al. (2006) who suggested that high concentrations of 2,4-D at 10 mg l^{-1} produced fewer fruits than with 4-CPA. The more the plants were exposed to high dose of 2,4-D spray resulted in lower number of fruits per plant due to increased rate of flower bud abscission. However, the report by Khan et al. (2006) indicated the significant role of GA_3 in tomato plant to increase fruit set that leads to larger number of fruits per plant and increased fruit size and final yield. An increased MFN per plant due to GA_3 application observed in this study also hold the finding of Khan et al. (2006) who stated that GA_3 at 10^{-8}, 10^{-6} and 10^{-4} molar proved to induce higher number of fruit per plant than the untreated

Table 6. Interaction effects of 2,4-D and GA_3 on fruit pericarp thickness (PT), total soluble solids (TSS) and lycopene contents of tomato plants grown at Melkassa, Ethiopia.

2,4-D (mg l^{-1})	GA_3 (mg l^{-1})	PT (mm)	TSS (°Brix)	Lycopene (mg/100 g)
0	0	3.93b	4.59b	12.33c
	10	4.93b	4.79b	12.46c
	15	5.13b	4.88b	13.01bc
	20	4.97b	4.82b	16.03a
5	0	5.92a	5.03a	14.25b
	10	4.81b	4.92ab	15.33a
	15	4.96b	4.83b	13.69bc
	20	5.10b	4.90ab	12.83bc
10	0	5.34ab	5.27a	13.30bc
	10	5.10b	5.03a	12.76bc
	15	5.37ab	4.95ab	14.28b
	20	4.83b	5.05a	14.60b
Mean		5.03	4.94	13.74
CV (%)		8.93	4.34	15.31

Means followed by the same letter in the table are not significantly different from each other according to DMRT at 5% probability level.

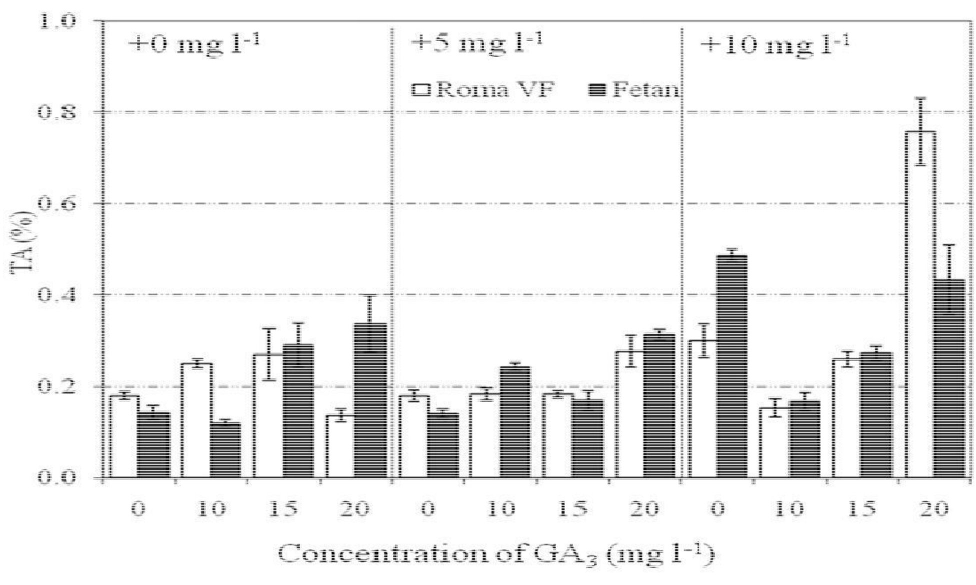

Figure 1. Interaction effects of variety, 2,4-D and GA_3 on fruit titratable acidity (TA) (%) of tomato plants grown at Melkassa, Ethiopia.

control. On the other hand, application of GAs can cause fruit set and growth of some fruits, in case where auxin may have no effect (Taiz and Zeiger, 2002). The significant effect of GA_3 in tomato plant further explained via its role in synthesis of protein including various enzymes, increased rate of shoot elongation and photosynthetic capacity leading to total leaf area and leaf dry weight (Ballantyine, 1995; Mostafa and Saleh, 2006).

Fruit yield (total, marketable and unmarketable)

Subsequent improvement in fruit yield as a result of higher percent of fruit set and MFN per plant due to 2,4-D

Table 7. Interaction effects of variety and GA_3 on fruit lycopene content (mg/100 g) of tomato plants grown at Melkassa, Ethiopia.

Variety	GA_3 (mg l^{-1})				Mean
	0	10	15	20	
Roma VF	12.76e	13.72c	12.99e	13.04de	13.13
Fetan	14.55ab	12.59e	14.32b	15.93a	14.35
Mean	13.66	13.16	13.66	14.49	
CV (%)			15.31		

Means followed by the same letter in the table are not significantly different from each other according to DMRT at 5% probability level.

and GA_3 was observed. Previous research result indicated increased MFN per plant, reduced fruit drop, increased fruit weight due to GA_3 spray (Naeem et al., 2001) which could result in increased fruit yield. Increased fruit size and weight due to 2,4- D and fruit number per plant due to GA_3 contributed to the overall increased fruit yield. However, 2,4-D at 10 mg l^{-1} resulted in reduced fruit set percentage and deformed and inferior fruits which contributed to low yield. On the other hand, increased concentration of GA_3 resulted in less unmarketable fruit size which reduces the final yield. The findings of Gimici et al. (2006) also indicated that high concentrations of 2,4-D at 10 mg l^{-1} decreased yield in tomato plant due to its herbicidal effect beyond certain concentration which cause flower bud abscission and fruit drop. However, combined application of GA_3 with 2,4-D can increase fruit yield to some extent when the concentration of 2,4-D has negative effect. Reduced concentration of 2,4-D at or below 5 mg l^{-1} seems to increase yield and other fruit quality attributes especially in variety Fetan by decreasing fruit drop compared to higher concentration beyond 5 mg l^{-1}. The current finding is also in consistent with the findings of Anwar (2010) and Pudir and Yadav (2001) that indicated improvement in tomato fruit yield at low concentration (5 mg $l^{-1)}$ of 2,4-D. The effect of 2,4-D and GA_3 in increasing fruit size was also another factor which could increase fruit yield.

Fruit length and percarp thickness

The interaction effect of 2,4-D and GA_3 indicated that fruit length was maximum for both levels of 5 and 10 mg l^{-1} 2,4-D with 10 mg l^{-1} of GA_3 but significantly reduced when the concentration of GA_3 increased. Gillaspy et al. (1993) indicated that after cell division and during cell expansion, which is associated with maximum fruit growth. The increase in cell volume due to expansion may contribute to the final size of the fruits as observed in this study. The effects of GA_3 resulted in smaller fruit size compared to Cycocel treated plants reported by Graham and Ballesteros (2006) also justify that fruit development (length) induced by 2,4-D may be regulated by GA_3 beyond certain concentrations. According to Rasul et al. (2008), 2,4-D at 25, 50 and 100 mg l^{-1} produced longer fruits as compared to Fulmet and CPPU in Teasle Gourd which indicating that 2,4-D is the most responsive auxin. According to Graham and Ballesteros (2006), cycocel treated plants born larger fruits while GA_3 treated ones bear smaller fruits even less than the control one. The effect of 2,4- D in our study indicated longer fruits with bigger size is also in agreement with the work of Khan et al. (2006). The authors reported an increase in fruit size due to 2,4- D application which could be due to stimulation of parthenocarpic fruit growth that resulted in increased fruit weight. Another possible reason that can be ascribed for the reduction in fruit size of tomato fruits at increased GA_3 concentration could stimulate shoot growth and suppressing the growth of developing fruit lets due to competition for assimilates results in decreased fruit width, size and number (Bakrim et al., 2007). Similar to our observation, Gimici et al. (2006) also reported that 2,4-D resulted in increased tomato fruit size, fresh and dry weight when used at recommended concentration. Similarly, Serrani et al. (2007a) reported that, tomato fruits induced by GA_3 and 2,4- D had thicker pericarp than pollinated fruits throughout its development, and more in response to 2,4-D than GA_3. The authors observed that the combined application of GA_3 and 2,4-D had an intermediate effect on pericarp thickness and number of layers compared to separate application. Therefore, this increase in fruit pericarp thickness may have an advantage to help the fruit skin become more resistant to mechanical bruising, pest attack and better shelf life due to reduced rate of water loss.

Total soluble solids (TSS) and titratable acidity (TA)

The significant increased in fruit TSS and TA content of tomato fruits observed due to 2,4-D and GA_3 at indicated treatment combinations have be maintained the previous reports. Increased In most reports it was generalized that parthenocarpic tomato fruits were shown to have higher levels of soluble solids and sugar, but lower level of acid compared with seeded fruits (Ho and Hewitt, 1986).

According to the authors, the rate of assimilate export from the leaves; rate of import by fruits, and the fruit carbon metabolism are factors that finally influence TSS of tomato fruit. The role of GA_3 in increasing tomato fruit TSS was reported by many authors. For instance, Graham and Ballesteros (2006) reported that GA_3 increased proteins, soluble carbohydrates, ascorbic acid, starch and -carotene in the tomato. Higher sugar content in tomato fruits was obtained from plants treated with 50 mg l^{-1} GA_3 (Kataoka et al., 2009). In general, TSS has been of major interest to the processing industries that manufacture concentrated tomato products (Ram, 2005) and for fresh market consumption (Ho, 1998). It is believed that increased TSS content of fruits could give more finished product per ton of raw tomato fruit and thus, require less energy to produce a certain quantity of concentrated product. Hence, the use of 2,4-D and GA_3 spray for tomato production is one option to improve TSS content of tomato fruit. Tomato pH is dependent on several factors, including cultivar, maturity stage, cultural practices as well as growing location and seasonal variations (Gould, 1992) but achievement of low fruit pH (data not shown) and high TA value by spray of 2,4-D in our study could be a useful investigation. Comparable to the present result, significant increase in TA content due to application of PGRs was reported due to increased formation of organic acids in the tissues most likely to accelerate activities within the Krebs cycle (Graham and Ballesteros, 2006). Thakur et al. (1996) indicated that acidity of tomato fruits was reduced when the whole plant was sprayed with GA_3 and 2,4-D; however, the ascorbic acid content increased with higher concentrations of 2,4-D and Para- chlorophenoxy acetic acid. On the other hand, reduced pH value of tomato fruit is a desirable quality and essential factor accounting for flavor. Thus processors typically add citric acid to tomato juice to ensure low pH values. Thus, inverse relationship between decreased pH and increased TA content is the desirable fruit quality parameter (Erdal et al., 2007; Fontes et al., 2000) to reduce the risk of microbial spoilage and requires moderate conditions for processing and enzyme inactivation.

Lycopene content

The role of PGRs in increasing tomato flavor, color intensity and lycopene contents was realized through its enhanced up take or utilization of certain plant nutrieits like nitrogen, phosphorous and potassium (Oded and Uzi, 2003). For instance, Khan et al. (2006) observed an increase in leaf phosphorous, nitrogen, and potassium content in addition to increased lycopene content of tomato fruit treated with GA_3. Low potassium inhibits lycopen synthesis and delays the development of a full red color in tomato ripening (Oded and Uzi, 2003). This seems that GA_3 application on tomato enhanced potassium uptake which was responsible for lycopen synthesis. Similarly, Afaf et al. (2007) indicated that GA_3 application increased phosphorous accumulation in leaves and stems of tomato plants that was also responsible for required lycopene content in the fruit.

Conclusions

This study clearly indicates that the effective concentration of these PGRs to improve tomato fruit yield and quality depends on the chemical nature of the PGRs used and the tomato cultivar. In the case of 2,4-D improvement of fruit yield and quality seems to be at or lower concentration of 5 mg l^{-1} especially in the case of variety Fetan but GA_3 at both 10 and 15 mg l^{-1} indicated better result for both varieties in yield and quality. In general, it is important to continue the experiment in different growing seasons and conditions on different types of tomatoes to confirm the present result. Method of application should be considered as spray flower only seems to be more important than applying on the whole plant in case of 2,4-D to avoid the herbicidal effect on the leaf part.

REFERENCES

Afaf TMK, Abd El-hameid AM, El-Greadly NHM (2007). A comparison study on the effect of some treatments on earliness, yield and quality of globe artichoke (*Cynara scolymus* L.). Res. J. Agric. Biol. Sci., 3: 695-700.

Alam SM, Khan, MA (2002). Fruit yield of tomato as affected by NAA spray. Asian J. Plant Sci., 1(1): 24.

Anwar W, Aziz T, Naveed F, Sahi ST (2010). Short Communication. Foliar applied 2, 4-dichlorophenoxy acetic acid improved tomato growth and yield. Soil Environ., 29(1): 77- 81.

Ballantyine DJ (1995). Cultivar, photoperiod and gibberellin influence shoot elongation and photosynthetic capacity of Hardy Azaleas. Hortic. Sci., 2: 257-259.

Bakrim A, Lamhamdi M, Sayah F, Chibi F (2007). Effects of plant hormones and 20-hydroxyecdysone on tomato (*Lycopersicon esculentum*) seed germination and seedlings growth. Afr. J. Biotechnol., 6: 2792-2802.

Batlang U (2008). Benzyladenine plus gibberellins (GA4+7) increase fruit size and yield in greenhouse-grown hot pepper (*Capsicum annuum* L.). J. Biol. Sci., 8(3): 659-662.

Bensen RJ, Zeevaart JAD (1990). Comparison of *ent-kaurene synthetase* A and B activities in cell-free extracts from young tomato fruits of wild-type and *gih-1, gih-2,* and *gih-3* tomato plants. J. Plant Growth Regul., 9: 237-242.

Central Statistical Agency CSA (2009). Agricultural sample survey 2008/2007. Report on area and production of crops (Private peasant holdings, main season). Stat. Bull., Addis Ababa Ethiopia, 01-446.

Erdal I, Erteke A, Senyigit U, Koyuncu MA (2007). Combined effects of irrigation and nitrogen on some Quality parameters of processing tomato. World J. Agric. Sci., 3: 57-62.

FAOSTAT (2007). FAOSTAT on-line. Rome: United Nations Food and Agriculture Organization. http://faostat.fao.org/default.aspx?lang=e.

Fekadu M, Ravishanker H, Lemma D (2004). Relationship between yield and plant traits of tomato genotypes under dry land condition of central Ethiopia. J. Veg. Crop Res., 60: 45-54.

Fekadu M, Dandena G (2006). Review of the status of vegetable crops production and marketing in Ethiopia. Uganda J. Agric. Sci., 12(2): 26-30.

Fontes PCR, Sampalo RA, Finger FL (2000). Fruit size, mineral composition and quality of trickle-irrigated tomatoes as affected by potassium rates. Pesq. Agropec. Bras. Brasilia, 35: 21-25.

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

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

George WL, Scott JW, Splittstoesser WE (1984). Parthenocarpy in tomato. Hortic. Rev., 6: 65-84

Gould WA (1992). Tomato Production, Processing and Technology, 3rd edition. CTI Publishers, Baltimore, MD.

Graham HD, Ballesteros M (2006). Effect of plant growth regulators on plant nutrients, J. Food Sci. Article first published online: 25 AUG 2006. DOI: 10.1111/j.1365-2621.1980.tb04086.x.

Heuvelink E, Korner O (2001). Parthenocarpic Fruit Growth Reduces Yield Fluctuation and Blossom-end Rot in. Sweet Pepper. Ann. Bot., 88: 69-74.

Ho LC (1998). Improving Tomato Fruit Quality by Cultivation. In KE Cockshull, D, Gray, GB Seymour and B. Thomas (eds.). Genetic and Environmental Manipulation of Horticultural Crops. CABI Publishing, pp. 17-29.

Ho LL, Hewitt JD (1986). Fruit Development. In: JG Atherton and J. Rudich (eds). The Tomato Crop. A Scientific Basis for Improvement. Chapman and Hall, pp. 201-233.

Kataoka K, Yashiro Y, Habu T, Sunamoto K, Kitajima A (2009). The addition of gibberellic acid to auxin solutions increases sugar accumulation and sink strength in developing auxin-induced parthenocarpic tomato fruits. Scientia Horticulturae, 123(2): 228-233.

Khan MMA, Gautam AC, Mohammad F, Siddiqui MH, Naeem M, Khan MN (2006). Effect of gibberellic acid spray on performance of tomato. Turk. J. Biol., 30: 11-16.

Kinet JM, Peet MM (1997). Tomato. In H.C Wien (*ed.*). The Physiology of Vegetable Crops. CAB International, pp. 207-248.

Lemma D (2002). Tomatoes. Research Experience and Production Prospects. Res. Report, Ethiopian Agricultural Research Organization Addis Ababa, Ethiopia, 43: 48.

Melkassa Agricultural Research Center MARC (2008). Ethiopian Institute of Agricultural Research, Center Profile, Melkassa, Ethiopia. p. 12.

Mostafa EAM, Saleh MMS (2006). Influence of spraying with gibberellic acid on behavior of Anna Apple trees. J. Appl. Sci. Res., 2: 477-483.

Naeem N, Ishtiaq M, Khan P, Mohammad N, Khan J, Jamiher B (2001). Effect of gibberellic acid on growth and yield of tomato Cv. Roma. J. Biol. Sci., 1(6): 448-450.

Oded A, Uzi K (2003). Enhanced performance of processing tomatoes by potassium nitrate-based nutrition. Acta Hortic. (ISHS), 613: 81-87. www.actahort.org/books/613/613_8.htm.

Pandolfini T, Rotino GL, Camerini S, Defez R, Spena A (2002). Optimization of transgene action at the post-transcriptional level: High quality parthenocarpic fruits in industrial tomatoes. BMC Biol., 2: 1-11.

Pudir JPS, Yadav PK (2001). Note on effect of GA3 NAA and 2, 4-D on growth, yield and quality of tomato var. Punjab Chuhara. Curr. Agric., 25: 137-138.

Ram HH (2005). Vegetable Breeding Principles and Practices, 2nd edition. Kalyani Publishers, Ludhiana-New Delhi. p. 653.

Rasul MG, Mian MAK, Cho Y, Ozaki Y, Okubo H (2008). Application of plant growth regulators on the parthenocarpic fruit development in Teasle Gourd (Kakrol, *Momordica dioica* Roxb.). J. Fac. Agric., 53: 39-42.

Statistical Analysis System SAS (2002). SAS institute version 9.00 Cary, NC, USA.

Sasaki H, Yano T, Yamasaki A (2005). Reduction of high temperature inhibition in tomato fruit set by plant growth regulators. JARQ., 39: 135-138.

Serrani JC, Fos M, Atare´s A, Garcı´a-Martı´nez JL (2007a). Effect of gibberellin and auxin on parthenocarpic fruit growth induction in the cv Micro-Tom of tomato. J. Plant Growth Regul., 26: 211-221.

Taiz L, Zeiger E (2002). Plant Physiology, 3rd edition. Sinaure Associates, Inc. USA, p. 690.

Thakur BR, Singh RK, Nelson P (1996). Quality attributes of processed tomato products: A review. Food Res. Int., 12: 375-401.

Wilcox J, Catignani G, Lazarus C (2003). Tomatoes and cardiovascular health. Crit. Rev. Food Sci. Nutr., 43(1):1–18.