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Impact of Plant Growth Regulators on Growth, Yield, and Quality of Broccoli (*CV*. Palam Samridhi) in Sub-Tropical Garhwal Hills

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This experiment was conducted at HNB Garhwal University, Uttarakhand to evaluate the effects of various plant growth regulators on growth, yield, and quality parameters of the Broccoli cultivar *Palam Samridhi*. The study revealed that the combined application of Indole-3-butyric acid (IBA) and kinetin at concentrations of 50 ppm and 20 ppm, respectively (T_{12}), significantly enhanced plant height, central curd weight, yield per plot, yield per hectare, total soluble solids (TSS), and chlorophyll content. In addition, the maximum plant spread was observed with the application of

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Indole-3-acetic acid (IAA) at 100 ppm (T_2), while the highest leaf area was recorded with the treatment IAA + IBA + kinetin at 100 ppm + 100 ppm + 10 ppm (T_{16}). The control treatment (T_{19}) consistently showed the lowest values across all growth and yield parameters. Overall, the cultivar *Palam Samridhi* demonstrated optimal performance with the application of IBA + kinetin @ 50 ppm + 20 ppm (T_{12}), indicating its potential for improved yield and quality under appropriate hormonal treatments.

Keywords: Ascorbic acid; curd maturity; leaf area; total soluble solids.

1. INTRODUCTION

In today's era the indiscriminate use of synthetic chemicals causing various harms to environment as well as consumers. So, this experiment was conducted to know the effects of various PGRs on broccoli. Broccoli (*Brassica oleracea var. italica*) is an economically important cool-season vegetable crop belonging to the *Brassicaceae* family. It is widely recognized for its high nutritional value, being a rich source of dietary fiber, vitamins A, C, and K, calcium, iron, and bioactive compounds such as glucosinolates and sulforaphane, which possess antioxidant and anticancer properties (Singh & Devi, 2015). The increasing consumer demand for functional and health-promoting foods has led to a growing interest in broccoli cultivation in India and worldwide (Prashanthi *et al.*, 2022).

In India, broccoli is gradually gaining popularity among farmers and consumers, especially in peri-urban and hilly regions. However, its national average productivity remains relatively low, ranging between 7-10 t/ha, compared to developed countries where productivity can exceed 15-20 t/ha under optimized conditions (Sumangla *et al.*, 2013). This gap is largely attributed to suboptimal agronomic practices, lack of varietal adaptation, and inadequate use of plant growth practices. In the Garhwal hills of Uttarakhand, where sub-tropical conditions prevail, broccoli cultivation is still in its nascent stage, and productivity remains even lower due to climatic variability, marginal soil fertility, and limited technological interventions.

Plant Growth Regulators (PGRs) have been recognized as an effective agronomic input to enhance plant performance. These organic compounds, when applied in small quantities, influence plant physiological processes such as cell division, elongation, flowering, fruit setting, and stress tolerance (Farman *et al.*, 2019). PGRs like gibberellic acid (GA_3), naphthalene acetic acid (NAA), and kinetin are commonly used to manipulate growth patterns and improve yield and quality in various vegetable crops (Quamruzzaman *et al.,* 2021). In broccoli, PGRs have shown potential to increase plant height, leaf area, curd weight, curd diameter, and overall marketable yield, depending on the cultivar and agro-climatic conditions. The cultivar Palam Samridhi, developed for improved yield and quality, has shown adaptability to Indian hill conditions (Sabagh *et al.*, 2021). However, scientific data on its response to different PGRs under sub-tropical environments, such as those in the Garhwal region, are limited. The region's unique climate, characterized by moderate temperatures, high humidity, and varied altitudes, offers a suitable but underutilized niche for high-value vegetable cultivation.

Hence, the present study was undertaken to evaluate the effect of selected plant growth regulators on the growth, yield, and quality of broccoli (*cv*. Palam Samridhi) under the sub-tropical conditions of the Garhwal hills. The objective is to identify optimal PGR treatments that can enhance curd development, yield productivity, and quality attributes, thereby improving the economic viability of broccoli cultivation in this region.

2. MATERIALS AND METHODS

The experiment was conducted at Horticultural Research Centre, Department of Horticulture, Chauras Campus, H. N. B. Garwhal University, Srinagar (Garhwal), Uttrakhand in 2017-18. Geographically, Horticultural Research Centre is situated in Alaknanda valley which lies between 78° 3' E longitudes and 30° 9' N latitude right in the heart of Garhwal region. The elevation of experimental site is 540 m above MSL, in the lesser Himalayan region. A composite soil sample was taken from the experimental plot from 0-15 cm depth to find out the reaction and fertility status (Jackson, 1967). The variety released from HPKV, Palampur, Himachal Pradesh. It is recommended for sub-tropical condition. Palam Samridhi is sprouting type, beside terminal head sprouts also appear from the axil of leaves of each plant which supplement additional yield at later stage. The experiment

Table 1. Treatments and their combinations

Treatments	Combinations
T_1	IAA @ 50 ppm
T_2	IAA @100 ppm
T_3	IBA @50 ppm
T_4	IBA @100 ppm
T_5	Kinetin @10 ppm
T_6	Kinetin @ 20 ppm
T_7	IAA + Kinetin @ 50 ppm+10 ppm
T_8	IAA + Kinetin @ 50 ppm + 20 ppm
T_9	IAA + Kinetin @ 100 ppm + 10 ppm
T_{10}	IAA + Kinetin @ 100 ppm + 20 ppm
T_{11}	IBA + kinetin @ 50 ppm + 10 ppm
T_{12}	IBA + kinetin @ 50 ppm + 20 ppm
T_{13}	IBA + kinetin @ 100 ppm + 10 ppm
T_{14}	IBA + kinetin @ 100 ppm + 20 ppm
T_{15}	IAA + IBA + kinetin @ 50 ppm + 50 ppm + 10 ppm
T_{16}	IAA + IBA + kinetin @ 100 ppm + 100 ppm + 10 ppm
T_{17}	IAA + IBA + kinetin @ 50 ppm + 50 ppm + 20 ppm
T_{18}	IAA + IBA + Kinetin @ 100 ppm + 100 ppm + 20 ppm
T_{19}	Control

comprised of 19 treatments consisting of different concentration of IAA, IBA, kinetin and their combinations which was laid out in completely randomized block design with three replications are presented in Table 1.

The seed of Palam Samridhi were sown in well prepared and manured raised nursery bed of 3 × 1 × 0.15 m size. The experimental field was deep ploughed & harrowed, followed by planking and levelling 7 days prior to date of transplanting of seedlings. The seedlings were transplanting at four to six leaf stage. Before transplanting seedlings were treated as per the experimental plan and treatment details. The Stock solutions of IAA, IBA and Kinetin (100 ppm) was prepared separately by dissolving 100 mg of the active ingredient of each in few ml of 0.1N NAOH solution respectively and then made up a volume of 1 liter with distilled water.

The stock solution was prepared as per the given formula:

Stock solution(ml) =

$$\frac{\text{Req. volume in(ml)} \times \text{Required concentration ppm}}{\text{PPM in stock solution}}$$

3. RESULTS

3.1 Periodical Plant Height

The data regarding to effect of PGR and their combinations on the plant height at 30 DAT of broccoli has been presented in Table 2. The maximum plant height (32.80 cm) was recorded in T_{12} (IBA + kinetin @ 50 ppm + 20 ppm) followed by 31.47 cm in T_6 (Kinetin @ 20 ppm) and 31.40 cm in T_5 (Kinetin @ 10 ppm). On the other hand, the minimum (25.90 cm) plant height was found in treatment T_{19} (control). The plant height at 60 DAT found maximum (56.93 cm in T_8 (IAA + Kinetin @ 50 ppm + 20 ppm) followed by 56.07 cm in T_{14} (IBA + kinetin @ 100 ppm + 20 ppm) and 56 cm in T_{13} (IBA + kinetin @ 100 ppm + 10 ppm) which was found significant over rest of treatment. Whereas the minimum (48.08 cm) plant height was found in treatment T_{16} (IAA + IBA + kinetin @ 100 ppm + 100 ppm + 10 ppm).

3.2 Plant Spread (cm^2)

The plant spread was significantly influenced by various treatments. The maximum (29. 46 cm) plant spread was found in T_2 (IAA @ 100 ppm) followed by 28.19 cm in T_3 (IBA @ 50 ppm) and 27 cm in T_1 (IAA @ 50 ppm) which was significantly higher over control while the minimum (23.39 cm) plant spread was found in T_{19} (control).

3.3 Leaf Area (cm^2)

The data regarding to leaf area has been presented in Table 2 which showed that the result was significantly affected by different treatments. The maximum (903.98 cm^2) leaf area was found in treatment T_{16} (IAA + IBA + kinetin

Table 2. Periodical Plant height, plant spread and leaf area as influenced by PGRs

Treatment	Plant height (cm)		Plant spread (cm)	Leaf area $(cm)^2$
	30 DAT	60 DAT		
IAA@ 50 ppm (T_1)	27.87	52.00	27.00	653.87
IAA@ 100 ppm (T_2)	29.67	52.99	29.46	665.98
IBA@ 50 ppm (T_3)	29.67	53.20	28.19	694.74
IBA @ 100 ppm (T_4)	28.83	53.27	26.84	787.30
Kinetin @ 10 ppm (T_5)	31.40	54.27	24.12	702.47
Kinetin @ 20 ppm (T_6)	31.47	52.67	26.18	813.26
IAA + Kinetin @ 50 ppm +10 ppm (T_7)	27.93	55.40	24.93	757.51
IAA + Kinetin @ 50 ppm + 20 ppm (T_8)	29.70	56.93	24.96	703.94
IAA + Kinetin @ 100 ppm + 10 ppm (T_9)	28.60	54.73	24.64	632.50
IAA + Kinetin @ 100 ppm + 20 ppm (T_{10})	28.87	53.80	24.74	820.50
IBA + kinetin @ 50 ppm + 10 ppm (T_{11})	29.73	55.07	26.33	654.68
IBA + kinetin @ 50 ppm + 20 ppm (T_{12})	32.80	48.87	24.66	679.77
IBA + kinetin @ 100 ppm + 10 ppm (T_{13})	30.03	56.00	25.02	791.83
IBA + kinetin @ 100 ppm + 20 ppm (T_{14})	30.97	56.07	26.38	764.18
IAA + IBA + kinetin @ 50 ppm + 50 ppm + 10 ppm (T_{15})	28.53	54.80	23.98	808.93
IAA + IBA + kinetin @ 100 ppm + 100 ppm + 10 ppm (T_{16})	27.83	48.30	25.07	903.98
IAA + IBA + kinetin @ 50 ppm +50 ppm + 20 ppm (T_{17})	28.30	52.40	24.24	745.09
IAA + IBA + Kinetin @ 100 ppm + 100 ppm + 20 ppm (T_{18})	29.33	53.47	25.03	859.00
Control (T_{19})	25.90	51.33	23.39	685.73
S.Em. ±	0.90	1.42	0.93	50.98
C.D. (P= 0.05)	2.29	4.07	2.67	146.22

@ 100 ppm + 100 ppm + 10 ppm) followed by 859 cm^2 treatment T_{18} (IAA + IBA + Kinetin @ 100 ppm + 100 ppm + 20 ppm) and 820 cm^2 in treatment T_{10} (IAA + Kinetin @ 100 ppm + 20 ppm) whereas, the minimum (632.50 cm^2) leaf area was recorded in treatment T_9 (IAA + Kinetin @ 100 ppm + 10 ppm).

3.4 Days Taken to Central Curd Maturity

The data presented in Table 3 shows that, the minimum (59.40 days) days taken to central curd maturity was recorded in T_8 (IAA + Kinetin @ 50 ppm + 20 ppm) followed by 59.43 days in T_9 (IAA + Kinetin @ 100 ppm + 10 ppm) and 59.80 days in T_2 (IAA @ 100 ppm). The maximum (66.00 days) number of days were taken for central curd maturity under T_{19} (control).

3.5 Days Taken to Secondary Curd Maturity

The data presented in Table 3, revealed that the various treatments significantly influenced the days taken to secondary curd maturity. The minimum (70.57 days) were taken by T_{18} (IAA + IBA + Kinetin @ 100 ppm + 100 ppm + 20 ppm) followed by 71.57 days under T_5 (Kinetin @ 10 ppm) and 71.67 days under T_9 (IAA + Kinetin @ 100 ppm + 20 ppm). The maximum (82.79 days) taken to secondary curd maturity was recorded in T_7 (IAA + Kinetin @ 50 ppm + 10 ppm).

3.6 Yield Parameter

Volume of central curd (cc): The data presented in Fig. 1 regarding to the volume of central curd revealed that various PGRs affected significantly over control. The maximum (122.73 cc) volume of central curd was noted under T_{17} (IAA + IBA + kinetin @ 50 ppm + 50 ppm + 20 ppm) followed by 104.53 cc in T_6 (Kinetin @ 20 ppm) and 97.80 in T13 (IBA + kinetin @ 100 ppm + 10 ppm). The minimum (66.40 cc) volume of central curd was found in T_9 (IAA + Kinetin @ 100 ppm + 10 ppm).

Number of secondary curd per plant: The data presented in Fig. 1, indicate that, the maximum (10.33) number of secondary curds was founded in T_4 (IBA @ 100 ppm) followed by 9.77 in treatment T_1 (IAA @ 50 ppm) and 9.67 in T_6 (Kinetin @ 20 ppm). The minimum (6.37) number of secondary curd was found in T_9 (IAA + Kinetin @ 100 ppm + 10 ppm).

Table 3. Days taken to curd maturity as influenced by PGRs

Treatment	Days taken to curd maturity	
	Central	Secondary
IAA@ 50 ppm (T_1)	60.33	73.33
IAA@ 100 ppm (T_2)	59.80	72.33
IBA@ 50 ppm (T_3)	61.90	80.33
IBA @ 100 ppm (T_4)	62.71	75.17
Kinetin @ 10 ppm (T_5)	63.33	71.67
Kinetin @ 20 ppm (T_6)	61.00	78.33
IAA + Kinetin @ 50 ppm +10 ppm (T_7)	62.00	82.79
IAA + Kinetin @ 50 ppm + 20 ppm (T_8)	59.40	78.95
IAA + Kinetin @ 100 ppm + 10 ppm (T_9)	59.43	71.57
IAA + Kinetin @ 100 ppm + 20 ppm (T_{10})	62.30	75.33
IBA + kinetin @ 50 ppm + 10 ppm (T_{11})	63.85	75.00
IBA + kinetin @ 50 ppm + 20 ppm (T_{12})	61.30	75.43
IBA + kinetin @ 100 ppm + 10 ppm (T_{13})	65.59	75.53
IBA + kinetin @ 100 ppm + 20 ppm (T_{14})	63.03	73.90
IAA + IBA + kinetin @ 50 ppm + 50 ppm + 10 ppm (T_{15})	62.50	72.57
IAA + IBA + kinetin @ 100 ppm + 100 ppm + 10 ppm (T_{16})	61.28	77.67
IAA + IBA + kinetin @ 50 ppm +50 ppm + 20 ppm (T_{17})	65.17	72.38
IAA + IBA + Kinetin @ 100 ppm + 100 ppm + 20 ppm (T_{18})	62.77	70.57
Control (T_{19})	66.00	72.89
S.Em. ±	1.37	1.40
C.D. (P=0.05)	3.93	4.01

Table 4. Weight of curd/plant

Treatment	Weight of central curd per plant (g)	Weight of secondary curd per plant (g)
IAA@ 50 ppm (T_1)	191.67	99.87
IAA@ 100 ppm (T_2)	144.67	98.47
IBA@ 50 ppm (T_3)	179.00	117.27
IBA @ 100 ppm (T_4)	180.67	112.40
Kinetin @ 10 ppm (T_5)	134.03	104.93
Kinetin @ 20 ppm (T_6)	142.83	96.27
IAA + Kinetin @ 50 ppm +10 ppm (T_7)	160.27	100.73
IAA + Kinetin @ 50 ppm + 20 ppm (T_8)	145.53	104.93
IAA + Kinetin @ 100 ppm + 10 ppm (T_9)	167.33	94.40
IAA + Kinetin @ 100 ppm + 20 ppm (T_{10})	214.27	96.40
IBA + kinetin @ 50 ppm + 10 ppm (T_{11})	169.83	105.80
IBA + kinetin @ 50 ppm + 20 ppm (T_{12})	228.73	131.03
IBA + kinetin @ 100 ppm + 10 ppm (T_{13})	194.27	124.80
IBA + kinetin @ 100 ppm + 20 ppm (T_{14})	163.34	158.80
IAA + IBA + kinetin @ 50 ppm + 50 ppm + 10 ppm (T_{15})	135.70	135.93
IAA + IBA + kinetin @ 100 ppm + 100 ppm + 10 ppm (T_{16})	228.50	144.00
IAA + IBA + kinetin @ 50 ppm +50 ppm + 20 ppm (T_{17})	168.17	81.00
IAA + IBA + Kinetin @ 100 ppm + 100 ppm + 20 ppm (T_{18})	141.57	88.87
Control (T_{19})	110.70	71.87
S.Em. ±	15.86	3.38
C.D. (P=0.05)	45.48	9.70

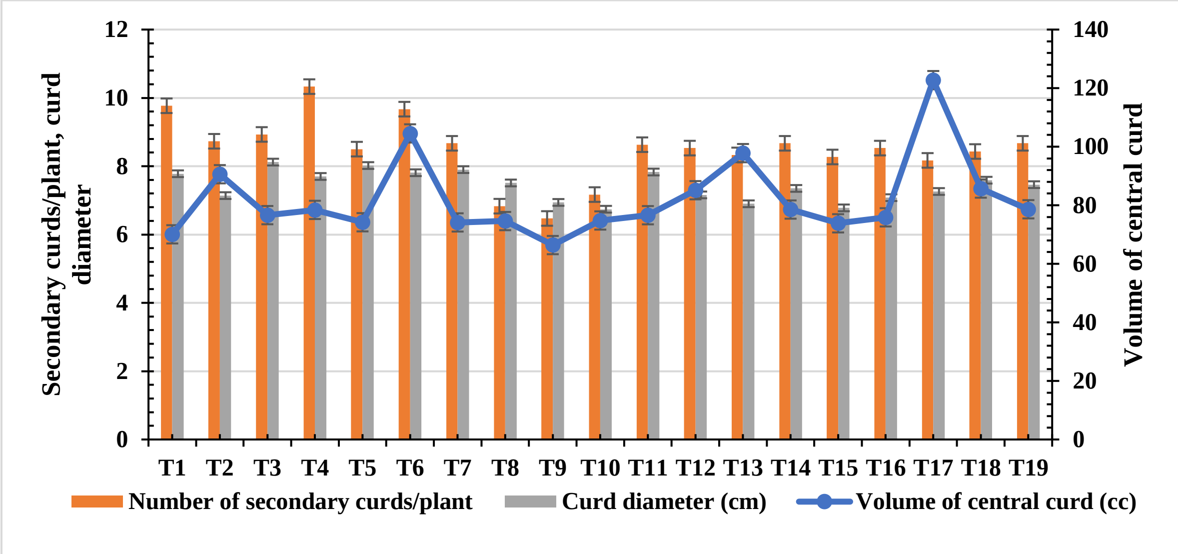

Fig. 1. Volume, secondary curds and curd diameter as influenced by PGRs

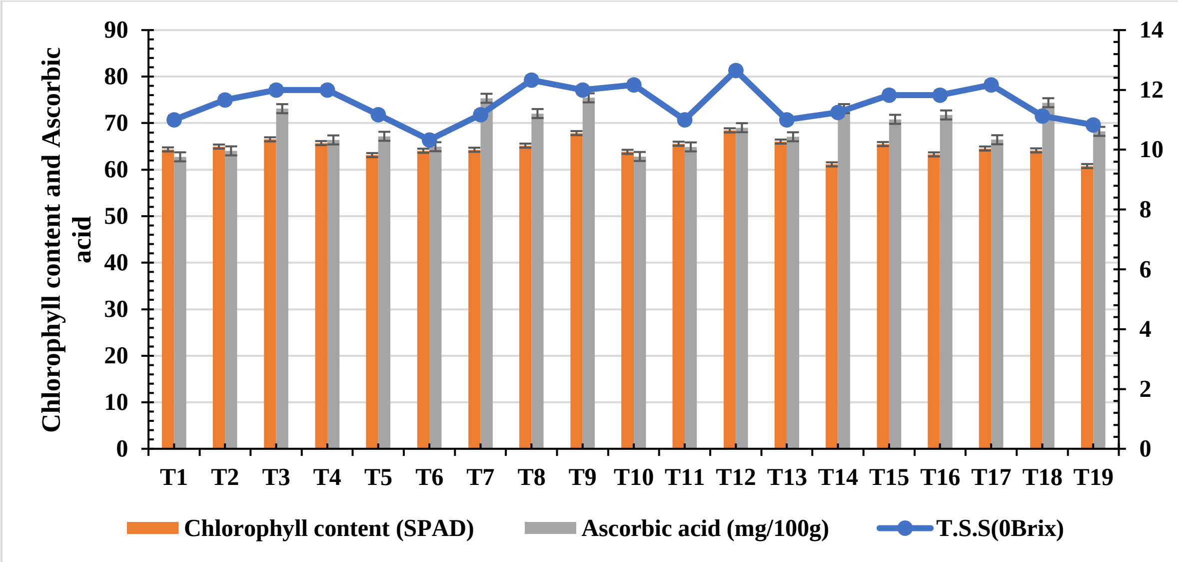

Fig. 2. Chlorophyll content, ascorbic acid, and TSS content as influenced by PGRs

Diameter of curd (cm): The diameter of curd as influenced significantly by various treatments. The maximum (8.12 cm) diameter of curd was recorded in T_3 (IBA @ 50ppm) followed by 8.02 cm in T_5 (Kinetin @ 10 ppm) and 7.90 cm in T_7 (IAA + Kinetin @ 50 ppm + 10 ppm) which was significantly higher over control. The minimum (6.74 cm) diameter of curd was found in T_{10} (IAA + Kinetin @ 100 ppm + 20 ppm).

Weight of central curd per plant (g): It is apparent from the data presented in Table 4 that the various concentrations of PGRs and their combinations significantly influenced the curd weight per plant. The maximum (228.73 g) central curd weight during the study was recorded under T_{12} (IBA + kinetin @ 50 ppm + 20 ppm) followed by 228.50 g in T_{16} (IAA + IBA + kinetin @ 100 ppm + 100 ppm + 10 ppm) and 214.07 g in T_{10} (IAA + Kinetin @ 100 ppm + 20 ppm). The lowest (110.70 g) central curd weight was found in T_{19} (control).

Weight of secondary curd per plant (g): The data presented in Table 4 revealed that, the maximum (158.80 g) weight of secondary curd per plant was found in T_{14} (IBA + kinetin @ 100 ppm + 20 ppm) which was

Table 5. Yield attributes and yield of Brocolli as influenced by PGRs

Treatment	Weight of central head per plot (kg)	Dry Weight of curd (g)	Yield per plot (kg)	Yield per hectare (Qt.)
IAA@ 50 ppm (T_1)	1.365	12.28	1.71	31.75
IAA@ 100 ppm (T_2)	1.368	12.46	1.79	33.12
IBA@ 50 ppm (T_3)	1.174	12.03	1.66	30.74
IBA @ 100 ppm (T_4)	1.184	9.90	1.67	30.92
Kinetin @ 10 ppm (T_5)	1.171	12.10	1.66	30.79
Kinetin @ 20 ppm (T_6)	1.172	11.93	1.65	30.62
IAA + Kinetin @ 50 ppm +10 ppm (T_7)	1.268	10.70	1.71	31.57
IAA + Kinetin @ 50 ppm + 20 ppm (T_8)	1.262	10.90	1.72	31.86
IAA + Kinetin @ 100 ppm + 10 ppm (T_9)	1.095	12.37	1.57	29.02
IAA + Kinetin @ 100 ppm + 20 ppm (T_{10})	1.398	10.94	1.88	34.83
IBA + kinetin @ 50 ppm + 10 ppm (T_{11})	1.444	10.13	1.91	35.31
IBA + kinetin @ 50 ppm + 20 ppm (T_{12})	1.578	11.49	2.03	37.65
IBA + kinetin @ 100 ppm + 10 ppm (T_{13})	1.456	12.41	1.91	35.41
IBA + kinetin @ 100 ppm + 20 ppm (T_{14})	1.085	12.21	1.58	29.31
IAA + IBA + kinetin @ 50 ppm + 50 ppm + 10 ppm (T_{15})	1.292	12.65	1.71	31.58
IAA + IBA + kinetin @ 100 ppm + 100 ppm + 10 ppm (T_{16})	1.237	11.66	1.69	31.31
IAA + IBA + kinetin @ 50 ppm +50 ppm + 20 ppm (T_{17})	1.176	11.75	1.58	29.28
IAA + IBA + Kinetin @ 100 ppm + 100 ppm + 20 ppm (T_{18})	1.055	11.55	1.47	27.25
Control (T_{19})	0.831	11.52	1.19	21.98
S.Em. ±	135.72	0.40	0.14	2.68
C.D. (P=0.05)	389.27	1.15	0.41	7.67

followed by 144.00 g and 135.93 g in T_{16} (IAA + IBA + kinetin @ 100 ppm + 100 ppm + 10 ppm) and T_{15} (IAA + IBA + kinetin @ 50 ppm + 50 ppm + 10 ppm) respectively. The minimum (71.87 g) weight of secondary curd was recorded in T_{19} (control).

Yield per plot (kg): The data presented in Table 5 which clearly shows that the result regarding the yield per plot was found to be significant between treatments. The maximum (2.03 kg) yield per plot was recorded in T_{12} (IBA + kinetin @ 50 ppm + 20 ppm) being statically higher than all other treatments, which was followed by 1.91 kg in T_{11} (IBA + kinetin @ 50 ppm + 10 ppm) & T_{13} (IBA + kinetin @ 100 ppm + 10 ppm) and 1.88 kg yield obtained from T_{10} (IAA + Kinetin @ 100 ppm + 20 ppm). On the other head, the lowest (1.19 kg) yield per plot was found control (T_{19}) treatment.

Yield per hectare (q): All the treatments under present experiment showed significant variation with respect to yield per hectare presented in Table 5. The results indicated that maximum (37.65 q) yield per hectare was recorded in T_{12} (IBA + kinetin @ 50 ppm + 20 ppm) treatments being statistically higher than other treatments, followed by 35.41 q and 35.31 q recorded in T_{13} (IBA + kinetin @ 100 ppm + 10 ppm) and T_{11} (IBA + kinetin @ 50 ppm + 10 ppm) respectively. The lowest (21.98 q) yield was found in T_{19} (control).

3.7 Quality Parameters

Total soluble solids (T.S.S.): The data presented in Fig. 2 clearly showed that the result regarding the T.S.S. was found to be non-significant between treatments. However, it was found that the maximum (12.65^0 Brix) content was found in T_{12} (IBA + kinetin @ 50 ppm + 20 ppm) followed by 12.33 (^{0}Brix) in T_8 (IAA + Kinetin @ 50 ppm + 20 ppm) and 12.17 (^{0}Brix) was found under T_{10} (IAA + Kinetin @ 100 ppm + 20 ppm). The minimum (10.83^{0}Brix) T.S.S was observed in T_{19} (control).

Chlorophyll content (SPAD): The representing data on the effect of PGR and their combinations on chlorophyll content in broccoli was shown in

Fig. 2 the result indicated that maximum (68.45 SPAD) content of chlorophyll was observed in T_{12} (IBA + kinetin @ 50 ppm + 20 ppm) followed by 67.85 and 66.52 SPAD was found under T_9 (IAA + Kinetin @ 100 ppm + 10 ppm) and T_3 (IBA @ 50 ppm). The minimum (60.97 SPAD) chlorophyll content was observed in T_{19} (control).

Ascorbic acid (mg/100 gm): The data presented in Fig. 2 clearly indicates that ascorbic acid content of leaves was significantly affected by the treatments. The maximum (75.44 mg) content of ascorbic acid was found in T_9 (IAA + Kinetin @ 100 ppm + 10 ppm) followed by 75.34 mg and 75.06 mg was found under T_7 (IAA + Kinetin @ 50 ppm + 10 ppm) and T_8 (IAA + Kinetin @ 50 ppm + 20 ppm) respectively. The minimum (62.76 mg) ascorbic acid content was observed in T_1 (IAA @ 50 ppm) treatments.

4. DISCUSSION

The maximum (32.80 cm) plant height was recorded in T_{12} (IBA + kinetin @ 50 ppm + 20 ppm). On the other hand, the minimum (25.90 cm) plant height was found in treatment T_{19} (control). Similar observations were also recorded by Lone *et al.*, (2005), they found that kinetin influence and stimulate the cell division of plant that improve the growth. IBA is useful in rapid growth such as shoot tissue which enhances the plant height. The cells of meristems have the capacity to divide and self-perpetuate. This result comes due to the combination of the treatments, because both growth regulators show good result in growth of plant. Similar finding was also reported by Abbasi *et al.* (2013) in cauliflower and they observed that the higher concentrations of all growth regulators were found to be more effective for improving the plant height. Ogbonna & Abrahm, (1989) also finds the similar result, that combined effect of the bio-regulators which is enhance physiological processes including cell enlargement.

4.1 Leaf Area (cm²)

The maximum (903.98 cm^2) leaf area was found in treatment T_{16} (IAA + IBA + kinetin @ 100 ppm + 100 ppm + 10 ppm). On the other hand, the minimum (632.50 cm^2) leaf area was recorded in treatment T_9 (IAA + Kinetin @ 100 ppm + 10 ppm). Similar finding has been reported by Khan *et al.*, (2002), observed that combination of growth regulators effect overall growth of plants. The different concentrations of IAA and kinetin also influence the leaf area similar finding reported by Kumar *et al.*, (1996). Present results also agree with the findings Shivankar & Rushi (2017) with respect to leaf area. IAA is important in physiological processes including cell enlargement and cell division meanwhile, IBA is useful in rapid growth such as shoot tissue, young leaves and elongation and kinetin helps to produce new leaves and chloroplasts in leaves which result in the increase in leaf area.

4.2 Plant Spread (cm)

The maximum (29.46 cm) plant spread was found in T_2 (IAA @ 100 ppm), whereas the minimum (23.39 cm) plant spread was found in T_{19} (control). Similar findings have been reported by Mir *et al.* (2020), he observed that plants treated with IAA increased plant spread. Kumar *et al.*, (1996) also found the same result on cabbage. It may be due to the auxin biosynthesis plays essential roles in many developmental processes (Pandey *et al.*, 2019).

4.3 Days Taken to Central Curd Maturity

The minimum 59.40 days taken to center curd formation were recorded in T_8 (IAA + Kinetin @ 50 ppm + 20 ppm). On the other hand, the maximum (66.00) number of days were taken for central curd formation under T_{19} (control). Similar finding was observed by Kumar *et al.*, (1996) that, the treatments NAA @ 50 ppm reduced the number of days required to start the head formation in cabbage. Chhonkar & Jha, (1963) also found that, the application of NAA to cabbage plants resulted in earlier head maturity. It may be due to auxin promote curd development in broccoli.

4.4 Days Taken to Secondary Curd Maturity

The minimum (70.57) days were taken by T_{18} (IAA + IBA + Kinetin @ 100 ppm + 100 ppm + 20 ppm) for secondary curd formation. On the other hand, the maximum (82.79) days taken to secondary curd formation found in T_7 (IAA + Kinetin @ 50 ppm + 10 ppm). Similar findings were observed by Krajnc *et al.* (2013) in cauliflower and they found that lower the concentration of plant growth hormones is more effective to formation of secondary curd formation. Pantoja-Guerra *et al.* (2023) also reported that, the application of NAA to cabbage plants resulted in earlier head maturity. The combined application of IAA + IBA + kinetin is efficient to improve the physiological processes including cell development with rapid growth such as shoot tissue, young leaves and elongation, while the kinetin helps in the leaf cell enlargement that stimulates leaf expansion.

4.5 Yield Parameter

Volume of central curd (cc): The maximum (122.73 cc) volume of central curd was observed under T_{17} (IAA + IBA + kinetin @ 50 ppm + 50 ppm + 20 ppm). The minimum (66.40 cc) volume of central head was found in T_9 (IAA + Kinetin @ 100 ppm + 10 ppm). Similar finding was observed by Pantoja-Guerra *et al.* (2023) and Abbasi *et al.* (2013), it may be due to IAA biosynthesis play essential role in many developmental processes of plant (Krajnc *et al.*, 2013), while IBA increase the ability of cell division in meristematic zones of the plants (Ahmed and Hasnain, 2014).

Number of secondary curd per plant: The maximum (10.33) number of secondary curds was found in T_4 (IBA @100 ppm) treatment. On the other hand, the minimum (6.37) number of secondary curd was found in T_9 (IAA + Kinetin @100 ppm + 10ppm). Similar observation was found by Azizi *et al.* (2015); Kumar & Ray (2000). IBA is very useful for rapid growth such as shoot tissue, young leaves and elongation of cells (Ashraf *et al.*, 2018).

Diameter of curd (cm): The maximum (8.12 cm) diameter of curd was found in T_3 (IBA @ 50 ppm), whereas, the minimum (6.74 cm) diameter of curd is found in T_{10} (IAA + Kinetin @ 100 ppm + 20 ppm). Kumar & Ray, (2000) find the similar observations for curd diameter, the IBA produced the largest curds and the highest curd yields. It means that the higher concentration of IBA gives good impact to accumulate, synthesis and improve the size of curd. It may be due the IBA promote the cell elongation, growth and development (Ashraf *et al.*, 2018).

Weight of central curd per plant: The maximum (228.73 gm) curd weight during the experiment was recorded under T_{12} (IBA + kinetin @ 50 ppm + 20 ppm). On the other hand, the minimum (110.70 gm) central curd weight was found in T_{19} (control). Lone *et al.*, (2005) finds that the combined use of IBA + kinetin also influenced the growth characters by the rapid growth such as shoot tissue, young leaves and elongation of cell. Patil *et al.*, (1987) reported the similar results in cabbage. Application of IBA gave significant results with regards to plant weight in onion (Tewari *et al.*, 2001).

Weight of secondary curd per plant: The maximum weight (158.80 gm) of secondary curd per plant was found in T_{14} (IBA + kinetin @ 100 ppm + 20 ppm). On the other hand, the minimum (71.87 gm.) secondary curds weight was recorded in T_{19} (control). Singh *et al.*, (2000) found the similar result on onion. Kumar & Ray (2000) also observed that IBA produced the tallest plants, the largest curds and the highest curd yields because IBA is useful in rapid growth such as shoot tissue, young leaves and elongation of cell.

Weight of central curd per plot (kg): The maximum (1.578 kg) yield of central curd per plot was recorded in T_{12} (IBA + kinetin @ 50 ppm + 20 ppm). Whereas, the minimum yield (0.831 kg) per plot during study was found in control (T_{19}). Patil *et al.*, (1987) in cabbage find the similar result with combination of kinetin. Krajnc *et al.* (2013) reported that Cytokinins (kinetin) gave the highest yield in cauliflower. It may be due to IBA which is useful in rapid growth such as shoot tissue, young leaves and elongation of cell and kinetin helps in the leaf cell enlargement that stimulates the plant growth and yield.

Dry Weight of curd (g): The maximum (12.65 g) dry weight was recorded in T_{15} (IAA + IBA + kinetin @ 50 ppm + 50 ppm + 10 ppm) treatment. While the minimum (9.90 g) dry weight of curd was recorded in the treatment T_4 (IBA @ 100 ppm). Similar observation was found by Shraiy & Hegazi, (2009) in pea. Singh & Saimbhi, (1968) also observed the similar findings in Chinese cabbage with different concentrations of PGR. Ashraf *et al.*, (2018) also reported the similar result. The combined use IAA + IBA helps in the accumulation of photosynthesis that show the ultimately high dry weight of curd cell development which increases the biomass resulted in higher dry weight.

Yield per plot (kg): The maximum (2.03 kg) yield per plot was recorded in T_{12} (IBA + kinetin @ 50 ppm + 20 ppm). The lowest yield (1.19 kg) per plot during study was found in T_{19} (control). Above findings also indicate the same result with the application of these treatments by Arora *et al.* (1989); Abbasi *et al.* (2013) and Khan *et al.* (2002). Similar result also confirmed by Singh *et al.* (2011) in sprouting broccoli.

Yield per hectare (q): The maximum (37.65 q) yield per hectare was recorded in T_{12} (IBA + kinetin @ 50 ppm + 20 ppm) treatments. The lowest yield (21.98 q) was found in control (T_{19}) during the investigation. The similar finding reported by Ahmed and Hasnain (2014); Parvin & Haque (2016) in cabbage.

4.6 Quality Parameters

Total soluble solids (^{0}Brix): The maximum (12.65 ^{0}Brix) content of T.S.S. was found in T_{12} (IBA + kinetin @ 50 ppm + 20 ppm). On the other hand, the minimum (10.83^{0}Brix) T.S.S. was observed in T_{19} (control) treatment. The data showed, there is no significant effect of any treatment on the total soluble solids.

Chlorophyll content (SPAD): The maximum (68.45 SPAD content of chlorophyll was found in T_{12} (IBA + kinetin @ 50 ppm + 20 ppm) treatment. The minimum 60.97 SPAD chlorophyll content was observed in T_{19} (control) treatments. Tryptophan is the precursor of auxin, which is essential for normal cell division, helps in the formation of total chlorophyll in the leaf.

Ascorbic acid (mg/100g): Maximum (75.44 mg) content of ascorbic acid was found in T_9 (IAA + Kinetin @ 100 ppm + 10 ppm) treatment, whereas the minimum ascorbic acid (62.76 mg) content was observed inT_1 (IAA @ 50 ppm). Similar finding was recorded by Khalili *et al.*, (2008) they reported that the kinetin also affects ascorbic acid content in broccoli. Singh *et al.*, (2005) in pointed gourd and Abbasi *et al.* (2013) in sprouting broccoli also observed that application of kinetin increases the ascorbic acid content.

5. CONCLUSION

Based on above result and discussion it can be concluded that the significantly higher plant height, central curd weight, yield/plot, yield/ha total soluble salts, and chlorophyll content was registered with the application of IBA + kinetin @ 50 ppm + 20 ppm (T_{12}). And also, the highest plant spread, was obtained under IAA @ 100 ppm (T_2), and the highest leaf area was registered under IAA + IBA + kinetin @ 100 ppm + 100 ppm + 10 ppm (T_{16}). The significantly lower plant parameters were registered under control (T_{19}). The cultivar Palam Samridhi gives better response with the application of IBA + kinetin @ 50 ppm + 20 ppm (T_{12}) in terms of yield and quality parameters.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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