



RESEARCH ARTICLE

Varietal performance and economic viability of cucumber under different plant growth regulator and spacing regimes in a polyhouse

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Abstract

The present study was conducted at the Research Farm of the Department of Vegetable Science, Chaudhary Charan Singh Haryana Agricultural University, Hisar. Two varieties of cucumber (PPC-6 and PK-1), two spacings (60 × 60 cm and 45 × 45 cm) and three PGRs with their combinations were used as experimental material and evaluated according to the objectives of the study during November-March of 2022–23 and 2023–24. The study involved determining growth parameters, yield parameters and economic returns of polyhouse cucumber. The statistical analysis was performed using a split-plot design in which varieties as main factor, spacing as sub factor and plant growth regulators as sub-sub factor. The study confirmed the effects as significant at the 5 % level. Among the two cucumber varieties studied, Pusa Parthenocarpic Cucumber-6 (PPC-6) outperformed Punjab Kheera-1 (PK-1) in all economic parameters. The highest gross return (Rs. 1716011 ha⁻¹), net return (Rs. 1248859 ha⁻¹) and benefit-cost (B:C) ratio (2.67) were recorded in PPC-6 with gibberellic acid (GA₃) at 10 ppm + naphthalene acetic acid (NAA) 25 ppm under closer spacing (60 × 45 cm) during 2022–23 and 2023–24, respectively. Treatments involving PGR combinations, particularly with ethrel, also showed high returns. In contrast, the lowest economic returns were observed in the PK-1 control treatment under wider spacing (60 × 60 cm) in 2022–23 and 2023–24, respectively. Overall, PPC-6 under wider spacing increased yield per plant, whereas closer spacing increased yield per hectare.

Keywords: benefit; cost ratio; ethrel; gibberellic acid; gross return; naphthalene acetic acid; net return

Introduction

Cucumber (*Cucumis sativus* L.), an annual vine of the family Cucurbitaceae, is one of the most widely grown vegetable crops worldwide. Its global demand has significantly increased in recent years, with cultivation occurring in open fields and protected environments such as greenhouses. Being a highly cross-pollinated crop, cucumber thrives in conditions of high humidity, light intensity, temperature, moisture and nutrient availability but is susceptible to frost (1). Protected cultivation offers a viable solution for year-round production, enabling higher yields, better pest management and increased planting density, which collectively improve economic returns (2).

China leads global cucumber production, contributing 51 % of the world's total output. Other key producers include Iran, Turkey, the USA, Ukraine, Spain, Mexico, Egypt, Uzbekistan, India and Russia. In India, cucumber is cultivated over 138.54 thousand hectares with a production of 1989.88 thousand metric tonnes and an average productivity of 15.16 t ha⁻¹ (3). Polyhouse cultivation in India significantly enhances cucumber yield, averaging 451.42 q acre⁻¹ compared to 210.78 q acre⁻¹ in open-field conditions. Major cucumber producing states using polyhouse

technology include West Bengal, Tamil Nadu, Telangana, Haryana, Uttar Pradesh, Punjab, Karnataka, Gujarat and Madhya Pradesh. In Haryana, cucumber is grown on 10.63 thousand hectares, producing 225.35 thousand metric tonnes under open field and protected cultivation (4). Notably, 65.9 % of Haryana's protected cultivation area (approximately 1236.2 ha) is under cucumber cultivation.

Plant growth regulators (PGRs) are effective tools to further improve productivity by modifying sex expression toward femaleness, thus increasing fruit set, fruit weight and yield (5, 6). When applied at the two- or four-leaf stage, PGRs can shift flower sex ratio and enhance overall crop performance. Their environmentally safe use also contributes to sustainable intensification (7, 8). Optimising plant density and canopy management through proper spacing, pruning and training significantly boosts yield per unit area (9, 10). Optimising plant geometry, along with the integration of improved cucumber cultivars and appropriate plant growth regulators under protected cultivation, will significantly enhance fruit quality, increase marketable yield and reduce pest and disease incidence, thereby improving overall economic returns and sustainability.

Materials and Methods

The present research was conducted within the controlled conditions of a polyhouse at the Research Farm of the Department of Vegetable Science, Chaudhary Charan Singh Haryana Agricultural University, Hisar, during the years 2022–23 and 2023–24, respectively. The soil of the experimental site includes clay (13.50 %), silt (16.40 %), sand (70.10 %), pH (7.30), electrical conductivity (0.24 Ds m⁻¹ at 25 °C), organic carbon (0.45 %), available nitrogen 118.50 kg ha⁻¹, available phosphorus 13.30 kg ha⁻¹, available potassium 210.8 kg ha⁻¹. The treatments comprised 40 combinations incorporating two varieties viz. Pusa Parthenocarpic Cucumber-6 (PPC-6); Punjab Kheera-1 (PK-1), two spacing (60 × 60 cm and 60 × 45 cm) and 3 plant growth regulators [Naphthalene acetic acid (NAA), gibberellic acid (GA₃), ethephon (etheph)] and their combinations. The plant growth regulators include NAA at 25 ppm, NAA at 50 ppm, GA₃ at 10 ppm, GA₃ at 20 ppm, etheph at 100 ppm, etheph at 200 ppm, etheph at 100 parts per million (ppm) + GA₃ at 10 ppm, NAA at 25 ppm + GA₃ at 10 ppm, NAA at 25 ppm + etheph at 100 ppm and control (water spray). The PGRs were applied at two and four true leaf stage of cucumber crop. The experiment was laid out in a split-plot design (SPD) with 3 replications in which varieties are taken as main plot, spacings as sub plot and plant growth regulators as sub-sub plot. Cucumber cultivar was sown during November–March month in 2022–23 and November–March month in 2023–24. Supplementary Table 1 details the cost of various operations applied during the experiment.

The economics of the treatment is the most important consideration for making any recommendation to the farmers for its wide adoption. The economics of different cultural practices, inputs, labour cost and returns for parthenocarpic cucumber under each treatment combination was worked out to find the most effective and economical treatment.

Marketable fruit yield per plant

Marketable fruit yield per plant (kg) was calculated by collecting data on the weight of marketable fruits and then calculating the average yield.

$$Y_p = W_f \times N_f$$

Where:

Y_p = Marketable fruit yield per plant (kg plant⁻¹)

W_f = Average fruit weight (kg fruit⁻¹)

N_f = Number of marketable fruits per plant

Gross returns

It was calculated by multiplying the quantity of each product by its market price and then summing the values for all products

$$G_R = Y_h \times P$$

Where:

G_R = Gross returns (Rs. ha⁻¹)

Y_h = Fruit yield (kg ha⁻¹)

P = Market price (Rs. kg⁻¹)

Net returns

It was calculated by subtracting the total cost of production from total income obtained from crop.

$$NR = GR - C$$

Where:

N_R = Net returns (Rs. ha⁻¹)

G_R = Gross returns (Rs. ha⁻¹)

C = Total cost of cultivation (Rs. ha⁻¹)

Benefit-cost ratio (B:C)

Treatment wise B:C was calculated to ascertain economic viability of the treatment using the following formula:

$$B:C = G_R/C$$

Where:

G_R = Gross returns

C = Total cost of cultivation

Statistical analysis

The experimental data were analysed using analysis of variance (ANOVA) appropriate for a split-plot design. Treatment means were compared using the least significant difference (LSD) test (or critical difference, CD) at a 5 % level of significance ($p = 0.05$). Statistical analysis was performed using SAS standard statistical software.

Results

The results of the experiment related to growth and yield parameters during 2022–23 and 2023–24 as shown in Table 1. In 2022–23, PPC-6 recorded a mean yield of 699.92 q ha⁻¹, which was significantly greater than 641.51 q ha⁻¹ in PK-1. Similarly, in 2023–24, PPC-6 produced 727.92 q ha⁻¹, while PK-1 yielded 668.06 q ha⁻¹. Closer spacing (60 × 45 cm) significantly increased the marketable yield per hectare compared to wider spacing (60 × 60 cm). In 2022–23, closer spacing recorded 758.23 q ha⁻¹, significantly higher than 583.20 q ha⁻¹ under wider spacing. Likewise, in 2023–24, the yield under closer spacing was 789.05 q ha⁻¹ compared to 606.92 q ha⁻¹ in the wider configuration. This was attributed to higher plant population density, resulting in greater cumulative yield despite slightly lower per-plant yield. The highest yield was obtained with NAA 25 ppm + GA₃ 10 ppm, which produced 705.24 q ha⁻¹ in 2022–23 and 729.46 q ha⁻¹ in 2023–24. These were statistically at par with yields from NAA 25 ppm + etheph 100 ppm (700.37 and 727.59 q ha⁻¹) and etheph 100 ppm + GA₃ 10 ppm (694.75 and 722.77 q ha⁻¹), indicating comparable effectiveness of these combined treatments in enhancing yield. On the other hand, the lowest yields were recorded in the control (water spray) with 584.67 q ha⁻¹ and 621.16 q ha⁻¹ across the respective years. The interactions between varieties, spacing and PGRs were found to be non-significant in both years. Table 2 and Fig. 1 represent the gross return, net return and B: C ratio of cucumber under polyhouse.

Gross return

Gross return is a critical measure of the total income generated from crop sales without accounting for production costs. In this study, gross return showed notable variation across treatments, influenced by the cucumber cultivar, spacing and the type and combination of PGRs used. The maximum gross return during both years was recorded with the treatment PPC-6 + S₂ (closer spacing) + GA₃ at 10 ppm + NAA at 25 ppm, amounting to Rs. 1653140.18 in 2022–23 and increasing further to Rs. 1716011.25 in 2023–24. This indicated that the synergistic effect of combined PGR application under closer spacing (S₂) led to increased number

Table 1. Effect of plant growth regulators and spacing on marketable fruit yield (q ha⁻¹) of cucumber under polyhouse

Plant growth regulators	2022-23					2023-2024				
	Pusa Parthenocarpic Cucumber-6		Punjab Kheera-1		PGRs mean	Pusa Parthenocarpic Cucumber-6		Punjab Kheera-1		PGRs mean
	Spacing (cm)		Spacing (cm)			Spacing (cm)		Spacing (cm)		
	60 × 60	60 × 45	60 × 60	60 × 45		60 × 60	60 × 45	60 × 60	60 × 45	
NAA at 25 ppm	608.81	787.56	552.65	723.65	668.17	632.59	817.79	575.41	752.41	694.55
NAA at 50 ppm	613.18	793.28	558.21	731.86	674.13	636.79	823.39	579.94	759.62	699.94
GA3 at 10 ppm	620.40	800.17	564.46	737.53	680.64	643.96	831.39	586.29	766.89	707.13
GA3 at 20 ppm	625.66	806.21	569.07	745.68	686.66	648.93	836.92	591.19	775.07	713.03
Ethrel at 100 ppm	592.20	769.37	541.33	710.29	653.30	614.87	799.31	562.20	738.54	678.73
Ethrel at 200 ppm	598.86	776.55	546.17	715.17	659.19	622.02	806.47	568.10	745.42	685.50
Ethrel at 100 ppm + GA ₃ at 10 ppm	631.80	817.20	575.10	754.90	694.75	657.73	850.26	598.43	784.66	722.77
NAA at 25 ppm + GA ₃ at 10 ppm	640.96	826.57	583.03	770.40	705.24	663.10	858.00	605.44	791.29	729.46
NAA at 25 ppm + ethrel at 100 ppm	637.32	822.70	577.80	763.66	700.37	660.87	854.20	603.36	791.92	727.59
Control (water spray)	538.92	690.58	487.97	621.21	584.67	571.02	728.69	516.16	668.77	621.16
Mean of varieties × spacing's	610.81	789.02	555.58	727.43		635.19	820.64	578.65	757.46	
Mean of spacing's	583.20		758.23			606.92		789.05		
Mean of varieties	699.92		641.51			727.92		668.06		
Factors										
	CD at 5 %		SE (m)			Factors		CD at 5 %		SE (m)
Varieties	13.14		2.13			Varieties		23.08		3.74
Spacing's	7.64		2.71			spacing's		9.14		3.25
Varieties × spacing's	NS		3.83			Varieties × spacing's		NS		4.59
PGRs	17.07		6.06			PGRs		20.44		7.26
Varieties × PGRs	NS		8.57			Varieties × PGRs		NS		10.26
spacing's × PGRs	NS		8.57			spacing's × PGRs		NS		10.26
Varieties × spacing's × PGRs	NS		12.12			Varieties × spacing's × PGRs		40.88		14.51

NAA: Naphthalene acetic acid; GA₃: Gibberellic acid; Ethrel: Ethephon; ppm: Parts per million; NS: Non-significant; SE(m): Standard error of mean; CD at 5 %: Critical difference at 5 % level of significance; PGRs: Plant growth regulators.

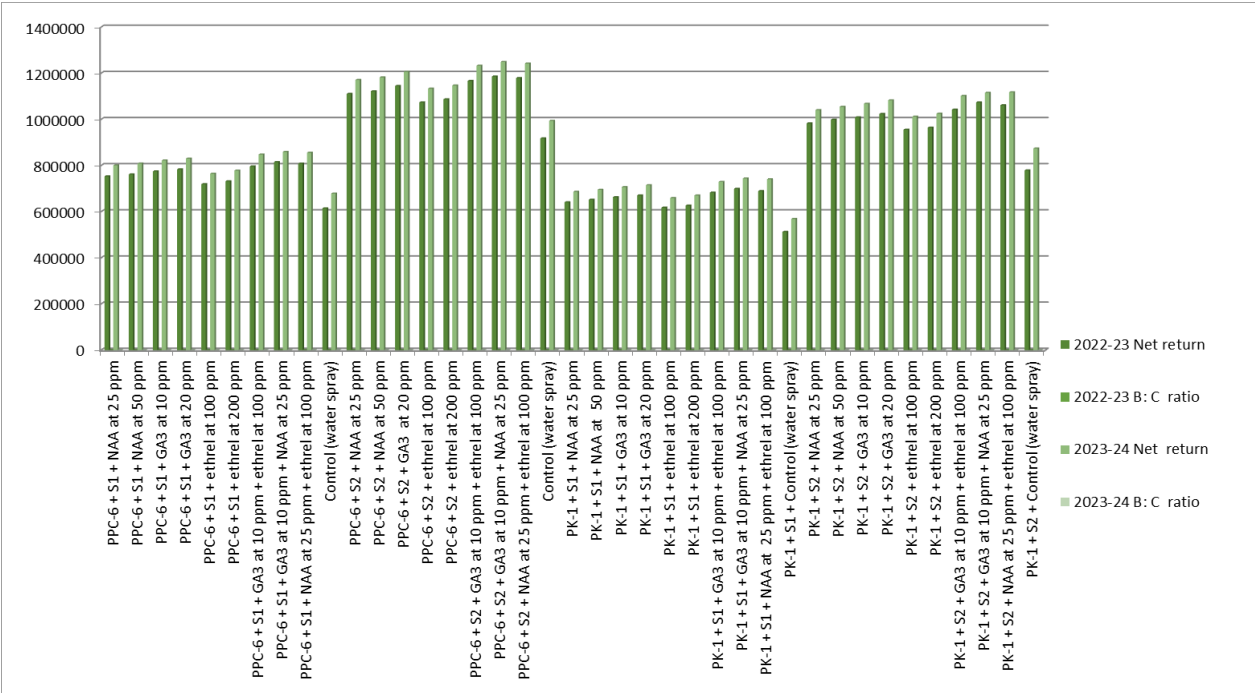


Fig. 1. Effect of varieties, spacing and plant growth regulators on net return and B:C ratio of polyhouse cucumber.

Table 2. Effect of plant growth regulators and spacing on economics or benefit cost ratio on fruit yield of cucumber during 2022–23 and 2023–24 under polyhouse

Treatments	2022–23				2023–24			
	Total cost of cultivation	Gross return	Net return	B: C ratio	Total cost of cultivation	Gross return	Net return	B: C ratio
PPC-6 + S ₁ + NAA at 25 ppm	464690.44	1217615.44	752925.00	1.62	464690.44	1265188.84	800498.40	1.72
PPC-6 + S ₁ + NAA at 50 ppm	464916.68	1226365.24	761448.56	1.64	464916.68	1273589.40	808672.72	1.74
PPC-6 + S ₁ + GA ₃ at 10 ppm	466126.20	1240794.05	774667.85	1.66	466126.20	1287921.42	821795.22	1.76
PPC-6 + S ₁ + GA ₃ at 20 ppm	467788.20	1251322.41	783534.21	1.67	467788.20	1297869.91	830081.71	1.77
PPC-6 + S ₁ + ethrel at 100 ppm	465246.28	1184398.93	719152.65	1.55	465246.28	1229745.66	764499.38	1.64
PPC-6 + S ₁ + ethrel at 200 ppm	466046.28	1197711.28	731665.00	1.57	466046.28	1244048.85	778002.57	1.67
PPC-6 + S ₁ + GA ₃ at 10 ppm + ethrel at 100 ppm	467708.28	1263600.00	795891.72	1.70	467708.28	1315467.56	847759.28	1.81
PPC-6 + S ₁ + GA ₃ at 10 ppm + NAA at 25 ppm	467152.44	1281931.69	814779.25	1.74	467152.44	1326203.91	859051.47	1.84
PPC-6 + S ₁ + NAA at 25 ppm + ethrel at 100 ppm	466272.52	1274644.11	808371.59	1.73	466272.52	1321738.72	855466.20	1.83
Control (water spray)	463664.20	1077848.82	614184.62	1.32	463664.20	1142043.71	678379.51	1.46
PPC-6 + S ₂ + NAA at 25 ppm	464690.44	1575126.92	1110436.48	2.39	464690.44	1635585.71	1170895.27	2.52
PPC-6 + S ₂ + NAA at 50 ppm	464916.68	1586551.14	1121634.46	2.41	464916.68	1646794.08	1181877.40	2.54
PPC-6 + S ₂ + GA ₃ at 10 ppm	466126.20	1600338.81	1134212.61	2.43	466126.20	1662776.35	1196650.15	2.57
PPC-6 + S ₂ + GA ₃ at 20 ppm	467788.20	1612425.17	1144636.97	2.45	467788.20	1673834.14	1206045.94	2.58
PPC-6 + S ₂ + ethrel at 100 ppm	465246.28	1538738.40	1073492.12	2.31	465246.28	1598616.38	1133370.10	2.44
PPC-6 + S ₂ + ethrel at 200 ppm	466046.28	1553093.97	1087047.69	2.33	466046.28	1612929.42	1146883.14	2.46
PPC-6 + S ₂ + GA ₃ at 10 ppm + ethrel at 100 ppm	467708.28	1634400.00	1166691.72	2.49	467708.28	1700516.47	1232808.19	2.64
PPC-6 + S ₂ + GA ₃ at 10 ppm + NAA at 25 ppm	467152.44	1653140.18	1185987.74	2.54	467152.44	1716011.25	1248858.81	2.67
PPC-6 + S ₂ + NAA at 25 ppm + ethrel at 100 ppm	466272.52	1645406.86	1179134.34	2.53	466272.52	1708401.08	1242128.56	2.66
Control (water spray)	463664.20	1381162.54	917498.34	1.98	463664.20	1457382.25	993718.05	2.14
PK-1 + S ₁ + NAA at 25 ppm	464690.44	1105297.06	640606.62	1.38	464690.00	1150819.00	686128.00	1.48
PK-1 + S ₁ + NAA at 50 ppm	464916.68	1116418.49	651501.81	1.40	464917.00	1159878.00	694962.00	1.49
PK-1 + S ₁ + GA ₃ at 10 ppm	466126.20	1128928.66	662802.46	1.42	466126.00	1172584.00	706458.00	1.52
PK-1 + S ₁ + GA ₃ at 20 ppm	467788.20	1138132.66	670344.46	1.43	467788.00	1182378.00	714589.00	1.53
PK-1 + S ₁ + ethrel at 100 ppm	465246.28	1082669.77	617423.49	1.33	465246.00	1124390.00	659143.00	1.42
PK-1 + S ₁ + ethrel at 200 ppm	466046.28	1092338.44	626292.16	1.34	466046.00	1136203.00	670157.00	1.44
PK-1 + S ₁ + GA ₃ at 10 ppm + ethrel at 100 ppm	467708.28	1150200.00	682491.72	1.46	467708.00	1196865.00	729157.00	1.56
PK-1 + S ₁ + GA ₃ at 10 ppm + NAA at 25 ppm	467152.44	1166051.25	698898.81	1.50	467152.40	1210872.00	743720.00	1.59
PK-1 + S ₁ + NAA at 25 ppm + ethrel at 100 ppm	466272.52	1155600.00	689327.48	1.48	466272.50	1206709.00	740436.00	1.59
PK-1 + S ₁ + Control (water spray)	463664.20	975945.02	512280.82	1.10	463664.20	1032312.00	568648.00	1.23
PK-1 + S ₂ + NAA at 25 ppm	464690.44	1447307.60	982617.16	2.11	464690.40	1504817.00	1040127.00	2.24
PK-1 + S ₂ + NAA at 50 ppm	464916.68	1463713.74	998797.06	2.15	464916.70	1519235.00	1054318.00	2.27
PK-1 + S ₂ + GA ₃ at 10 ppm	466126.20	1475060.15	1008933.95	2.16	466126.20	1533785.00	1067659.00	2.29
PK-1 + S ₂ + GA ₃ at 20 ppm	467788.20	1491345.54	1023557.34	2.19	467788.20	1550146.00	1082358.00	2.31
PK-1 + S ₂ + ethrel at 100 ppm	465246.28	1420584.37	955338.09	2.05	465246.30	1477086.00	1011840.00	2.17
PK-1 + S ₂ + ethrel at 200 ppm	466046.28	1430331.17	964284.89	2.07	466046.30	1490841.00	1024794.00	2.20
PK-1 + S ₂ + GA ₃ at 10 ppm + ethrel at 100 ppm	467708.28	1509801.11	1042092.83	2.23	467708.30	1569317.00	1101609.00	2.36
PK-1 + S ₂ + GA ₃ at 10 ppm + NAA at 25 ppm	467152.44	1540800.00	1073647.56	2.30	467152.40	1582572.00	1115420.00	2.39
PK-1 + S ₂ + NAA at 25 ppm + ethrel at 100 ppm	466272.52	1527309.06	1061036.54	2.28	466272.50	1583842.00	1117569.00	2.40
PK-1 + S ₂ + Control (water spray)	463664.20	1242411.68	778747.48	1.68	463664.20	1337539.00	873874.00	1.88

PPC-6: Pusa Parthenocarpic Cucumber-6; PK1: Punjab Kheera-1; S₁: 60 × 60 cm spacing; S₂: 60 × 45 cm spacing; NAA: Naphthalene acetic acid; GA₃: Gibberellic acid; Ethrel: Ethephon; ppm: Parts per million; B:C ratio: Benefit: cost ratio.

of vines per unit area, better plant vigour, enhanced fruit set and ultimately higher yields translating to greater market returns. The second-highest gross return was seen in the treatment PPC-6 + S₂ + NAA at 25 ppm + ethrel at 100 ppm, registering Rs. 1645406.86 in 2022–23 and Rs. 1708401.08 in 2023–24. These results affirm that combining auxins (NAA) and ethylene releasers (ethrel) positively influenced flowering, fruit development and uniformity, thereby improving yield quality and quantity. Cultivar PK-1 also demonstrated significant improvement under similar conditions. For example, PK-1 + S₂ + GA₃ at 10 ppm + NAA at 25 ppm yielded Rs. 1540800.00 and Rs. 1582572.00 during the two years, respectively, though slightly lower than PPC-6. Overall, gross return trends clearly revealed that closer spacing (S₂) and PGR combinations were consistently superior across both cultivars. In contrast, the lowest gross returns were observed in the control (water spray) treatments under wider spacing (S₁), particularly with PK-1, which produced only Rs. 975945.02 in 2022–23 and Rs. 1032312.00 in 2023–24. These figures highlight the economic limitations of traditional cultivation practices without the support of modern agronomic interventions.

Net return

Net return, representing the actual profit after subtracting the total cost of cultivation, followed trends similar to gross return but provides a more realistic indicator of economic viability. The highest net return was obtained with the treatment PPC-6 + S₂ + GA₃ at 10 ppm + NAA at 25 ppm, which yielded profits of Rs.1185987.74 in 2022–23 and Rs. 1248858.81 in 2023–24. Following closely were PPC-6 + S₂ + NAA at 25 ppm + ethrel at 100 ppm and GA₃ at 10 ppm + ethrel at 100 ppm. Both treatments recorded net returns exceeding Rs.11.7 lakhs in both years. The differences among treatments were statistically significant. Such combinations are known to influence physiological processes such as sex expression, fruit elongation and ripening, ultimately improving productivity and profitability. The PK-1 cultivar under S₂ spacing also performed well, particularly with GA₃ + NAA combinations, yielding up to Rs.1115420.00 in net return in 2023–24. While slightly lower than PPC-6, this still reflects a strong economic advantage compared to non-treated plots. On the other hand, control treatments under S₁ spacing yielded the lowest net returns. For example, PK-1 + S₁ + water spray generated only Rs. 512280.82 in 2022–23 and Rs. 568648.00 in 2023–24, suggesting that not using PGRs and

maintaining closer spacing significantly limits profit potential.

Benefit-cost ratio

The B:C ratio provides a key index of profitability, expressing how many rupees are returned for each rupee spent. A ratio above 1.5 is generally considered good in horticultural production under controlled environments. The maximum B:C ratio was recorded in PPC-6 + S₂ + GA₃ at 10 ppm + NAA at 25 ppm, reaching 2.54 in 2022–23 and rising to 2.67 in 2023–24. This means the farmer earned Rs. 2.67 for every Rs. 1 spent, emphasising the excellent cost-efficiency of this treatment. Similarly, PPC-6 + S₂ + NAA + ethrel and GA₃ + ethrel combinations also achieved ratios above 2.5, signifying high profitability. Among the PK-1 treatments, the B:C ratio peaked at 2.39 in 2023–24 under PK-1 + S₂ + GA₃ + NAA, followed closely by other combinations involving ethrel and NAA. These values demonstrate that even for the slightly less productive PK-1 cultivar, optimised spacing and hormone combinations can drive profitability to economically desirable levels. In stark contrast, the lowest B:C ratios were found in control plots, particularly PK-1 + S₁ + control, which showed a B:C ratio of 1.10 in 2022–23 and 1.23 in 2023–24. These treatments likely had limited fruiting due to absence of growth-promoting regulators, high competition under closer spacing and reduced resource use efficiency.

Discussion

Gross return is directly influenced by the quantity and market value of the produce. In the present study, PPC-6 consistently recorded higher gross returns compared to PK-1 across both years, primarily due to its early maturity and higher fruit yield potential under polyhouse conditions. The maximum gross return of Rs. 1716011 ha⁻¹ was obtained with GA₃ at 10 ppm + NAA at 25 ppm under closer spacing (60 × 45 cm), indicating the positive influence of plant growth regulators on enhancing fruit set and yield components. This was closely followed by combinations of NAA + ethrel and GA₃ + ethrel, suggesting a synergistic effect of PGRs in improving flowering, fruit development and productivity (11, 12). These findings align with the results of previous studies (13, 14), where PGR applications significantly increased marketable yields and economic returns in cucumbers. These treatments combined the benefits of improved spacing and hormone synergy, which likely enhanced photosynthetic efficiency, flower retention and fruit filling. The lowest gross return of Rs. 975945 ha⁻¹ was recorded in the untreated PK-1 under closer spacing (60 × 60 cm), emphasising the importance of varietal choice and use of PGRs in high-tech cultivation for maximising revenue.

Net return reflects the actual profitability after deducting production costs from the gross return. In this study, the highest net return of Rs. 1248859 ha⁻¹ was recorded in PPC-6 with GA₃ at 10 ppm + NAA at 25 ppm during 2023–24, highlighting the economic effectiveness of this treatment combination. The NAA plays a critical role in promoting fruit retention and increasing fruit size, while GA₃ enhances cell elongation and vegetative growth, resulting in increased productivity and profit (15, 16). Treatments involving NAA + ethrel and GA₃ + ethrel also provided comparable net returns, indicating that the integration of these hormones can effectively boost yield while maintaining reasonable input costs. These results are consistent with the findings of previous studies (17, 14), reporting higher net returns with optimal PGR combinations under protected environments. In contrast, the lowest net return of Rs. 512281 ha⁻¹

was observed in PK-1 under control conditions.

The B:C ratio is a key indicator of economic efficiency and sustainability. The highest B:C ratio of 2.67 was observed in PPC-6 treated with GA₃ at 10 ppm + NAA at 25 ppm under 60 × 45 cm spacing in 2023–24, which signifies that for every rupee invested, there was a return of Rs. 2.67. This superior economic performance is attributed to the increased yield per unit area, better fruit quality and effective resource utilisation promoted by this PGR combination. Similar high B:C ratios were noted for NAA + ethrel (2.66) and GA₃ + ethrel (2.64) treatments, confirming that strategic hormonal interventions lead to improved input-use efficiency (13, 18). On the other hand, the lowest B:C ratio of 1.10 was recorded in PK-1 under the control treatment.

Conclusion

Overall, the findings clearly establish that the integration of plant growth regulators (PGRs) like gibberellic acid (GA₃), naphthalene acetic acid (NAA) and ethephon (ethrel), especially when applied in combinations and maintaining closer plant spacing (S₂) significantly enhanced the economic returns of cucumber cultivation under polyhouse conditions. The Pusa Parthenocarpic Cucumber-6 (PPC-6) cultivar consistently outperformed Punjab Kheera-1 (PK-1), particularly when combined with GA₃ at 10 ppm + NAA at 25 ppm, achieving the highest gross and net returns and the best benefit:cost (B:C) ratios in both years. Therefore, for commercial polyhouse cucumber production, this integrated approach offers a highly viable and profitable cultivation strategy.

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Authors' contributions

RF, ML, PP, VS and KK contributed to conceptualisation of the study. RF, S, ML and KK were involved in writing the original draft preparation. The writing-review and editing was carried out by RF, AS, VS and S. Visualisation was performed by KK, ML, VS, AS, PP and S. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

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