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Effect of Plant Growth Regulators on the Growth and Yield of Capsicum (*Capsicum annuum* L.)

Talvinder Kaur[1], Ashutosh Sharma[1], Sonika Sharma[1*], Neha Sharma[2], Shivam Sharma[1*]

[1]DAV University, Sarmastpur, Jalandhar, Punjab (India)-144012
[2]Department of Vegetable Science, CSK HPKV Palampur (H.P), India-176062
Email: shivamsharma7154@gmail.com; ssonika88@gmail.com
*Corresponding author

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Abstract— *An experiment was conducted in the experimental Farm of DAV University, Jalandhar during kharif, 2023 to assess the combined effect of plant growth regulators and varieties on growth and yield of capsicum. The experiment comprised of four treatments of plant growth regulators, (G_0 = No growth regulator (control), G_1= GA_3 @ 50 ppm, G_2= SA @ 50 ppm, G_3= MeJa @ 2mM) and three varieties (V_1=PSM-1, V_2= F_1- hybrid, V_3= Orobelle) was replicated thrice and laid out in Randomized Block Design. Among plant growth regulators, maximum growth and yield parameters were observed in GA_3 @ 50 ppm. Among the varieties, V_1= PSM-1 were recorded to be the best regarding growth and yield parameters. For combined effect, G_1V_1 gave the highest growth and yield and G_0V_3 gave the lowest growth and yield. The highest gross return, net returns and cost benefit ratio was significantly observed in T1 (GA_3 @ 50ppm × PSM-1) following by in T5 (GA_3 × F1- hybrid). So, 50 ppm GA_3 may be used for capsicum cultivation.*

Keywords— ***Capsicum, Plant growth regulators, Gibberellic acid, Salicylic acid, Methyl jasmonate***

I. INTRODUCTION

Capsicum (*Capsicum annuum* L.) is an annual herbaceous plant that belongs to the Solanaceae family. It is commonly referred to as peppers, paprika, or capsicum (Shimla mirch) and has its origins in South and Central America. The genus Capsicum comprises over 30 species, with five of them (*C. annuum, C. frutescens, C. chinense, C. baccatum, and C. pubescens*) being domesticated and primarily cultivated for vegetable consumption. Capsicum is considered the world's second-most important vegetable after tomatoes [1]. In India, capsicum is cultivated across 24,000 hectares, with a total production of 3.21 lakh metric tons. West Bengal is the largest producer of capsicum in the country, accounting for 29.61 % of the total, followed by Karnataka (10.54 %), Haryana (10.49 %), Jharkhand (10.10 %), Himachal Pradesh (8.68 %), and Punjab (5.06 %) [2].

Plant growth regulators (PGRs) and natural biostimulants are used to enhance horticulture products, improving plant growth and increasing yield in various crops such as cucumber, tomato, pepper, potato, onion, pea, and melon [3, 4]. They help to reduce flower and fruit drops, improve production per unit area and time, and stimulate the translocation of photosynthates, leading to better retention of flowers and fruits [5, 6]. Sweet pepper's responses to PGRs vary [7]. PGRs are diverse substances that can modify plant physiological or morphological processes at very low concentrations.

Gibberellic acid (GA_3) is a plant hormone that regulates growth and development. It is produced by plants, fungi, and bacteria. GA_3 accelerates plant growth and development by enhancing plant height, shoot weight, and root length [8]. Salicylic acid has a wide range of biological activities, making it a valuable tool for optimizing plant growth, development, and stress management [9]. The application of salicylic acid can lead to increased fruit size and overall yield in capsicum plants. It can also improve the color, texture, and flavor of capsicum fruits, enhancing their marketability [10].

Methyl jasmonate is a plant hormone that plays a role in various stress responses, including defense against

pathogens and herbivores. In *Capsicum* species (e.g., bell peppers and hot peppers), methyl jasmonate can influence several aspects of plant growth and development like enhance stress resistance, increase secondary metabolites and induce defense mechanisms [11].

II. MATERIALS AND METHODS

The research work was conducted at the experimental Farm, DAV University, Jalandhar during the period from March 2023 to August 2023. The location of the site was 31° 25' 18" N / 75° 37' 14" E, with an average elevation altitude of 238 meters above mean sea level. Plant growth regulators and varieties was used for present study. The experiment comprised four treatments of plant growth regulators, (G_1= GA_3 @ 50 ppm, G_2= SA @ 50 ppm, G_3= MeJa @ 2mM, G_0 = No growth regulator(control)) and three varieties (V_1=PSM-1, V_2= F_1- hybrid, V_3= Orobelle). The experiment was laid out in the Randomized Block Design (RBD) with three replications and twelve treatments. Plant growth regulators was done through foliar application of Gibberellic acid, salicylic acid and methyl jasmonate. The Plant growth regulators were applied at the 30, 60 and 90 days after transplanting. The treatments consisted of T_1 (GA_3 × PSM-1), T_2 (SA × PSM-1), T_3 (MeJa × PSM-1), T_4 (Control × PSM-1), T_5 (GA_3 × F_1- hybrid), T_6 (SA× F_1- hybrid), T_7 (MeJa × F_1- hybrid), T_8 (Control × F_1- hybrid), T_9 (GA_3 × Orobelle), T_{10} (SA × Orobelle), T_{11} (MeJa × Orobelle) and T_{12} (Control × Orobelle). Observations were recorded on randomly selected plants with different characters *i.e.,* plant height (cm), number of branches per plant, number of leaves per plant, leaf area index, days from transplanting to 1st flowering, days from transplanting to 50 % flowering, number of flowers per plant, days from transplanting to 1st harvest, number of fruits per plant, percent fruit setting, fruit length (cm), fruit diameter (cm), fruit weight (g), yield per plant (g), yield per plot (kg) and yield per hectare (tons) and economics. The data was analysed as per design of the experiment.

III. RESULTS

3.1 Growth parameters

The analysis of variance revealed significant differences among the treatments for all the plant growth attributes under study.

3.1.1 Plant height (cm)

The data recorded on the effect of plant growth regulators and varieties on various growth attributes of capsicum presented in Table 1. Maximum plant height was obtained when GA_3 was applied at the rate of 50 ppm in G_1. In case of varieties maximum plant height was obtained in V_1 (PSM-1).

3.1.2 Number of branches per plant

Maximum number of branches per plant was obtained when GA_3 was applied at the rate of 50 ppm. In case of varieties maximum number of branches per plant was recorded in F_1- hybrid variety. The interaction between plant growth regulators and varieties the maximum plant height was obtained in (GA_3 × F_1- hybrid) in treatment T_5.

3.1.3 Number of leaves per plant

Maximum number of leaves per plant was obtained when GA_3 was applied at the rate of 50 ppm. In case of varieties maximum number of leaves per plant was obtained in variety V_1 (PSM-1). The possible reason may be that application of Azotobacter improved nitrogen status of the soil because this is free nitrogen fixer. The variation in number of leaves per plant of capsicum varieties with different plant growth regulators observed in treatment T_1 (GA_3 × PSM-1).

3.1.4 Leaf area Index

Maximum leaf area Index was recorded in G_1 (GA_3 @ 50 ppm) which was significantly highest than all PGR's. Among varieties, maximum leaf area Index was recorded in V_1 (PSM-1). The maximum interaction effect on leaf area Index at the harvest time was recorded in (GA_3 × PSM-1) in treatment T_1.

3.2 Days to first flowering/50 % flowering/number of flowers per plant/days to first harvest/number of fruits per plant/percent fruit setting

With the plant growth regulator, they reduced days to first flowering and 50 % flowering, an increased number of flowers per plant, reduced days to first harvest, a greater number of fruits per plant, and improved fruit setting percentages by spray of GA_3 @ 50 ppm. In varieties maximum days to first flowering and 50 % flowering, an increased number of flowers per plant, maximum days to first harvest, a greater number of fruits per plant, and maximum fruit setting percentages was recorded in variety V_1 (PSM-1). In interaction between plant growth regulators and varieties maximum days to first flowering, 50 % flowering, number of flowers per plant, days to first flowering, number of fruits per plant, and percent fruit settings was obtained in T_1(GA_3 @ 50ppm × PSM-1).

3.3 Yield parameters

3.3.1 Fruit length/ fruit diameter/ fruit weight/ yield per plant/ yield per plot/ yield per hectare

The data recorded on the effect of plant growth regulators and biofertilizers on various yield attributes of capsicum presented in Table 2. In plant growth regulator application, the higher Fruit length/ fruit weight/ yield per plant/ yield per plot/ yield per hectare were noticed in G_1 (GA_3 @ 50 ppm). In varieties the fruit diameter/ fruit weight/ yield per plant/ yield per plot/ yield per hectare was noticed in V_1 (PSM-1) and maximum fruit diameter was recorded in V_2 (F_1- hybrid).Among the interaction, significantly higher fruit diameter/ fruit weight/ yield per plant/ yield per plot/ yield per hectare was observed in the interaction of plant growth regulator and varieties in G_1V_1 (GA_3 @ 50ppm × PSM-1) and in fruit length was observed in the interaction of plant growth regulator and varieties in G_1V_2 (GA_3 @ 50 ppm × F_1-hybrid).

4. Economics

The highest gross return, net returns and cost benefit ratio was significantly observed in T_1 (GA_3 @ 50ppm × PSM-1) following by in T_5 (GA_3 × F_1- hybrid). Based on the results obtained in this experiment, it is concluded that the treatment T_1 (GA_3 @50ppm × PSM-1) was found to be superior over all other treatments in relation to growth and yield parameters in capsicum under the agro-climatic conditions.

IV. DISCUSSION

For plant height similar outcomes have been reported by [12] in sweet pepper, [13] in brinjal, [14, 15, 16] in tomato, and [17] in tomato. [18] supported the results as increases in plant height may be due to GA_3 which increase the cell division and cell elongation in sub apical meristem. The variation was found due to combined effect of plant growth regulators and varieties on plant height at harvest (86.15cm) in (GA_3 × PSM-1) in treatment T_1. The possible reason for increase in the number of branches per plant due to impact of plant's overall growth and photosynthetic capacity [19]. The similar trend was also reported in sweet pepper [15], [16, 20] in tomato and [21] in potato. To encourage the formation of lateral buds and increase the number of adaptable branches [22]. [18] supported the results as increases in number of leaves may be due to activity of GA_3 at the apical meristem resulting in more nucleo-protein synthesis responsible for increasing leaf initiation. Application of efficient and healthy strain of Azotobacter in rhizosphere have resulted in greater fixation of atmospheric nitrogen for use by the plant resulting in vigorous growth of plant. Similar results have been reported by [23, 24, 25]. For leaf area index, similar results have been reported by [26-30]. The foliar application of plant growth regulators, including GA_3, leads to significantly improved growth parameters by [31]. Similar results have been reported by [26-30] in different vegetables crops. The increasing concentration of plant growth regulators mixture only up to GA_3 @ 50 ppm proved highly beneficial which enhanced the maximum yield of the capsicum varieties. Another probable reason for increasing yield attributes might be due to the increasing growth characters by cell division, cell elongation and cell expansion that might have ultimately increased in the yield. Similar trend was also observed by [32, 33, 34] in cabbage and [35] in sprouting broccoli. In addition, results obtained for economics od capsicum were found in close conformity with the findings of [36].

V. CONCLUSION

Based on the results experimentation it seems quite logical to conclude that application of plant growth regulator G_1 (GA_3 @ 50 ppm) observed maximum growth, yield and economics. Among the varieties V_1 (PSM-1) were recorded to be the best regarding the growth, yield and economics of capsicum. In case of interaction between plant growth regulators and varieties maximum growth, yield and economics was recorded in T_1 (GA_3 @ 50ppm × PSM-1). These results might be effective and efficient in further capsicum improvement programs.

Table 1. Effect of plant growth regulators on Plant height(cm), Number of branches per plant, Number of leaves per plant, Leaf area Index, days transplanting to 1st flowering, days to 50 % flowering, Number of flowers per plant, days from transplanting to 1st harvest, Number of fruits per plant and percent fruit setting on capsicum varieties

Treatments	Plant height(cm)	Number of branches per plant	Number of leaves per plant	Leaf area Index	Days from transplanting to 1st flowering	Days to 50 % flowering	Number of flowers per plant	Days from transplanting to 1st harvest	Number of fruits per plant	Percent fruit setting
Varieties										
V_1	83.43	10.66	108.14	0.73	42.87	90.02	12.20	56.91	10.01	82.00
V_2	74.64	14.57	91.25	0.68	53.55	96.70	8.07	64.02	6.05	74.97
V_3	67.96	10.14	100.14	0.55	45.98	93.30	9.34	58.32	7.22	77.28
S.E (m) ±	**0.649**	**0.057**	**0.050**	**0.011**	**0.640**	**0.668**	**0.059**	**0.681**	**0.053**	**0.656**
C.D(5 %)	**2.291**	**0.199**	**0.178**	**0.040**	**2.259**	**2.357**	**0.208**	**2.402**	**0.187**	**2.314**
Plant growth regulators										
G1	78.56	12.38	100.49	0.70	46.06	91.25	10.56	57.79	8.33	78.99
G2	76.46	12.07	100.07	0.65	46.62	93.35	10.02	58.66	7.94	78.39
G3	75.35	11.63	99.53	0.64	48.11	93.59	9.59	60.31	7.52	77.74
G0	73.67	11.09	99.29	0.62	49.08	95.18	9.31	62.25	7.25	77.20
S.E (m) ±	**0.749**	**0.065**	**0.058**	**0.013**	**0.736**	**0.772**	**0.068**	**0.786**	**0.061**	**0.758**
C.D(5 %)	**2.643**	**0.231**	**0.205**	**0.046**	**2.102**	**2.235**	**0.240**	**2.774**	**0.216**	**0.256**

Table 1(a). Interaction effect of plant growth regulators on Plant height(cm), Number of branches per plant, Number of leaves per plant, Leaf area Index, days transplanting to 1st flowering on capsicum varieties.

Varieties	**Plant height (cm) (At Harvest)**					**Number of branches per plant (At Harvest)**					**Number of leaves per plant (At Harvest)**					**Leaf area Index**					**Days from transplanting to 1st flowering**				
	Plant growth regulators																								
	G1	G2	G3	G0	Mean	G1	G2	G3	G0	Mean	G1	G2	G3	G0	Mean	G1	G2	G3	G0	Mean	G1	G2	G3	G0	Mean
V1	86.15	83.17	82.86	81.55	**83.43**	11.35	10.97	10.47	9.86	**10.67**	108.67	108.33	107.94	107.63	**108.14**	0.76	0.73	0.72	0.70	**0.73**	43.66	43.02	42.65	42.15	**42.87**
V2	78.68	75.86	73.25	70.79	**74.64**	15.05	14.85	14.54	13.85	**14.57**	91.98	91.54	90.83	90.65	**91.25**	0.70	0.68	0.67	0.66	**0.68**	56.92	54.85	51.55	50.86	**53.55**
V3	70.85	70.36	69.95	68.68	**69.96**	10.75	10.39	9.87	9.55	**10.14**	100.83	100.35	99.81	99.58	**100.14**	0.64	0.55	0.52	0.51	**0.55**	46.65	46.45	45.66	45.17	**45.98**
S.E (m) ±	**0.03**					**0.02**					**0.05**					**0.01**					**0.03**				
C.D at (5%)	**0.08**					**0.05**					**0.13**					**0.03**					**0.08**				

Table 1(b). Interaction effect of plant growth regulators on Days to 50% flowering, Number of flowers per plant, days from transplanting to 1st harvest, Number of fruits per plant and percent fruit setting on capsicum varieties.

Varieties	**Days to 50% flowering**					**Number of flowers per plant**					**Days from transplanting to 1st harvest**					**Number of fruits per plant**					**Percent fruit setting**				
	Plant growth regulators																								
	G1	G2	G3	G0	Mean	G1	G2	G3	G0	Mean	G1	G2	G3	G0	Mean	G1	G2	G3	G0	Mean	G1	G2	G3	G0	Mean
V1	92.65	90.55	88.64	88.24	**90.02**	12.85	12.35	11.95	11.65	**12.20**	58.75	58.33	53.30	57.27	**56.91**	10.58	10.06	9.84	9.54	**10.01**	82.34	81.46	82.29	81.89	**82.00**
V2	96.95	96.36	98.64	94.85	**96.70**	8.85	8.05	7.85	7.54	**8.08**	66.06	64.76	63.02	62.25	**64.02**	6.55	6.25	5.86	5.55	**6.05**	73.99	77.68	74.58	73.62	**74.97**
V3	95.94	93.85	92.77	90.65	**93.30**	9.97	9.66	8.98	8.75	**9.34**	61.95	57.83	57.06	56.45	**58.32**	7.86	7.52	6.86	6.66	**7.22**	78.83	77.84	76.36	76.08	**77.28**
S.E (m) ±	**0.02**					**0.02**					**0.67**					**0.01**					**0.21**				
C.D at (5%)	**0.06**					**0.06**					**1.98**					**0.03**					**0.62**				

Table 2. Effect of plant growth regulators on fruit length(cm), fruit diameter (cm), fruit weight(g), yield per plant (g), yield per plot (kg) and yield per hectare (tons) on capsicum varieties.

Treatments	**Fruit length(cm)**	**Fruit diameter (cm)**	**Fruit weight(g)**	**Yield per plant (g)**	**Yield per plot (kg)**	**Yield per hectare (tons)**
Varieties						
V_1	8.94±0.30	7.12±0.33	82.22±0.59	296.32±2.40	4.45±0.04	74.22±0.76
V_2	13.34±0.32	3.15±0.41	77.80±1.03	287.83±4.33	4.32±0.07	72.00±1.16
V_3	11.62±0.37	6.44±0.49	69.12±1.43	282.43±1.52	4.23±0.02	70.51±0.36
S.E (m) ±	**0.126**	**0.126**	**0.470**	**1.610**	**0.068**	**0.456**
C.D (5%)	**0.444**	**0.446**	**1.657**	**5.678**	**0.240**	**1.609**
Plant growth regulators						
G1	11.92±1.30	6.35±1.17	78.79±3.21	294.49±4.43	4.43±0.08	73.78±1.37
G_2	11.64±1.31	6.02±1.24	76.95±3.79	292.13±4.53	4.39±0.07	73.14±1.18
G_3	11.18±1.20	5.41±1.28	75.73±4.02	285.95±4.80	4.29±0.07	71.46±1.19
G_0	10.47±1.32	4.51±1.23	74.05±4.38	282.88±3.54	4.24±0.05	70.59±0.38
S.E (m) ±	**0.145**	**0.146**	**0.542**	**1.859**	**0.078**	**0.527**
C.D.	**0.513**	**0.515**	**1.913**	**6.557**	**0.277**	**1.858**

Table 2 (a). Interaction effect of plant growth regulators on fruit length(cm), fruit diameter (cm), fruit weight(g), yield per plant (g), yield per plot (kg) and yield per hectare (tons) on capsicum varieties.

Varieties	**Fruit length(cm)**					**Fruit diameter(cm)**					**Fruit Weight (g)**				
	Plant growth regulators														
	G1	G2	G3	G0	Mean	G1	G2	G3	G0	Mean	G1	G2	G3	G0	Mean
V1	9.54	9.24	8.85	8.15	**8.94**	7.84	7.43	6.85	6.35	**7.12**	83.55	82.83	81.45	81.04	**82.22**
V2	14.03	13.74	12.85	12.73	**13.34**	4.04	3.55	2.85	2.17	**3.15**	80.14	78.15	77.77	75.14	**77.80**
V3	12.18	11.95	11.83	10.53	**11.62**	7.16	7.06	6.53	5.02	**6.44**	72.68	69.86	67.97	65.98	**69.12**
S.E (m) ±	**0.01**					**0.01**					**0.02**				
C.D at (5%)	**0.03**					**0.03**					**0.07**				

Varieties	**Yield per plant (g)**					**Yield per plot (kg)**					**Yield per hectare (tons)**				
	Plant growth regulators														
	G1	G2	G3	G1	G2	G3	G1	G2	G3	G1	G2	G3	G1	G2	G3
V1	300.85	298.96	295.54	300.85	298.96	295.54	300.85	298.96	295.54	300.85	298.96	295.54	300.85	298.96	295.54
V2	296.65	293.87	280.95	296.65	293.87	280.95	296.65	293.87	280.95	296.65	293.87	280.95	296.65	293.87	280.95
V3	285.96	283.56	281.36	285.96	283.56	281.36	285.96	283.56	281.36	285.96	283.56	281.36	285.96	283.56	281.36
S.E (m) ±	**0.08**			**0.08**			**0.08**			**0.08**			**0.08**		
C.D at (5%)	**0.23**			**0.23**			**0.23**			**0.23**			**0.23**		

Table 3. Cost and return of capsicum cultivation as influenced by variety and plant growth regulators

Treatment	Cost of cultivation (Rs/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	B:C Ratio
G1V1	59413.4	229200	169786.6	**2.86**
G2V1	58932.4	223990	165057.6	**2.80**
G3V1	59103.4	221500	162396.6	**2.75**
G0V1	53756.4	197160	143403.6	**2.67**
G1V2	60013.4	222170	162156.6	**2.70**
G2V2	59532.4	221810	162277.6	**2.73**
G3V2	59703.4	210650	150946.6	**2.53**
G0V2	54356.4	182840	127683.6	**2.35**
G1V3	60813.4	219980	159166.6	**2.62**
G2V3	60332.4	212500	152167.6	**2.52**
G3V3	60503.4	211000	150496.6	**2.49**
G0V3	**55156.4**	**181330**	**126973.6**	**2.30**

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