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Effect of plant growth hormones on growth, yield and quality of green chilli (*Capsicum annuum* L.) cv. 'Pant C – 1'

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Abstract
The present study was carried out at Experimental Farm, Department of Horticulture, School of Agriculture, Suresh Gyan Vihar University, Jaipur (Rajasthan) to find out the effect of 2, 4-D, NAA and GA_3 on growth, yield and fruit quality of chilli (*Capsicum annuum* L.) during the year 2022-23. The experiment was laid down in Randomized Block Design which consisted 10 treatment combinations *viz;* Control (T_0), 2, 4 – D @ 5 ppm (T_1), 2, 4 – D @ 10 ppm (T_2), 2, 4 – D @ 15 ppm (T_3), NAA @ 25 ppm (T_4), NAA @ 50 ppm (T_5), NAA @ 75 ppm (T_6), GA_3 @ 25 ppm (T_7), GA_3 @ 50 ppm (T_8) and GA_3 @ 75 ppm (T_9) and treatments were replicated three times.
The various concentrations of 2, 4-D, NAA and GA_3 significantly influenced the various parameters *viz.;* vegetative growth, yield and quality parameters and the highest (33.14 cm), (43.13 cm), (54.38 cm) and (61.43 cm) plant height at 45, 60, 75 and 90 DAT, respectively, maximum (163.14) leaves per plant, (15.20) branches per plant, (102.57) green chilli fruits per plant, minimum (38.35 days) to 50% flowering and the longest (8.27 cm) fruit, maximum (2.82 cm) fruit girth, heaviest (9.66 g) fruit weight and the highest (789.25 g/plant), (18.94 kg/plot), (21.92 t/ha) green chilli yield and (0.64 t/ha) dry red chilli yield were recorded under foliar application of GA_3 @ 50 ppm (T_8) treatment. However, the maximum (61.54%) fruit set per plant was observed in 2,4-D @ 10 ppm (T_2) treatment followed by (60.10%) and (58.94%) fruit set in 2,4-D @ 5 ppm (T_1) and 2,4-D @ 15 ppm (T_3), respectively. The foliar application of different concentrations of 2, 4-D, NAA and GA_3 showed the non-significant effect on number of flowers per plant. Results further indicated that the maximum net return (₹. 2, 99, 672.68 /ha) and highest B: C ratio (3.82) was recorded under GA_3 @ 50 ppm (T_8) treatment followed by (₹. 2, 54, 527.43 /ha) & B:C ratio (3.38) and (₹. 2, 38, 313.93 /ha) and B:C ratio (3.25) in GA_3 @ 75 ppm (T_9) and 2, 4-D @ 10 ppm (T_2), respectively in green chilli production under semi-arid conditions of Jaipur.

Keywords: Plant growth hormones, growth, yield, green chilli, *Capsicum annuum* L.

Introduction
Capsicum annuum L. is an important vegetable crop. It is also considered important spices crop and is a member of Solanaceae family. It has diploid chromosomes i.e. 2n=24. It is originated in Mexico, Southern Peru and Bolivia (Villalon, 1981) [39]. It grows as an annual herb, profusely branching, bushy type plant. Chilli is exotic crop and was introduced in India by the Britishers in the 19th century. It was introduced in Shimla hills by the Portuguese and Capsicum from Brazil to India during 1584. The Christian missionaries introduced Capsicum species in the North-eastern states separately (Thamburaj and Singh, 2003) [36]. Chilli and Capsicum are broadly cultivated in tropical and sub-tropical countries especially in Africa, USA, Japan, Mexico, India, Turkey, etc. It is grown on commercial scale as a cash crop in India (Anonymous, 2000) [2].
India is ranking on first position and considered as the largest producer, consumer and exporter of Chilli in the world. It is possible due to favourable soil and climatic conditions prevailing for Chilli production (Anonymous, 2021) [3]. India ranks on first position in area and second in production next to china. The chilli cultivated in 4.26 million ha area with 34.5 million tons total production in the world (FAO, 2018). Chilli is 3rd most important vegetable crop growing next to tomato and potato (Naz *et al.*, 2006) [20]. India is accounting 7.43 lakh ha area and 19.14 lakh MT production with 2576 kg/ha productivity (Anonymous, 2021) [3]. It is growing under 13,812 ha area and accounts 13649 MT production in Rajasthan. The Jodhpur, Alwar, Jaipur, Bhilwara, Tonk, Sawai Madhopur and Udaipur are major chilli producing districts in Rajasthan. Chilli is mainly used as culinary purposes to add flavour, colour, vitamin and pungency.

It has an important source of nutritive values. It also uses in much pharmaceutical industry and has plenty of medicinal properties (Chowdhury, 1976) [8]. It has appealing color and is used in curry (Udoh *et al.*, 2005) [38]. The chilli is rich in vitamins and minerals, good source of vitamin A and C (Saimbhi *et al.*, 1977 and Sayed and Bagavandoss, 1980) [26, 28]. Sayed and Bagavandoss (1980) [28] reported that around 160 calories of energy through 36 g carbohyderates, 18 g proteins, 16 g fats, 480 mg calcium, 3.1 mg, phosphorus, 31 mg iron, 2.5 mg niacin, 640 I.U. vitamin A and 40 mg vitamin C from every 100 grams of dried chilli fruits.

The chilli is a fruit vegetable and very popular for its high content in bioactive compounds and has strong antioxidant capacity. It is most popular fresh vegetable worldwide due to its combination of colour, flavour and nutritional value. The bioactive compounds of chilli provide beneficial effects in human health due to their antioxidant properties. It protect against the oxidative damage to cells and thus prevent the development of common degenerative diseases such as cancer, cardiovascular diseases, cataracts, diabetes, Alzheimer's, and Parkinson's (Blanco-Rios *et al*., 2013) [6]. Fresh green chillies have exceptionally high quantities of vitamin - C and their attractive red color is due to several carotenoid pigments that include B-carotene with provitamin A activity and oxygenated carotenoids, which are exclusive to these fruits and have proven to be effective at scavenging free radicals (Deepa *et al.*, 2006) [9].

The yield and quality of chilli may be improved through changes of hormonal behaviours. The use of plant growth regulators (PGRs) might be a useful alternative to increase crop production. Now-a-days, many plant growth regulators used for increasing the productivity and marketability of many vegetable crops, and also reduce the plant stress, tolerance to abiotic stress etc. The application of plant growth regulators in solanaceous vegetable crops is very effective in reducing the flower and fruit drops thereby enhancing production in per unit of area and per unit of time (Chitwan *et al.*, 2006) [7]. The plant growth hormones are also used to enhance and stimulate the translocation of photo assimilates and it helps in better retention of flowers and fruits (Sreenivas *et al.*, 2017) [32].

Gibberellic acid (GA_3) is a phytohormone that is needed in very small quantities even at low concentration it accelerates plant height of the plant. Gibberellins are used to promote fruit set in some fruit vegetables including tomatoes and yield can increases dramatically up to four times (Singh and Singh, 2019) [31]. It is due to phenolic compounds interact with gibberellins, which promote cell elongation (Taiz and Zeiger, 2002) [34]. Pundir *et al.* (2020) [25] stated that naphthalene acetic acid (NAA) is a synthetic plant hormone which is used in plant to promote the growth. NAA is also have beneficial effect like, increased photosynthetic activity, accelerated transport and efficiency of utilizing photosynthetic products resulting in rapid cell elongation and cell division in the meristem which are ultimately responsible for growth, development and higher yield (Sarker *et al.*, 2009) [27].

2,4-Dichlorophenoxyacetic acid is a synthetic auxin. It is used as herbicide and kills the target weed by mimicking the plant growth hormone auxin (indole acetic acid), and when administered at effective doses. It causes uncontrolled and disorganized plant growth that leads to plant death. The naphthalic acetic acid (NAA) enhance the source of sink relationship and hormone modified translocation of photosynthates, which will help in better retention of flowers and fruits (Pandita *et al.*, 1980, and Lata and Singh, 1993) [22, 15].

The available information regarding the impact of plant growth regulators on chilli is not sufficient. Keeping in view, the present investigation was undertaken with the objective to find out the best plant growth regulator with optimum concentration for quality chilli production under semi-arid conditions of Jaipur.

Materials and Methods

The present research was carried out on Experimental Farm, Department of Horticulture at Suresh Gyan Vihar University, Jaipur (Rajasthan) to investigate the effect of different plant growth regulators (PGRs) on chilli during the year 2023. The experiment was laid down in Randomized Block Design which consisted 10 treatment combinations *viz;* Control (T_0), 2, 4 – D @ 5 ppm (T_1), 2, 4 – D @ 10 ppm (T_2),2, 4 – D @ 15 ppm (T_3), NAA @ 25 ppm (T_4), NAA @ 50 ppm (T_5), NAA @ 75 ppm (T_6), GA_3 @ 25 ppm (T_7), GA_3 @ 50 ppm (T_8) and GA_3 @ 75 ppm (T_9) and treatments were replicated three times. Appraisal of the result indicated that the influence of plant growth regulators on important parameters like vegetative growth, yield and quality attributes of chilli were significantly influenced by micronutrients under local agro-climatic conditions of Jaipur (Rajasthan). The observations were measured on the five randomly selected and tagged plants in each plot and their mean value was calculated. The test of significance of variation in data obtained from various growth, yield and quality characters. A significance of difference in the treatment effect was tested through 'F' test at 5% level of significance and Critical Difference (CD) was calculated, wherever the results found significant.

Results and Discussion

The experimental findings computed on the basis of the observations recorded and statistical analyses are presented precisely in this chapter under the following heads:

Vegetative Growth Parameters

The foliar spray of different concentration of 2,4-D, NAA and GA_3 had significant impact and remarkable increase was observed on growth and yield characteristics by exogenous application of Gibberellic acid, NAA and other growth hormones. Similar results were also reported by earlier workers such as Bharti *et al*. (2020) [5]; Pundir *et al.* (2020) [25] and Hariom and Topno (2023) [14]. Gibberellic acid increased the vegetative growth of a crop and is primarily responsible for higher plant height because number of photosynthesizing sites, number of branches that is affected by initial growth stages. The significant increase in plant height was observed in all treatment combinations of the exogenous application of various growth regulators. Amongst the treatment, the maximum (33.14 cm), (43.13 cm), (54.38 cm) and (61.43 cm) plant height were recorded under GA_3 @ 50 ppm (T_8) treatment at 45, 60, 75 and 90 DAT, respectively (Table 1). The plant height increased due to application of plant hormones that promoted vegetative growth by active cell division, cell enlargement and cell elongation and thus helped in improving growth characteristics and also facilitated reproductive growth of plant (Pareek *et al.*, 2000) [23]. The maximum (163.14) leaves per plant were observed at GA_3 @ 50 ppm (T_8) treatment followed by (158.57), (154.06), (149.27) and (148.24) at GA_3 @ 75 ppm (T_9), GA_3 @ 25 ppm (T_7), NAA @ 50 ppm (T_5) and NAA @ 75 ppm (T_6) treatments, respectively. The minimum (131.04) leaves per plant were observed in control (Table 1). This increase in height and number of leaves per plant might be due to exogenous application of gibberellic acid that increases in cell division, cell wall plasticity and cell elongation (Yugandhar *et al*., 2014) [40]. The maximum (15.20) branches per plant were recorded in GA_3 @ 50 ppm (T_8) treatment followed by (13.90) in GA_3 @ 75 ppm (T_9) the data presented in Table 1. These findings are in accordance with the findings of Elankavi *et al.* (2009) [10] who also observed that the exogenous application of GA_3 significantly increases various growth parameters *viz.,* tree height, number of leaves and yield attributes. The increase in number of branches per plant might be due to application of gibberellic acid which enhances the lateral buds and branches, because it breaks apical dominance (Modise *et al.*, 2009) [16]. The results are in conformation with the findings of Shukla *et al.* (2011) [30]; Tapdiya *et al.* (2018) [35] and Hariom and Topno (2023) [14].

Table 1: Effect of plant growth regulators on vegetative growth parameters

Treatments	Plant height (cm)				Number of leaves per plant	Number of branches per plant	Number of days to 50% flowering
	45 DAT	60 DAT	75 DAT	90 DAT			
Control (Water spray) (T_0)	16.20	25.79	37.37	43.42	131.04	9.84	61.31
2, 4 – D @ 5 ppm (T_1)	19.44	29.02	39.60	45.65	144.60	10.27	50.39
2, 4 – D @ 10 ppm (T_2)	18.56	28.15	39.73	45.78	141.57	9.93	48.76
2, 4 – D @ 15 ppm (T_3)	17.84	27.43	40.08	46.13	137.73	9.90	49.98
NAA @ 25 ppm (T_4)	24.96	34.55	46.13	51.85	145.73	11.34	48.45
NAA @ 50 ppm (T_5)	27.36	36.95	48.47	55.58	149.27	13.26	47.51
NAA @ 75 ppm (T_6)	26.21	35.80	47.38	53.43	148.24	12.04	48.25
GA_3 @ 25 ppm (T_7)	28.05	38.30	49.89	55.94	154.06	12.06	44.69
GA_3 @ 50 ppm (T_8)	33.14	43.13	54.38	61.43	163.14	15.20	38.35
GA_3 @ 75 ppm (T_9)	30.16	40.11	51.70	57.75	158.57	13.90	43.85
SEm$\pm$	0.97	1.11	1.60	1.66	5.21	0.51	1.53
C.D. (p=0.05)	2.90	3.33	4.78	4.96	15.61	1.54	4.59
CV (%)	6.93	5.67	6.08	5.55	6.12	7.55	5.52

Flowering and Fruit Set

Flower drop and fruit set are one of the most important key factors in fruit and vegetable crops since it impacts the amount of fruit production and the total yield. Several other factors such as the formation of male and female flowers, pollination, germination of pollen grains on stigmatic surfaces, growth of pollen tube and finally complete fertilization, all influences fruit set. The foliar spray of growth regulators in chilli increased fruit set dramatically. Fruit set is a most critical stage in the conversion of a flower into a fruit in order to get maximum yield and highest grower's profits. The maximum (61.54%) fruit set per plant was recorded in 2,4-D @ 20 ppm (T_2) treatment followed by (60.10%) and (58.94%) fruit set in 2,4-D @ 5 ppm (T_1) and 2,4-D @ 15 ppm (T_3), respectively (Table 2). It might be due to 2,4-D at higher concentration increases fruit abscission. Moreover, Modise *et al.* (2009) [16] reported that 20 mg L^{-1} 2,4-D increased fruit abscission. The similar results were also reported by Naga *et al.* (2022) [17] and Hariom and Topno (2023) [14].

Fruit drop is a major problem in chilli and it can be caused by a various factors such as changes in temperature, a lack of moisture during flowering or fruiting and nutrient deficiencies. Each of these aspects causes plant hormonal disparities (Modise *et al.*, 2009) [16]. Spraying plant growth regulators was found to be effective in reducing premature fruit drop (Naga *et al.* (2022) [17].

The maximum (102.57) green chilli fruits per plant was recorded in 2,4-D @ 10 ppm (T_2) treatment followed by (95.24) green chilli fruits per plant in 2,4-D @ 5 ppm (T_1). Treatment T_1 was observed at par with treatment (T_2); whereas, the minimum (62.34) green chilli fruits per plant was recorded in control (Table 2). It might be due to maximum fruit set, minimum fruit drop and maximum fruit retention by 2, 4-D treatment that ultimately increases the number of fruits per plant. Similar results were also reported by Naga *et al.* (2022) [17] and Hariom and Topno (2023) [14].

Yield Attributing Parameters

Fruit size is not only a factor that affects productivity, but it can also influences customer demand in the market (Guardiola and García-Luis, 2000) [13]. The plant growth regulators (GA_3, NAA, and 2,4-D) resulted in a considerable increase in fruit length, breadth, weight and volume of chilli fruit (Kaur *et al.*, 2016) [9]. The role of gibberellic acid in improving fruit quantity namely, fruit weight and fruit size may be due to its role in increasing cell elongation and cell division (Eman *et al*., 2007) [11]. The maximum (8.27 cm) fruit length was observed in GA_3 @ 50 ppm (T_8) treatment followed by (7.41 cm) fruit length under GA_3 @ 75 ppm (Table 2). These results are in close conformity with the findings of Shankhwar *et al.* (2017) [29]; Naga *et al*. (2022) [17] and Hariom and Topno *et al*. (2023) [14].

The application GA_3 had significantly influenced the fruit growth like fruit length and diameter. The foliar spray with 50 ppm GA_3 resulted in the greatest (2.82 cm) fruit girth was observed in GA_3 @ 50 ppm (T_8) treatment followed by (2.66 cm) and (2.59 cm) fruit girth under GA_3 @ 75 ppm (T_9) and NAA @ 50 ppm (T_5), respectively (Table 2). It might be due to exogenous application of gibberellic acid that increases in cell wall plasticity and cell elongation (Yugandhar *et al*., 2014) [40]. These results are in close conformity with the findings of Naga *et al.* (2022) [17].

Table 2: Effect of plant growth regulators on yield and yield attributing characters

Treatments	Number of flowers per plant	Fruit set (%)	Number of days to first picking	Number of fruits per plant	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Green chilli yield			Dry chilli yield (t/ha)	B:C Ratio
								(g/plant)	(kg/plot)	(t/ha)		
Control (T_0)	164.08	36.69	70.15	62.34	4.81	1.13	5.54	335.45	8.05	9.32	0.26	1.64
2, 4 – D @ 5 ppm (T_1)	158.48	60.10	59.22	95.24	5.89	1.98	6.21	582.18	13.97	16.17	0.47	2.84
2, 4 – D @ 10 ppm (T_2)	166.68	61.54	57.60	102.57	5.71	2.03	6.58	668.38	16.04	18.57	0.54	3.25
2, 4 – D @ 15 ppm (T_3)	148.87	58.94	58.81	87.74	5.39	1.84	6.50	562.22	13.49	15.62	0.45	2.73
NAA @ 25 ppm (T_4)	152.70	52.03	57.29	79.44	5.71	2.18	6.79	534.60	12.83	14.85	0.43	2.60
NAA @ 50 ppm (T_5)	167.78	54.19	56.35	90.91	6.47	2.59	7.47	665.94	15.98	18.50	0.54	3.23
NAA @ 75 ppm (T_6)	147.88	50.14	57.09	74.14	6.27	2.38	7.23	526.74	12.64	14.63	0.42	2.55
GA_3 @ 25 ppm (T_7)	154.44	46.54	53.52	71.87	7.17	2.49	8.28	587.13	14.09	16.31	0.47	2.85
GA_3 @ 50 ppm (T_8)	169.26	49.00	47.18	82.93	8.27	2.82	9.66	789.25	18.94	21.92	0.64	3.82
GA_3 @ 75 ppm (T_9)	169.19	48.20	52.69	81.54	7.41	2.66	8.56	702.44	16.86	19.51	0.57	3.38
SEm$\pm$	8.37	1.66	1.69	2.58	0.30	0.11	0.36	28.86	0.65	0.65	0.02	
C.D. (p=0.05)	NS	4.98	5.05	7.73	0.89	0.32	1.09	86.42	1.93	1.94	0.07	
CV (%)	9.06	5.57	5.12	5.39	8.18	8.49	8.63	8.40	7.82	6.77	7.95	

The role of gibberellic acid in improving the fruit size may be due to its role in increasing cell division and cell elongation and it ultimately increases fruit weight (Eman *et al*., 2007) [11]. The foliar spray of 50 ppm GA_3 resulted in the highest (9.66 g) fruit weight was recorded in GA_3 @ 50 ppm (T_8) treatment (Table 2). Srivastava *et al.* (2009) [33] reported that the GA_3 increased the fruit weight by increasing cell elongation, enlargement of vacuoles and loosening of cell wall after increasing cell wall plasticity. Also, (Elankavi *et al*. (2009) [10] reported that treatments of GA_3 encourage cell expansion in the fruit mesocarp, which in turn, causes an increase in fruit volume. These results are in close conformity with the findings of Shukla *et al.* (2011) [30]; Tapdiya *et al.* (2018) [35], Ahmed *et al.* (2022) [1] and Naga *et al.* (2022) [17].

Yield Parameters

Among the different concentrations of 2,4-D, NAA and GA_3 and the highest (789.25 g/plant) and (18.94 kg/plot) green chilli yield per plant was recorded under foliar spray of GA_3 @ 50 ppm (T_8) treatment presented in Table 2. Similar trend was also reported on yield per hectare and the treatment 2, 4-D @ 20 ppm (T_2) produced the highest (21.92 t/ha) green chilli yield. Hence, the foliar application of 2, 4-D @ 20 ppm performed significantly superior (Table 2). It might be due to exogenous application of gibberellic acid that increases in cell wall plasticity and cell elongation (Yugandhar *et al*., 2014) [40]. These results are in accordance with the findings of Thapa *et al.* (2003) [37]. The highest (0.64 t/ha) dry red chillies yield was recorded under foliar spray GA_3 @ 50 ppm (T_8) followed by (0.57 t/ha) under GA_3 @ 75 ppm (Table 2). Similar results were also reported by earlier workers such as Shankhwar *et al.* (2017) [29]; Naga *et al.* (2022) [17] and Hariom and Topno (2023) [14].

B:C ratio

The highest B: C ratio (3.82) of green chilli production was recorded in GA_3 @ 50 ppm (T_8) treatment followed by (3.38) in GA_3 @ 75 ppm (T_9) and (3.25) B:C ration in 2,4-D @ 10 ppm (T_2), respectively (Table 2). It might be due to increase in net return and B:C ratio might be due to exogenous application of GA_3 that increases fruit length & weight and number of chilliies per plant that ultimately increased the yield per plant as well as per hectare. These results are in close conformity with the findings of Patil and Ingle (2011) [24] and Bakshi *et al.* (2018) [4] in kinnow. Similar results were also reported by Nasreen *et al*., (2013) [18] in mandarin.

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