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Response of Parthenocarpic Cucumber (*Cucumis sativus* L.) to Fertigation and Pruning Systems under Polyhouse Conditions in Kashmir

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Abstract
An investigation was conducted at the Sher-e-Kashmir University of Agricultural Sciences and Technology, Kashmir, during the 2019 and 2020 seasons to determine the optimal management practices for parthenocarpic cucumber (cv. Pusa Parthenocarpic Cucumber-6) under protected cultivation. The study evaluated six levels of fertigation (ranging from a control with no fertigation up to 300:225:375 kg ha^{-1} NPK) and two pruning systems (no pruning vs. a single stem system) in a Factorial Randomized Complete Block Design. The results demonstrated that the integration of fertigation and pruning significantly enhanced crop performance. The treatment combining 250:188:312 kg ha^{-1} NPK fertigation with a single stem pruning system (P1F4) proved to be the most effective, yielding the highest fruit production (120.25 t ha^{-1}), number of fruits per plant (32.5), and individual fruit weight (136.6 g). This combination also promoted superior vegetative growth, including a vine length of 3.94 m and a leaf area of 859.8 cm^2. Key quality attributes, such as dry matter content (6.13%) and soluble solids, were also maximized under this treatment. Economically, the P1F4 treatment was the most viable, generating the highest net returns (Rs. 495,584) and benefit-cost ratio (5.69). The study concludes that this specific combination of precise nutrient and canopy management is the optimal strategy for maximizing productivity, fruit quality, and profitability of parthenocarpic cucumber in the temperate polyhouse conditions of Kashmir.

Keywords: Parthenocarpic cucumber, fertigation, pruning, polyhouse cultivation, nutrient use efficiency, crop economics

Introduction

Cucumber (*Cucumis sativus* L.) is a globally significant vegetable crop, valued for its culinary versatility and nutritional profile, which includes essential vitamins and minerals [1, 2]. The increasing demand for year-round availability of high-quality cucumbers has driven the adoption of protected cultivation technologies. Polyhouses, in particular, offer a controlled environment that mitigates climatic adversities, enabling off-season production and leading to substantial improvements in both yield and quality, a crucial advantage in temperate regions like Kashmir [3].

The advent of parthenocarpic cucumber varieties, which set fruit without pollination, has been a transformative development for greenhouse cultivation. Cultivars like Pusa Parthenocarpic Cucumber-6 are gynoecious, producing predominantly female flowers, which leads to earlier, more consistent fruit set and higher overall productivity [4, 5]. However, to fully realize the genetic potential of these high-yielding hybrids, it is imperative to optimize agronomic practices, particularly nutrient management and canopy architecture [6, 7].

Conventional fertilizer application methods often result in low nutrient use efficiency and environmental concerns such as nutrient leaching. Fertigation, the application of soluble fertilizers through a drip irrigation system, presents a highly efficient alternative. This technique ensures that water and nutrients are delivered directly to the plant's root zone in precise amounts, synchronizing nutrient availability with crop demand. This leads to improved nutrient uptake, reduced fertilizer wastage, and minimized environmental pollution [8, 9].

Simultaneously, managing the plant's architecture through pruning is essential for indeterminate crops like cucumber grown in high-density greenhouse systems. Pruning, especially maintaining a single stem, prevents excessive vegetative growth, improves air circulation, and enhances light penetration into the canopy. This balanced approach between vegetative and reproductive growth is critical for maximizing the number of marketable fruits and overall quality [10, 11]. While the individual benefits of fertigation and pruning are known, there is a lack of comprehensive research on their interactive effects on parthenocarpic cucumber in the specific temperate agro-climatic conditions of the Kashmir Valley. This study was therefore designed to evaluate various fertigation and pruning combinations to identify an integrated strategy that enhances the growth, yield, quality, and economic viability of protected cucumber cultivation.

Materials and Methods

Experimental Site and Conditions

The investigation was carried out over two consecutive years (2019 and 2020) in a naturally ventilated polyhouse at the Vegetable Experimental Farm, Division of Vegetable Science, SKUAST-Kashmir (1585 m altitude, 34.50°N latitude, 74.40°E longitude). The experimental soil was a silty clay loam, alkaline in reaction (pH 7.51), with medium levels of available nitrogen (288.83 kg ha^{-1}), phosphorus (15.71 kg ha^{-1}), and potassium (155.97 kg ha^{-1}).

Experimental Design and Treatments

A factorial experiment was conducted using a Randomized Complete Block Design (RCBD) with three replications. The treatments comprised six fertigation levels and two pruning systems.

- **Factor 1: Fertigation Levels (F)**: F0 (Control), F1 (100:75:125 NPK kg ha^{-1}), F2 (150:112:188 NPK kg ha^{-1}), F3 (200:150:250 NPK kg ha^{-1}), F4 (250:188:312 NPK kg ha^{-1}), and F5 (300:225:375 NPK kg ha^{-1}).
- **Factor 2: Pruning Systems (P)**: P0 (No pruning) and P1 (Single stem system).

Each experimental unit consisted of 6 plants in a plot of 2 m², with a spacing of 120 cm × 60 cm.

Crop Management Practices

The parthenocarpic hybrid 'Pusa Parthenocarpic Cucumber-6' was used. Seeds were sown in protrays on April 30th, and healthy seedlings were transplanted on May 26th of each year. A uniform basal dose of vermicompost (2 kg $plot^{-1}$) was applied. Water-soluble fertilizers (urea, SSP, MOP) were applied through the drip irrigation system in three equal splits at 15, 45, and 75 days after transplanting (DAT). For the single stem pruning treatment (P1), all axillary shoots were removed starting three weeks after transplanting, allowing only the main stem to grow vertically along a support string. This was performed twice a week to maintain the plant architecture. Need-based plant protection measures were taken to manage pests (aphids, mites) and diseases (powdery mildew). Fruits were harvested at the marketable stage, and harvesting continued for 21 pickings over the season.

Data Collection and Analysis

Observations were recorded from five randomly selected and tagged plants per plot. Growth parameters included vine length, internode length, and leaf area. Yield parameters consisted of the number of fruits per plant, individual fruit weight, and total yield (kg $plant^{-1}$ and t ha^{-1}). Fruit quality was assessed by measuring chlorophyll content, moisture percentage, dry matter content, Vitamin C, and Soluble Solids Content (SSC) using standard laboratory methods [12, 13]. Post-harvest soil samples were analyzed for pH, EC, and available N, P, and K. The economic viability of each treatment was determined by calculating the cost of cultivation, gross returns, net returns, and the benefit-cost (B:C) ratio. All collected data were statistically analyzed using Analysis of Variance (ANOVA), and treatment means were compared at a 5% level of significance [14].

Results

The integrated application of fertigation and pruning systems had a statistically significant effect on the vegetative, reproductive, and qualitative traits of parthenocarpic cucumber.

Growth Parameters

Fertigation and pruning had a significant impact on vine length, internode length, and leaf area. The vegetative growth of the cucumber plants was substantially improved by both fertigation and pruning. As shown in Table 1, the single stem pruning system (P1) consistently outperformed the no-pruning system (P0) across all key growth parameters. The interaction between high fertigation and pruning (P1F5) yielded the most vigorous growth, with a vine length of 4.09 m ((Table 1), internode length of 9.66 cm(Table 2), and leaf area of 993.9 cm²(Table 3).Among fertigation levels, the highest application rate (F5: 300:225:375 kg NPK/ha) produced the longest vines (3.49 m), greatest internode length (8.14 cm), and largest leaf area (727 cm²). This indicates a strong synergistic effect where ample nutrient supply fuels the focused vertical growth promoted by the single stem system (Table 4).

Table 1: Effect of fertigation and pruning on vine length (m) of parthenocarpic cucumber

Pruning	Year	F0	F1	F2	F3	F4	F5	Mean
P0	2019	1.84	2.28	2.38	2.48	2.67	2.84	2.41
	2020	1.86	2.34	2.44	2.48	2.87	2.98	2.49
	Pooled	1.85	2.31	2.41	2.45	2.77	2.91	2.45
P1	2019	2.16	2.31	2.94	3.21	3.86	3.98	3.07
	2020	2.36	2.46	2.99	3.38	4.02	4.17	3.23
	Pooled	2.26	2.39	2.97	3.30	3.94	4.09	3.15
Mean	2019	2.00	2.29	2.66	2.81	3.26	3.41	
	2020	2.11	2.40	2.71	2.93	3.44	3.57	
	Pooled	2.06	2.35	2.69	2.87	3.43	3.49	

C.D. ($p\leq0.05$): P = 0.16 (2019), 0.18 (2020), 0.21 (Pooled); F = 0.28, 0.32, 0.37; P×F = 0.40, 0.45, 0.52

Table 2: Effect of fertigation and pruning on internode length (cm) of parthenocarpic cucumber

Pruning	Year	F0	F1	F2	F3	F4	F5	Mean
P0	2019	4.18	4.83	5.53	5.80	6.49	6.57	5.57
	2020	4.27	4.93	5.88	5.97	6.53	6.64	5.64
	Pooled	4.21	4.87	5.73	5.79	6.51	6.61	5.56
P1	2019	7.23	8.20	7.07	8.00	8.65	9.63	8.13
	2020	6.92	8.03	8.13	8.79	8.71	9.71	8.43
	Pooled	6.92	8.05	7.57	8.35	8.68	9.66	8.27
Mean	2019	5.71	6.52	6.30	6.90	7.57	8.10	
	2020	5.60	6.48	7.01	7.38	7.60	8.17	
	Pooled	5.57	6.46	6.65	7.07	7.59	8.14	

C.D. ($p\leq0.05$): P = 0.29 (2019), 0.04 (2020), 0.15 (Pooled); F = 0.51, 0.84, 0.27; P×F = 0.72, 0.11, 0.41

Table 3: Effect of fertigation and pruning on leaf area (cm²) of parthenocarpic cucumber

Pruning	Year	F0	F1	F2	F3	F4	F5	Mean
P0	2019	396.1	453.3	481.6	498.0	509.7	518.6	476.2
	2020	394.3	453.3	483.1	499.9	507.3	521.9	476.7
	Pooled	395.2	453.2	482.4	499.3	508.4	520.1	476.4
P1	2019	642.3	644.3	714.0	851.3	858.3	932.3	773.8
	2020	643.8	647.4	703.8	851.5	861.6	935.6	773.9
	Pooled	643.0	645.8	708.5	851.6	859.8	933.9	773.8
Mean	2019	519.1	548.8	597.3	678.1	680.5	725.5	
	2020	519.0	550.4	593.5	680.7	679.5	728.7	
	Pooled	519.3	549.5	595.8	679.4	679.8	727.0	

C.D. ($p \leq 0.05$): P = 1.73, 2.20, 1.58; F = 3.01, 3.81, 2.74; P×F = 4.25, 5.40, 3.87

Table 4: Effect of fertigation and pruning on key growth parameters (Pooled Data)

Treatment	Vine Length (m)	Internode Length (cm)	Leaf Area (cm²)
Pruning (P)			
P0 (No Pruning)	2.45	5.56	476.4
P1 (Single Stem)	3.15	8.27	773.8
C.D. ($p \leq 0.05$)	0.21	0.15	1.58
Fertigation (F)			
F0 (Control)	2.06	5.57	519.3
F1	2.35	6.46	549.5
F2	2.69	6.65	595.8
F3	2.87	7.07	679.4
F4	3.43	7.59	679.8
F5	3.49	8.14	727.0
C.D. ($p \leq 0.05$)	0.37	0.27	2.74
Interaction (P × F)			
P0F0 (Control)	1.85	4.21	395.2
P1F4	3.94	8.68	859.8
P1F5	4.09	9.66	933.9
C.D. ($p \leq 0.05$)	0.52	0.41	3.87

Yield and Yield Components

Yield components were significantly enhanced by increasing fertigation levels and implementing pruning. The highest number of fruits per plant (32.5) (Table 5), individual fruit weight (136.6 g) (Table 6), and total fruit yield (120.3 t/ha) (Table 7) were achieved in the treatment combining single stem pruning with a fertigation rate of 250:188:312 kg NPK/ha (P1F4). This highlights that a slightly lower but optimally balanced nutrient dose (F4), when combined with efficient canopy management (P1), is more effective for fruit production than simply maximizing fertilizer input (F5).

Table 5: Effect of fertigation and pruning on number of fruits per plant

Pruning	Year	F0	F1	F2	F3	F4	F5	Mean
P0	2019	14.7	20.3	22.1	24.1	25.8	20.1	21.0
	2020	15.9	21.3	24.3	26.3	26.8	21.3	22.6
	Pooled	15.3	20.8	23.2	25.2	26.3	20.7	22.1
P1	2019	24.8	25.1	27.5	29.8	31.7	31.0	28.3
	2020	25.9	26.1	28.5	30.8	32.9	32.0	28.8
	Pooled	25.3	25.6	28.0	30.3	32.3	31.5	28.6
Mean	2019	19.8	22.7	24.8	26.9	28.8	25.5	
	2020	20.9	23.7	26.4	28.5	29.9	26.6	
	Pooled	20.3	23.2	25.6	27.8	29.4	26.1	

C.D. ($p \leq 0.05$): P = 0.44, 0.63, 0.77; F = 0.76, 1.11, 1.35; P×F = 1.07, 1.57, 1.90

Table 6: Effect of fertigation and pruning on individual fruit weight (g)

Pruning	Year	F0	F1	F2	F3	F4	F5	Mean
P0	2019	125.5	132.7	132.8	134.3	134.2	134.4	132.3
	2020	124.5	133.5	133.4	135.4	134.5	135.6	132.8
	Pooled	124.8	132.4	134.0	133.8	134.7	135.2	132.5
P1	2019	133.0	133.7	135.2	135.4	136.9	135.1	134.9
	2020	133.3	134.2	135.5	137.7	138.5	130.2	134.9
	Pooled	132.6	134.3	135.5	136.2	136.6	132.6	134.6
Mean	2019	129.2	133.2	134.0	134.9	135.6	134.7	
	2020	128.9	133.9	134.4	136.6	137.1	132.3	
	Pooled	128.7	133.4	134.7	135.0	135.9	133.6	

C.D. ($p \leq 0.05$): P = 0.138, 1.117, 0.402; F = 0.240, 1.934, 0.696; P×F = 0.339, 2.735, 0.985

Table 7: Effect of fertigation and pruning on fruit yield (t/ha)

Pruning	Year	F0	F1	F2	F3	F4	F5	Mean
P0	2019	53.9	76.3	84.1	109.0	117.3	100.7	90.2
	2020	56.3	78.2	88.1	116.2	121.5	106.6	94.5
	Pooled	55.0	77.3	86.1	112.6	119.4	103.7	92.3
P1	2019	57.2	78.0	88.5	111.1	118.5	102.6	92.6
	2020	57.8	78.5	89.6	115.0	122.0	106.3	94.8
	Pooled	57.5	78.2	89.0	113.0	120.3	104.4	93.7
Mean	2019	55.6	77.2	86.3	110.0	117.9	101.6	
	2020	57.0	78.3	88.8	115.6	121.7	106.4	
	Pooled	56.3	77.7	87.5	112.8	119.8	104.0	

C.D. ($p \leq 0.05$): P = 0.308, 0.213, 0.187; F = 0.534, 0.368, 0.324; P×F = 0.755, 0.521, 0.458

Quality Attributes

Fruit quality parameters, including dry matter content, vitamin C, and soluble solids content (SSC), were positively influenced by both fertigation and pruning. The combination of single stem pruning with higher fertigation levels (P1F5) yielded the highest SSC (3.06 °Brix) (Table 8). The P1F4 treatment produced fruits with the highest dry matter content (6.13%)(Table 9) and the highest Vitamin C (7.66 mg/100g)(Table 10), indicating a concentration of nutrients and photosynthates that leads to superior quality.

Table 8: Effect of fertigation and pruning on fruit SSC content (°Brix) of cucumber (*Cucumis sativus* L.) var. Pusa parthenocarpic cucumber-6

Pruning	Year	F0	F1	F2	F3	F4	F5	Mean
P0	2019	1.17	1.78	1.89	2.01	1.87	2.87	1.93
	2020	1.29	1.73	1.93	2.01	1.98	2.92	1.97
	Pooled	1.23	1.75	1.91	2.01	1.93	2.90	1.96
P1	2019	2.36	2.46	2.58	2.35	2.53	3.05	2.52
	2020	2.38	2.48	2.60	2.68	2.38	3.07	2.60
	Pooled	2.37	2.47	2.59	2.52	2.36	3.06	2.60
Mean	2019	1.77	2.12	2.24	2.18	2.96	2.10	
	2020	1.83	2.10	2.26	2.34	2.99	2.18	
	Pooled	1.80	2.11	2.25	2.26	2.98	2.14	

C.D. ($p \leq 0.05$): Pruning (P) = 0.07 (2019), 0.07 (2020), 0.04 (Pooled)
Fertigation (F) = 0.12 (2019), 0.13 (2020), 0.07 (Pooled)
P × F = 0.17 (2019), 0.17 (2020), 0.09 (Pooled)

Table 9: Effect of fertigation and pruning on fruit dry matter content (%) of cucumber (Cucumis sativus L.) var. Pusa parthenocarpic cucumber-6

Pruning	Year	F0	F1	F2	F3	F4	F5	Mean
P0	2019	2.91	3.57	3.94	4.23	4.90	4.48	4.00
	2020	3.02	3.82	3.98	4.94	5.11	4.84	4.28
	Pooled	2.97	3.70	3.96	4.59	5.01	4.66	4.14
P1	2019	3.14	4.82	5.11	5.76	5.98	5.45	5.05
	2020	3.42	4.90	5.21	5.92	6.28	5.65	5.23
	Pooled	3.28	4.86	5.16	5.84	6.13	5.55	5.14
Mean	2019	3.02	4.12	4.53	4.98	5.44	4.97	
	2020	3.23	4.36	4.59	5.43	5.69	5.24	
	Pooled	3.12	4.28	4.56	5.21	5.57	5.10	

C.D. ($p \leq 0.05$):
Pruning (P) = 0.11 (2019), 0.13 (2020), 0.88 (Pooled)
Fertigation (F) = 0.20 (2019), 0.22 (2020), 0.15 (Pooled)
P × F = 0.28 (2019), 0.32 (2020), 0.22 (Pooled)

Table 10: Effect of fertigation and pruning on fruit vitamin C content (mg/100g) of cucumber (Cucumis sativus L.) var. Pusa parthenocarpic cucumber-6

Pruning	Year	F0	F1	F2	F3	F4	F5	Mean
P0	2019	3.47	4.66	4.76	6.21	5.66	6.64	5.23
	2020	4.11	4.50	4.89	6.66	5.74	6.75	5.44
	Pooled	3.79	4.58	4.83	5.93	5.70	6.70	5.34
P1	2019	4.13	5.12	6.41	6.50	7.32	8.76	5.94
	2020	5.85	5.96	6.75	6.88	7.99	9.01	6.66
	Pooled	4.99	5.54	6.41	6.69	7.66	8.85	6.35
Mean	2019	3.80	4.89	5.59	6.36	6.70	7.69	
	2020	4.98	5.23	5.65	6.14	7.92	7.88	
	Pooled	4.39	5.06	5.62	6.25	7.31	7.78	

C.D. ($p \leq 0.05$):
Pruning (P) = 0.25 (2019), 0.19 (2020), 0.21 (Pooled)
Fertigation (F) = 0.43 (2019), 0.39 (2020), 0.41 (Pooled)
P × F = 0.62 (2019), 0.75 (2020), 0.79 (Pooled)

Economic Analysis

The economic evaluation indicated that the P1F4 treatment (single stem pruning with 250:188:312 kg NPK/ha fertigation) generated the highest economic returns (Table 11). This treatment incurred a total cost of Rs. 105,568 but generated the highest gross returns (Rs. 601,252) and net returns (Rs. 495,584). This resulted in the highest benefit-cost ratio of 5.69, confirming its economic superiority and viability for commercial cultivation. The control treatment (P0F0) was the least profitable, with a B:C ratio of only 3.28.

Table 11: Cost of cultivation of different treatment combinations

Treatment combination	Total Variable cost	Total Fixed cost	Total cost of Cultivation (TFC+TVC)
P0F0	56201.89	27700.4	83902.29
P0F1	66251.58	27700.4	93951.98
P0F2	68477.20	27700.4	96177.60
P0F3	72148.93	27700.4	99849.33
P0F4	81288.98	27700.4	108989.38
P0F5	86369.41	27700.4	114069.81
P1F0	56080.14	27700.4	83780.54
P1F1	64748.75	27700.4	92449.15
P1F2	69612.06	27700.4	97312.46
P1F3	99476.40	27700.4	99476.40
P1F4	105568.26	27700.4	105568.26
P1F5	112162.16	27700.4	112162.16

Discussion

Influence on Growth and Development

Fertigation significantly influenced growth traits, with the highest vigor observed at the F5 fertilization level. This enhanced growth is attributed to improved nutrient availability and uptake, which supports cellular division and elongation, as previously reported [15, 16]. Furthermore, the F4 treatment expedited phenological stages like flowering and maturity, likely due to a balanced nutrient supply enhancing metabolic activities. Pruning to a single stem (P1) also significantly increased vegetative growth and hastened flowering, possibly by modulating hormonal balances, improving light penetration, and optimizing assimilate allocation [10, 7]. The synergistic interaction between fertigation and pruning resulted in maximal vegetative development, aligning with findings that suggest combined management improves overall crop potential.

Impact on Yield and its Components

The highest yield and its components were recorded in plants receiving the F4 fertigation level coupled with the single stem pruning system. These results indicate that enhanced nutrient uptake and efficient source-sink relationships promote better fruit development. Fertigation improves nutrient solubility and availability, ensuring a steady supply for yield formation [17, 18]. Pruning likely reduces intra-plant competition for resources, allowing more allocation to economic yield [19, 20]. The combined use of optimal fertigation and pruning appears to optimize plant physiology for maximum reproductive output.

Enhancement of Fruit Quality

Quality traits such as chlorophyll, vitamin C, dry matter, and soluble solids were positively influenced by both treatments. Increased chlorophyll and vitamin C at higher fertigation levels indicate improved photosynthetic capacity and antioxidant potential. Pruning improved light interception and reduced canopy density, which enhanced the biochemical attributes of the fruit [21, 22]. The reduced moisture and increased dry matter content suggest a healthier fruit metabolic status, favoring better quality and shelf life [16].

Economic Viability

From an economic standpoint, the study clearly demonstrates that strategic investment in inputs like soluble fertilizers and the labor for pruning yields significant returns. The P1F4 treatment, despite having higher input costs than the control, generated substantially higher yields of marketable-quality fruits, leading to the highest net returns and B:C ratio. This confirms that the efficiency gains from fertigation and pruningin terms of higher yield and quality per unit of inputtranslate directly into improved profitability. This finding is crucial for farmers and stakeholders looking to adopt sustainable and economically viable practices for protected cucumber cultivation.

Conclusion

Based on the comprehensive findings of this two-year study, it can be unequivocally concluded that the integrated management of fertigation and pruning is essential for optimizing the performance of parthenocarpic cucumber under protected cultivation in Kashmir. The application of 250:188:312 kg NPK ha^{-1} through fertigation, combined with a single stem pruning system (P1F4), emerged as the superior treatment. This combination resulted in the highest marketable fruit yield, superior fruit quality, and the most favorable economic returns, achieving a benefit-cost ratio of 5.69. While higher fertilizer rates promoted vegetative growth, the F4 level provided the optimal balance for maximizing reproductive output. Therefore, this integrated agronomic package is strongly recommended for commercial cucumber growers in the region to enhance productivity, ensure high-quality produce, and maximize profitability in a sustainable manner.

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