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Influence of cytokinins on shoot growth, yield, quality and economics of broccoli (*Brassica oleracea* var. *italica*) under Balaghat region

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ABSTRACT

A field experiment was conducted during Rabi 2024–25 at Sardar Patel University, Balaghat (M.P.) to evaluate the effect of cytokinins on broccoli cv. Matsuri. Nine treatments comprising control, three levels of BAP, three levels of kinetin and two combined treatments were tested in a randomized block design with three replications. Growth, phenological, yield, quality and economic parameters were recorded and analyzed. The combined application of BAP 20 ppm + kinetin 20 ppm produced the best response for almost all characters, including plant height, leaf number, leaf area, stem diameter, plant spread, early curd initiation and maturity, curd size, curd weight, marketable yield, quality attributes and benefit–cost ratio. The treatment recorded 70 cm plant height, 28.5 leaves plant⁻¹, 190 cm² leaf area, 0.78 cm stem diameter, 195 q ha⁻¹ yield, 105 mg 100 g⁻¹ ascorbic acid and 2.52 B:C ratio. The study indicates that balanced cytokinin application can improve broccoli productivity and profitability under Balaghat conditions.

Keywords: BAP, Broccoli, Cytokinin, Kinetin, Quality, Yield, Economics

Introduction

Broccoli (*Brassica oleracea* var. *italica*) is an important cole crop cultivated for its immature green inflorescence. It has gained increasing importance in India because of its nutritional richness, high market value and rising consumer preference for health-promoting vegetables. Broccoli curds contain appreciable quantities of vitamin C, vitamin K, dietary fibre, minerals and bioactive compounds such as glucosinolates and phenolic antioxidants. These nutritional qualities make broccoli an important vegetable for fresh consumption and for diversified vegetable production systems (FAO, 2022; Gapper *et al.*, 2005) [1, 2].

The productivity of broccoli depends on the development of a vigorous vegetative frame before curd initiation. Adequate plant height, leaf number, leaf area, stem diameter and plant spread determine the photosynthetic capacity of the crop and influence the supply of assimilates to the developing curd. The curd is a strong sink, and its final size, compactness and weight depend on the balance between vegetative growth and reproductive development. Any practice that improves canopy development and maintains active leaves during curd formation can therefore enhance yield and quality.

Plant growth regulators are widely recognized as tools for modifying growth, development and productivity in horticultural crops. Among these, cytokinins are particularly important because they promote cell division, shoot initiation, leaf expansion, chloroplast development, nutrient mobilization and delay of senescence. Skoog *et al.* (1957) [3] established the role of cytokinins in cell division and organ formation, while later studies showed their influence on chlorophyll retention and senescence regulation (Rushing, 1990; Gapper *et al.*, 2005) [4, 2]. These functions are highly relevant to broccoli because prolonged leaf activity supports curd filling and quality improvement.

Benzylaminopurine (BAP) and kinetin are two commonly used cytokinins in crop physiology and horticulture. BAP has been reported to stimulate shoot growth and leaf development strongly, while kinetin is associated with chlorophyll retention, metabolic activity and delayed senescence. In *Brassica* crops, cytokinins have been associated with improved vegetative growth, enhanced curd or head development, better harvest index and improved quality attributes (Bisht *et al.*, 2018; Biswal and Rout, 2020) [5, 6]. Singh and Rana (2009–2010) [7] reported improvement in growth, yield and quality of sprouting broccoli with growth-regulator treatment involving kinetin, suggesting the potential of cytokinin-based interventions.

The present study was planned to assess the influence of different concentrations of BAP and kinetin, applied individually and in combination, on growth, yield, quality and economics of broccoli cv. Matsuri. The study also aimed to identify the most profitable treatment based on yield improvement and benefit–cost ratio

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tio. The results are discussed in relation to cytokinin physiology and earlier suggested readings on *Brassica* and vegetable crops.

Materials and Methods

The experiment was conducted during Rabi 2024–25 at the Research Farm, Department of Horticulture, School of Agriculture Science, Technology & Research, Sardar Patel University, Balaghat (M.P.). The site represents the Eastern plateau and hills region and has a climate suitable for winter vegetable cultivation. The soil was sandy loam, slightly alkaline, well drained and medium in fertility.

The crop used was broccoli cv. Matsuri. The experiment consisted of nine treatments: T_1 control, T_2 BAP 10 ppm, T_3 BAP 20 ppm, T_4 BAP 30 ppm, T_5 kinetin 10 ppm, T_6 kinetin 20 ppm, T_7 kinetin 30 ppm, T_8 BAP 15 ppm + kinetin 15 ppm and T_9 BAP 20 ppm + kinetin 20 ppm. The experiment was laid out in randomized block design with three replications.

Recommended agronomic practices were followed uniformly. Observations were recorded on plant height, number of leaves, leaf area, stem diameter, curd initiation, curd maturity, plant spread, curd diameter, curd depth, curd weight, marketable curd weight, total yield per plant, yield per hectare, harvest index, TSS, ascorbic acid, dry matter and economics. Data were analyzed statistically using the method of analysis of variance for randomized block design (Gomez *et al.*, 1984) [8].

Results and Discussion

Plant height showed a progressive and significant improvement with cytokinin application at 30, 45 and 60 DAS. The control recorded only 55 cm height at 60 DAS, whereas T_9 reached 70 cm and T_8 reached 68 cm. This indicates that combined BAP and kinetin enhanced cell division and cell elongation during vegetative growth. The response agrees with the classical role of cytokinins in shoot development reported by Skoog *et al.* (1957) [3] and with later suggested readings describing cytokinin-mediated promotion of shoot vigour in *Brassica* crops (Bisht *et al.*, 2018; Biswal *et al.*, 2020) [5, 6]. Leaf number was also improved by cytokinin treatments. At 60 DAS, the number of leaves increased from 20 in the control to 28.5 in T_9 . More leaves provide greater photosynthetic area and create a stronger source for carbohydrate production. BAP treatments were generally superior to kinetin at comparable levels, but the combined treatments were best, suggesting that the two cytokinins complemented each other in stimulating leaf initiation and expansion. Similar increases in leaf production and shoot growth under cytokinin influence have been described by Murthy *et al.* (2012) [9] and Sharma *et al.* (2018) [10].

Leaf area followed the same pattern as plant height and leaf number. T_9 recorded the maximum leaf area of 190 cm² at 60 DAS, while the control recorded 140 cm². Larger leaf area indicates better canopy development and higher potential for light interception. Cytokinins are known to delay senescence and maintain chlorophyll content, which may explain the higher leaf expansion and sustained vegetative activity. Rushing (1990) [4] and Gapper *et al.* (2005) [2] reported that cytokinins help maintain chlorophyll and reduce senescence in broccoli tissues, supporting the present findings.

Stem diameter increased from 0.55 cm in the control to 0.78 cm in T_9 . A thicker stem reflects better plant vigour, vascular development and mechanical support. In broccoli, strong stems are essential because large curds require adequate support and efficient transport of water, nutrients and assimilates. The improvement in stem diameter under cytokinin treatment may be due to enhanced cambial activity and cell division, which have been associated with cytokinin action in vegetable crops (Biswal *et al.*, 2020) [6].

Days to 50% curd initiation and maturity were reduced by cytokinin application. The control required 65 days for 50% curd initiation and

85 days for 50% maturity, while T_9 required only 58 and 77 days, respectively. Earliness is commercially valuable because it allows timely market entry and better crop scheduling. The reduction in duration may be attributed to improved physiological activity, faster assimilate accumulation and balanced hormonal regulation. Singh and Rana (2009–2010) [7] also suggested that growth-regulator treatments can improve growth and maturity behaviour in sprouting broccoli.

Plant spread increased from 40 cm in the control to 50 cm in T_9 . Wider plant spread reflects better canopy architecture and lateral growth. This may have improved interception of solar radiation and promoted curd development. Cytokinins are known to reduce apical dominance and support lateral bud activity, which helps explain the wider spread observed under combined treatments. The findings are consistent with the suggested reading of Bisht *et al.* (2018) [5], who emphasized the role of cytokinins in improving *Brassica* growth and productivity.

Curd diameter, curd depth and curd weight were markedly improved by cytokinin application. T_9 produced the highest curd diameter (10.8 cm), curd depth (7.2 cm) and curd weight (0.62 kg plant⁻¹), whereas the control produced 8.5 cm, 5.5 cm and 0.45 kg plant⁻¹, respectively. These results indicate that cytokinins enhanced cell division and expansion in curd tissues. The better vegetative growth recorded under T_9 also increased the supply of photosynthates to the curd, resulting in larger and heavier heads. Similar effects of growth regulators on broccoli yield attributes have been reported by Sharma *et al.* (2018) [10] and Singh *et al.* (2021) [11].

Marketable curd weight and total yield per plant showed clear improvement under cytokinin treatments. Marketable curd weight increased from 0.35 kg plant⁻¹ in the control to 0.55 kg plant⁻¹ in T_9 . Total yield per plant increased from 0.45 kg to 0.68 kg. This improvement is important because marketable yield determines grower income. The higher marketable curd weight under combined treatments may be due to better curd compactness, enhanced assimilate partitioning and delayed senescence. Rai *et al.* (2017) [12] reported that cytokinin-mediated improvement in *Brassica* productivity is associated with improved source–sink relationship.

Yield per hectare increased substantially with cytokinin application. T_9 recorded 195 q ha⁻¹ followed by T_8 with 190 q ha⁻¹, while the control yielded 145 q ha⁻¹. The increase in yield per hectare was the cumulative result of greater vegetative vigour, larger leaf area, stronger stem, early curd development and improved curd weight. Harvest index also increased from 45% in the control to 57% in T_9 , showing more efficient conversion of total biomass into economic yield. This confirms that combined cytokinin application improved not only total growth but also productive partitioning.

Quality parameters improved significantly under cytokinin treatments. TSS increased from 6.5°Brix in the control to 7.6°Brix in T_9 . Higher TSS indicates greater soluble sugar accumulation and better eating quality. Ascorbic acid increased from 85 mg 100 g⁻¹ to 105 mg 100 g⁻¹, showing improvement in nutritional value. Dry matter increased from 8.5% to 10.0%, indicating denser curd texture and possibly better storability. These changes may be associated with greater photosynthetic efficiency, delayed senescence and improved translocation of assimilates. Gapper *et al.* (2005) [2] and Rushing (1990) [4] support the role of cytokinins in maintaining broccoli tissue quality.

Economic analysis showed that cytokinin application was financially beneficial. Although the cost of production increased slightly because of growth-regulator application, the increase in yield and marketable quality more than compensated for the added cost. T_9 recorded the highest gross return of ₹3,90,000 ha⁻¹, net return of ₹2,35,000 ha⁻¹ and B:C ratio of 2.52. T_8 was the next best treatment with a B:C ratio of 2.47. Therefore, the combined application of BAP and kinetin was economically superior to individual applications and the control.

Table 1a. Effect of cytokinin treatments on all growth, yield and quality observations

Treatment	Plant height 30 DAS	Plant height 45 DAS	Plant height 60 DAS	Leaves 30 DAS	Leaves 45 DAS	Leaves 60 DAS	Leaf area 30 DAS	Leaf area 45 DAS	Leaf area 60 DAS	Stem diameter
<i>T</i> ₁ Control	15	35	55	8	14	20	45	90	140	0.55
<i>T</i> ₂ BAP 10 ppm	16.5	38	60	9	16	23	50	100	155	0.62
<i>T</i> ₃ BAP 20 ppm	17.5	40.5	64	9.5	17.5	25	55	110	170	0.68
<i>T</i> ₄ BAP 30 ppm	18	42	66	10	18.5	26.5	58	115	180	0.72
<i>T</i> ₅ Kinetin 10 ppm	16	37	59	8.5	15.5	22	48	95	160	0.6
<i>T</i> ₆ Kinetin 20 ppm	17	39.5	62.5	9.2	17	24	53	105	168	0.65
<i>T</i> ₇ Kinetin 30 ppm	17.8	41	65	9.8	18	25.5	57	112	175	0.7
<i>T</i> ₈ BAP15+Kin15	18.5	43	68	10.2	19	27	60	120	185	0.75
<i>T</i> ₉ BAP20+Kin20	19	44.5	70	10.5	20	28.5	62	125	190	0.78
S.Em ±	0.8	1.5	2.2	0.4	0.7	1.0	3	6	8	0.03
CD (<i>P</i> = 0.05)	2.3	4.3	6.3	1.2	2.0	2.9	9	18	24	0.09

Table 1b. Effect of cytokinin treatments on all growth, yield and quality observations

Treatment	Days to 50% Curd Initiation	Days to 50% Curd Maturity	Plant Spread (cm)	Curd dia	Curd depth	Curd wt	Market wt	Yield/plant	Yield q/ha	HI	TSS	Ascorbic	Dry matter
<i>T</i> ₁ Control	65	85	40	8.5	5.5	0.45	0.35	0.45	145	45	6.5	85	8.5
<i>T</i> ₂ BAP 10 ppm	63	82	43	9.2	6	0.5	0.4	0.52	160	48	6.8	90	9.0
<i>T</i> ₃ BAP 20 ppm	61	80	45	9.8	6.5	0.55	0.45	0.58	175	51	7.0	95	9.3
<i>T</i> ₄ BAP 30 ppm	60	79	47	10.2	6.8	0.58	0.48	0.62	182	53	7.2	98	9.5
<i>T</i> ₅ Kinetin 10 ppm	64	83	42	8.9	6.1	0.52	0.38	0.5	155	47	6.7	88	8.8
<i>T</i> ₆ Kinetin 20 ppm	62	81	44	9.5	6.4	0.55	0.43	0.56	170	50	6.9	93	9.1
<i>T</i> ₇ Kinetin 30 ppm	61	80	46	9.9	6.7	0.57	0.46	0.6	178	52	7.1	96	9.4
<i>T</i> ₈ BAP15+Kin15	59	78	48	10.5	7	0.6	0.52	0.65	190	55	7.4	102	9.8
<i>T</i> ₉ BAP20+Kin20	58	77	50	10.8	7.2	0.62	0.55	0.68	195	57	7.6	105	10.0
S.Em ±	1	1.2	1.5	0.3	0.2	0.02	0.02	0.02	5	1.5	0.2	2.5	0.3
CD (<i>P</i> = 0.05)	3	3.5	4.5	0.9	0.6	0.06	0.06	0.07	14.5	4.5	0.6	7.5	0.9

Table 2. Economics of broccoli cultivation as influenced by cytokinin treatments

Treatment	Cost of production (₹ ha ⁻¹)	Gross return (₹ ha ⁻¹)	Net return (₹ ha ⁻¹)	B:C ratio
<i>T</i> ₁ Control	1,50,000	2,90,000	1,40,000	1.93
<i>T</i> ₂ BAP 10 ppm	1,51,000	3,20,000	1,69,000	2.12
<i>T</i> ₃ BAP 20 ppm	1,52,000	3,50,000	1,98,000	2.3
<i>T</i> ₄ BAP 30 ppm	1,53,000	3,64,000	2,11,000	2.38
<i>T</i> ₅ Kinetin 10 ppm	1,51,000	3,10,000	1,59,000	2.05
<i>T</i> ₆ Kinetin 20 ppm	1,52,000	3,40,000	1,88,000	2.24
<i>T</i> ₇ Kinetin 30 ppm	1,53,000	3,56,000	2,03,000	2.33
<i>T</i> ₈ BAP15+Kin15	1,54,000	3,80,000	2,26,000	2.47
<i>T</i> ₉ BAP20+Kin20	1,55,000	3,90,000	2,35,000	2.52

Conclusion

The present investigation demonstrated that cytokinin application significantly improved the growth, yield, quality and profitability of broccoli cv. Matsuri under Balaghat conditions. Among all treatments, the combined application of BAP 20 ppm + kinetin 20 ppm was the most effective treatment. It produced maximum plant height, number of leaves, leaf area, stem diameter and plant spread, indicating superior vegetative growth and canopy development.

The same treatment also advanced curd initiation and maturity, which is important for early harvesting and improved crop planning. Yield attributes such as curd diameter, curd depth, curd weight, marketable curd weight, total yield per plant and yield per hectare were highest under T_9 . The increase in harvest index confirmed that cytokinin application improved the efficiency of biomass conversion into marketable curd yield.

Quality improvement was another important outcome. T_9 recorded maximum TSS, ascorbic acid and dry matter content, indicating better taste, nutritional value and curd density. The treatment also produced the highest gross return, net return and benefit–cost ratio, confirming its economic superiority.

On the basis of the present study, BAP 20 ppm + kinetin 20 ppm may be considered the best treatment for enhancing broccoli growth, yield, quality and profitability under similar agro-climatic conditions.

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