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Effect of PGRs on fruit set and other horticultural traits in greenhouse tomato under South Gujarat conditions

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Abstract
The present investigation was carried out at Regional Horticultural Research Station, ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari, Gujarat during *kharif*, 2016. The experiment involved fourteen different treatments 4-CPA 20 ppm (T_1), 4-CPA 30 ppm (T_2), 4-CPA 40 ppm (T_3), 2,4-D 2.50 ppm (T_4), 2,4-D 5.00 ppm (T_5), 2,4-D 7.50 ppm (T_6), 4-CPA 20 ppm followed by GA_3 (30 ppm) within 24 hours (T_7), 4-CPA 30 ppm followed by GA_3 (30 ppm) within 24 hours (T_8), 4-CPA 40 ppm followed by GA_3 (30 ppm) within 24 hours (T_9), 2,4-D 2.50 ppm followed by GA_3 (30 ppm) within 24 hours (T_{10}), 2,4-D 5.00 ppm followed by GA_3 (30 ppm) within 24 hours (T_{11}), 2,4-D 7.50 ppm followed by GA_3 (30 ppm) within 24 hours (T_{12}), Control- No spray (T_{13}), 4-CPA 30 ppm- Inflorescence dipping (T_{14}) which was laid out in a Randomized Block Design with three replications. Among different levels of treatment, 30 ppm 4-CPA (Inflorescence dipping) exhibited maximum plant height of 203.47, 251.73 and 306.67 cm at 120, 180 days after planting and at final picking, respectively whereas, control had maximum leaf area (843.33 cm^2). Plants treated with 30 ppm 4-CPA (Inflorescence dipping) were found to be superior to all other treatments for majority of the reproductive parameters like fruit set percent (72.50), fruits per cluster (5.80) and number of fruits per plant (58). The superiority of 4-CPA at the rate of 30 ppm (Inflorescences dipping) was also reflected by tomato plants in terms of significantly maximum fruit yield per plant (4.95 kg) as well as fruit yield per m^2 (12.69 kg) except average fruit weight. Subsequently, economic analysis of investigation revealed T_{14} (30 ppm 4-CPA-Inflorescence dipping) as highly remunerative treatment exhibiting BCR of 0.85 with net realization of Rs. 116629.00.

Keywords: Tomato, protected cultivation, PGRs, growth, fruit set, yield, economics

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable belonging to family Solanaceae and plays an important role in human nutrition by providing essential amino acids, vitamins and minerals (Sanju *et al.*2003) [18]. Lycopene is a very potent antioxidant present in tomato contributing towards the prevention of cancers (Agrawal and Rao, 2000) [1].

Development of high yielding varieties/hybrids both from public and private sector has significantly played important role in enhancing crop production in greenhouse tomato. In South Gujarat conditions, the period during monsoon doesn't allow outdoor cultivation of tomato, so presents a lot of potential in terms of providing off-season production and remunerative returns through tomato cultivation. But, tomato cultivation during high humid conditions often faces problems of poor fruit setting due to poor or negligible release of pollens for pollination and fertilization thereby affecting fruit set and ultimately the yield.

Plant growth regulators (PGRs) play very important role to enhance the fruit setting in various crops and induces the phenomenon of parthenocarpy. So, regulation of vegetative and reproductive growth as well as overcoming the problems related to pollination and fertilization for fruit development can be achieved and manipulated through the use of PGRs like auxins and gibberellins. The plant growth regulators (PGRs) are a wide category of compounds that can promote, inhibit or change plant physiological or morphological processes at very low concentrations. PGRs can affect rooting, flowering, fruiting and fruit growth, leaf or fruit abscission, senescence, regulation of some metabolic processes and plant resistance to temperature or water stresses. Auxin application induces fruit setting, which ultimately increase the yield of plant. 4-chlorophenoxyacetic acid (4-CPA) and 2, 4-dichlorophenoxyacetic acid (2, 4-D) are synthetic auxins, which reduce pre-harvest fruit drop with increased number of fruits per plant and yield (Sasaki *et al.* 2005) [21].

Earlier research also indicates increased fruit setting and fruit size in tomato due to application of plant growth regulators such as 2,4-D and 4-CPA at low concentrations (Khan *et al.* 2006) [13]. The most widely available plant growth regulator is GA_3, which have a particularly interesting role in commercial farming since they lead to plant elongation and development, seed germination, fruit setting and growth, delay fruit maturation and abscission of leaves. The application of GA_3 in tomato plants has been shown to induce marked stem elongation, increase fresh weight, accelerate flowering and produce greater numbers of flowers per plant and increase fruit set, (Davies, 1995; Kazemi *et al.* 2014) [9, 12]. It is well documented in the literature that a mixture of 4-CPA and GA_3 have shown an increased tomato fruit set and proportion of normal fruits compared to plants of the same crop treated with 4-CPA (Sasaki *et al*. 2005) [21]. Thus, the hormonal use in the plant system and their importance is the outstanding discovery and achievement of plant sciences. So, investigation was aimed to find out the suitable plant growth regulators and its concentration for increasing fruit set and yield in tomato.

Materials and Methods

The experiment was carried out at Regional Horticultural Research Station (RHRS), ASPEE College of Horticulture and Forestry (ACHF), Navsari Agricultural University, Navsari, Gujarat during *kharif*, 2016 in tomato cv. Bargad under naturally ventilated polyhouse (NVPH) The location is situated at a latitude and longitude of 20º 57' N and 72º 54' E, respectively with an altitude of about 12 m amsl. The experiment was planned with fourteen treatments *viz.*, 4-CPA 20 ppm (T_1), 4-CPA 30 ppm (T_2), 4-CPA 40 ppm (T_3), 2,4-D 2.50 ppm (T_4), 2,4-D 5.00 ppm (T_5), 2,4-D 7.50 ppm (T_6), 4-CPA 20 ppm followed by GA_3 (30 ppm) within 24 hours (T_7), 4-CPA 30 ppm followed by GA_3 (30 ppm) within 24 hours (T_8), 4-CPA 40 ppm followed by GA_3 (30 ppm) within 24 hours (T_9), 2,4-D 2.50 ppm followed by GA_3 (30 ppm) within 24 hours (T_{10}), 2,4-D 5.00 ppm followed by GA_3 (30 ppm) within 24 hours (T_{11}), 2,4-D 7.50 ppm followed by GA_3 (30 ppm) within 24 hours (T_{12}), Control- No spray (T_{13}), 4-CPA 30 ppm- Inflorescence dipping (T_{14}) in a Randomized Block Design (RBD) with three replications. Tomato plants were spaced at the spacing of 60 x 45 cm and fertigated with N:P:K at the rate of 25: 12.5: 12.5 kg/ 1000 m^2 along with farmyard manure (2 t/1000 m^2). The fertigation was scheduled after 10-15 days of planting at weekly interval. The common dose of micronutrient (G-5) at the rate of 5 kg/1000 m^2 was applied at the time of planting. 10 sprays of each treatment were made during cropping season of tomato. First spray was done at the time of 50% flowering and remaining sprays were done at the interval of 20 days. Spray of GA_3 were done within 24 hrs after the spray of 4-CPA and 2, 4-D. Dipping of each truss with 4-CPA was also carried out at weekly interval. The data were taken from five randomly selected plants on plant height (cm) at 60, 120, 180 DAP and at final harvest, leaf area (cm^2), number of fruits per cluster, fruit setting (%), number of fruits per plant, days to first picking, days to last picking, average fruit weight (g), fruit yield per plant (kg), fruit yield per m^2. The recorded data were statistically analyzed to find out the variation resulting from the experimental treatments by employing 'F' test at five per cent level of significance on the basis of null hypothesis. The mean values were subjected to statistical analysis through WASP-Web Agri Stat. Package 2.0 developed by Ashok Kumar Jangam and Pranjali Thali at ICAR Research Complex for Goa, Ela, Old God, Goa, India (Anonymous, 2017a) [2]. The appropriate standard errors (S.Em. ±) were calculated in each case and the Critical Difference (CD) at five per cent level of probability was worked out to compare the treatment means. The coefficient of variation (CV%) was also worked out for all the cases.

The average selling rate for the produce of experiment was worked out after ascertaining market rate from time to time at Shree Navsari Jalalpore Taluka Horticulture Cooperative Society Ltd., Navsari, Gujarat. To work out and simplify calculations, the data generated through an accounting method was subjected to analysis as suggested by Berry *et al*. (1979) [4] and Gittinger (1982) [10]. The actual values on fixed investment were subjected to amortized accounting by adopting certain assumptions (Table 1).

Table 1: Assumptions for the calculation of fixed cost

Sr. No.	Particulars	Useful life (yrs)	Remarks
1	Polyhouse Structure	10	*Conditional life of red soil has been considered equivalent to that of structure's life assuming that sufficient organic matter will be incorporated into it over the period of time.
2	Red soil*	10	
3	Plant support system	5	

The prevailing market value (s) was taken into consideration while calculating cost of each variable component. The labour wages were established as per the notification of Assistant Labour Commission and Minimum Wages Act, Gandhinagar, Government of Gujarat State for respective years of experimentation (Anonymous, 2017b) [3]. The details input cost for different fixed and variable components of cost used during the period of investigation in tomato are given in Table 2.

Table 2: Details of input cost for fixed and variable components used during the period of investigation in tomato

Fixed Components of cost:			
Name of Component	**Cost (Rs.)**	**Name of Component**	**Cost (Rs.)**
Polyhouse	935.00/m^2	Red soil	800.00/ cubic feet
Plant support system	10.00/ m^2		
Variable Components of cost:			
Seed	360/ 10 g	NPK	88.00/ kg
UV Stabilized system	220.00/ kg	Potassium Nitrate	90.00/ kg
Formaldehyde	50.00/ l	MPP	111.00/ kg
Vermicompost	200.00/ bag (50 kg)	$CaNO_3$	42.00/ kg
Micro-nutrient (Grade-5)	200.00/ kg	MAP	92.00/ kg
Plastic carry bags	160.00/ kg	Potassium Sulphate	70.00/ kg
Urea (46:00:00)	6.30/kg	Labour wages	178.00/ day
Phosphoric acid	135.00/ kg	Selling rate	Rs. 20.00 per kg

Results and Discussion

The Performance of tomato in response to foliar application of different levels of PGRs under NVPH during rainy season are presented as mean values with statistical notation in Tables 1 and 2.

Vegetative parameters

The results on various growth parameters *viz.*, Plant height (cm) at 60, 120, 180 DAP and at final harvest and leaf area (cm^2), Number of fruits per cluster, Fruit setting (%), Number

of fruits per plant, Days to first picking, Days to last picking in tomato cv. Bargad NVPH as influenced by foliar application of PGRs are presented in Table 3. The PGRs influenced plant height significantly throughout the growing season of tomato at all the stages of growth except at 60 days after planting, which had non-significant differences among the treatments for plant height. Treatment T_{14} (4-CPA @ 30 ppm- Inflorescence dipping) recorded highest plant height of 203.47, 251.73 and 306.67 cm at 120, 180 DAP and at final picking, respectively. The maximum plant height displayed by treatment T_{14} at 120 days DAP was statistically at par with treatment T_{13} (200.47 cm), T_7 (193.73 cm), T_8 (190.47 cm), T_1 (188.67 cm), T_9 (185.13 cm), T_2 (183.80 cm), T_{10} (180.07 cm) and T_3 (178.60 cm). After 180 days of DAP, the highest plant height recorded in T_{14} was statistically at par with treatment T_{13} (249.33 cm), T_7 (243.80 cm), T_8 (241.87 cm), T_1 (238.40 cm), T_{10} (235.27 cm), T_9 (235.00 cm), T_2 (233.53 cm), T_3 (2283. cm) and T_{11} (228.33 cm). While at final picking, this treatment (T_{14}) displayed statistically similar plant height with treatment T_{13} (303.00 cm), T_7 (302.13 cm), T_8 (299.69 cm), T_9 (293.00 cm), T_1 (290.60 cm), T_2 (285.53 cm), T_{10} (283.60 cm) and T_{11} (280.13 cm). It might be due to its effect on rapid cell elongation and multiplication of cells in sub-apical meristem. The rapid growth as observed under the influence of 4-CPA is a result of both the greater number of cells formed and elongation of individual cells. Karim *et al.* (2015) [11] in tomato and Das *et al.* (2015) [8] in bell pepper also substantiated similar trends of increase in plant height during their period of study.

Among different levels of PGRs, treatment T_{13} recorded significantly maximum leaf area (843.33 cm^2) per plant, which was at par with T_7 (840.00 cm^2), T_3 (837.00 cm^2), T_8 (836.00 cm^2), T_9 (833.00 cm^2), T_{14} (831.67 cm^2), T_1 (823.33 cm^2) T_2 (814.00 cm^2), T_{10} (770.00 cm^2) and T_{11} (766.00 cm^2). The results are not in agreement with the findings of earlier worker Singh *et al.* (2012) [23] in bell pepper, who otherwise experienced an increase in leaf area by foliar spray of GA_3. This might be due to 4-CPA, 2, 4-D and GA_3 deviates major portion of photosynthates from vegetative parts of plant to reproductive ones (Chaudhary *et al*. 2006) [6].

Reproductive parameters

The results of on various reproductive parameters namely number of fruits per cluster, fruit setting (%), number of fruits per plant, days to first picking, days to last picking in tomato cv. Bargad NVPH as influenced by foliar application of PGRs are presented in Table 4. In case of number of fruits per cluster, treatment T_{14} (4-CPA 30 ppm-Inflorescence dipping) showed significantly highest number of fruits per cluster (5.80), which was at par with the treatments T_{11} (3.50), T_4 (3.40), T_7 (3.40), T_{12} (3.40), T_1 (3.20) and T_5 (3.20). This might be due to plants treated with 4-CPA (30 ppm-Inflorescence) dipping remained physiologically more active resulting in earliness, more number of flowers and maximum fruit set. The present findings are in agreement with those reported by Singh *et al.* (2002) [22], Tonder and Combrink (2003) [25] and Sarkar *et al.* (2014) [20] in tomato.

Treatment T_{14} (4-CPA 30 ppm-Inflorescence dipping) recorded significantly highest fruit set of 72.50 per cent compared to all other treatments. The 2nd highest fruit set was obtained in treatment T_{10} (45.00%) with statistically similar fruit set in T_{11} (44.17%), T_4 (42.50%), T_7 (42.50%), T_{12} (42.50%), T_1 (40.00%) and T_5 (40.00%). This could be attributed to enhanced photosynthetic activity, increased production and accumulation of carbohydrates, favourable effect on vegetative growth and retention of flowers which increased fruit set percentage. 4-CPA also has a potential to induce parthenocarpic fruits and check flowers and fruits drop. These results are in accordance with the findings of Tonder and Combrink (2003) [25] in tomato and Das *et al.* (2015) [8] and Sarkar *et al.* (2015) [19] in bell pepper.

The statistical comparison showed the significant influence of different treatments on number of fruits per plant. However, the maximum number of fruits (58.00) were obtained in the treatment of T_{14} (4-CPA 30 ppm-Inflorescence dipping), which was statistically superior over all other treatments. This might be due to rapid and better nutrient translocation from roots to apical parts of plant, making treated plants physiologically more active thereby resulting in more number of flowers and higher fruit set percent. On other hand, it also induced parthenocarpic fruit set, thus increased the number of fruits per plant. The present findings are in agreement with those reported by Swaroop *et al.* (2001) [24], Choudhary *et al.* (2013) [7], Karim *et al.* (2015) [11] and Rahman *et al.* (2015a) [16] in tomato and Das *et al.* (2015) [8], Sarkar *et al.* (2015) [19] in bell pepper. The mean data analyzed for days to last picking and days to first picking presented in Table 4 showed non-significant differences among various treatments.

Yield parameters

The results on effect of foliar application of PGRs on various yield parameters *viz.*, average fruit weight (g), fruit yield per plant (kg), fruit yield per m^2 in tomato under NVPH are presented in Table 5. The mean data analyzed for average fruit weight showed non-significant differences among various treatments. However, maximum fruit weight of tomato was found in treatment T_8 (93.80 g).

The fruit yield per plant was significantly maximum (4.95 kg) under T_{14} in comparison to remaining levels of PGRs application. It was attributable to higher fruit set percentage and number of fruits per plant. These results are in close agreement with the findings of earlier researchers like Swaroop *et al.* (2001) [24], Tonder and Combrink (2003) [25], Chaudhary *et al*. (2013) [7], Sarkar *et al.* (2014) [20] and Rahman *et al.* (2015a) [16] in tomato and Das *et al.* (2015) [8], Sarkar *et al.* (2015) [19] in bell peper.

Among different treatments, T_{14} (4-CPA 30 ppm-Inflorescence dipping) noticed significantly maximum yield per m^2 (12.69 kg) over all other treatments. This is attributed to the presence of higher fruit set (%), number of fruits per plant and highest fruit yield per plant. These results are in close agreement with the findings of earlier researchers like Bhosle *et al.* (2002) [5], Tonder and Combrink (2003) [25], Chaudhary *et al*. (2013) [7], Karim *et al.* (2015) [11] and Rahman *et al*. (2015b) [15] in tomato and Das *et al*. (2015) [8] and Sarkar *et al*. (2015) [19] in bell peper.

Economics

Considering useful life of polyhouse structure for 10 years, the capital investment was worked out to Rs. 54542.00 for a single season of tomato. As red soil was added inside protected structure for taking up the present investigation, so investment for 800 cubic feet soil per 1000 square meter was Rs. 4200.00. Tomato plants were trained vertically on overhead plant support system and the capital investment on this component was also found to be nominal (Rs. 1166.00) based on its expected life of five years. Therefore, overall expenditure for fixed component worked out to be 59908.00. The analysis of production system of tomato under NVPH displayed total cost of cultivation ranging from Rs. 131065 to

137241 invariably dependent on cost of PGRs and packing of produce for sale in the market. Thus, treatment T_{14} was observed to be best treatment exhibiting BCR of 0.85 with net realization of Rs. 116629 under polyhouse conditions during rainy season. Sahu *et al*. (2016) [17] and Kumar *et al*. (2015) [14] had also highlighted the importance of protected cultivation for better economic returns in bell pepper and cucumber, respectively It is inferred from the present study that majority of growth and yield parameters displayed good amount of variability upon foliar application of PGRs in tomato for various horticultural traits under NVPH. Thus, PGRs exerted a profound influence on various horticultural traits and offers a lot of scope to exploit their potential for off-season cultivation in protected condition. On the basis of present finding it can be concluded that foliar application of 4-CPA, 2, 4-D and GA_3 influenced various growth, reproductive and yield parameters invariably. However, the Inflorescence dipping with 4-CPA at the concentration of 30 ppm was observed to be the best for higher fruit set thereby enhancing the yield level of tomato under high-humid conditions during rainy season under NVPH. Subsequently, economic analysis of protected cultivation of tomato identified T_{14} (4-CPA 30 ppm-Inflorescence dipping) as highly remunerative treatment displaying net realization of Rs. 116629.00.

Table 3: Influence of foliar application of PGRs on various vegetative parameters of greenhouse tomato under South Gujarat conditions

Treatments	Plant height at 60 DAP(cm)	Plant height at 120 DAP (cm)	Plant height at 180 DAP (cm)	Plant height at final picking (cm)	Leaf area (cm^2)
T_1	115.07	188.67	238.40	290.60	823.33
T_2	105.13	183.80	233.53	285.53	814.00
T_3	100.07	178.60	228.33	273.67	837.00
T_4	110.20	163.73	213.40	258.33	755.00
T_5	108.73	161.87	211.87	256.67	749.00
T_6	100.33	153.60	203.33	248.53	745.00
T_7	120.07	193.73	243.80	302.13	840.00
T_8	110.20	190.47	241.87	299.67	836.00
T_9	105.13	185.13	235.00	293.00	833.00
T_{10}	115.07	180.07	235.27	283.60	770.00
T_{11}	110.20	175.20	228.33	280.13	766.00
T_{12}	105.07	170.13	221.67	271.67	763.67
T_{13}	114.07	200.47	249.33	303.00	843.33
T_{14}	120.20	203.47	251.73	306.67	831.67
S.E.m±	4.52	9.62	9.61	11.06	26.93
$C.D._{0.05}$	NS	27.97	27.94	32.15	78.27
C.V.%	7.12	9.23	7.20	6.78	5.83

Table 4: Influence of foliar application of PGRs on various reproductive parameters of greenhouse tomato under South Gujarat conditions

Treatments	Number of fruits per cluster	Fruit setting (%)	Days to first picking	Number of fruits per plant	Days to last picking
T_1	3.20	40.00	75.67	32.00	246.00
T_2	2.80	35.00	76.33	28.00	244.67
T_3	2.60	32.50	76.33	26.00	243.67
T_4	3.40	42.50	73.67	34.00	244.00
T_5	3.20	40.00	75.00	32.00	242.67
T_6	2.80	35.00	78.67	28.00	241.33
T_7	3.40	42.50	75.00	34.00	248.00
T_8	3.00	37.50	77.33	30.00	246.67
T_9	2.80	35.00	77.67	28.00	245.67
T_{10}	3.60	45.00	74.00	36.00	246.00
T_{11}	3.50	44.17	76.67	35.00	244.67
T_{12}	3.40	42.50	75.00	34.00	242.67
T_{13}	1.80	22.50	76.67	18.00	230.10
T_{14}	5.80	72.50	69.00	58.00	250.33
S.E.m±	0.20	2.50	3.76	2.00	15.74
$C.D._{0.05}$	0.58	7.28	NS	5.81	NS
C.V.%	10.69	10.72	8.63	10.71	11.17

Table 5: Influence of foliar application of PGRs on yield and its attributes of greenhouse tomato under South Gujarat conditions

Treatments	Average fruit weight (g)	Fruit yield per plant (kg)	Fruit yield per m^2 (kg)
T_1	91.67	2.92	7.54
T_2	91.78	2.58	6.67
T_3	91.98	2.35	6.06
T_4	92.10	3.11	8.06
T_5	92.80	2.93	7.58
T_6	92.13	2.53	6.56
T_7	93.73	3.17	8.21
T_8	93.80	2.56	6.37
T_9	93.60	2.59	6.69

T_{10}	92.57	3.31	8.55
T_{11}	92.93	3.26	8.44
T_{12}	92.73	3.12	8.08
T_{13}	93.70	1.70	4.38
T_{14}	93.80	4.95	12.69
S.E.m±	3.61	0.20	0.55
$C.D._{0.05}$	NS	0.58	1.59
C.V.%	6.74	11.69	12.56

Table 6: Economic analysis of greenhouse tomato under foliar application of PGRs in South Gujarat conditions

Treatments	Amortized fixed cost for a single season (Rs.)	Variable cost (Rs.)	Total cost of cultivation (Rs.)	Yield (t/1000m^2)	Gross return (Rs.)	Net Realization (Rs.)	BCR
T_1	59908	74820	134728	7.54	150839	16111	0.12
T_2	59908	74647	134555	6.67	133422	-1133	-0.01
T_3	59908	74534	134442	6.06	121225	-13217	-0.10
T_4	59908	74886	134794	8.06	161158	26364	0.20
T_5	59908	74777	134685	7.58	151592	16907	0.13
T_6	59908	74542	134451	6.56	131109	-3341	-0.02
T_7	59908	76226	136135	8.21	164269	28134	0.21
T_8	59908	76066	135974	6.37	127377	-8597	-0.06
T_9	59908	76400	136309	6.69	133809	-2500	-0.02
T_{10}	59908	75765	135674	8.55	171084	35410	0.26
T_{11}	59908	75827	135735	8.44	168776	33041	0.24
T_{12}	59908	75819	135727	8.08	161580	25853	0.19
T_{13}	59908	71157	131065	4.38	87541	-43524	-0.33
T_{14}	59908	77332	137241	12.69	253870	116629	0.85

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