International Journal of Economic Plants

https://ojs.pphouse.org/index.php/IJEP

IJEP September 2025, 12(5): 01-07

Crossref

Article IJEP6466a

Full Research

Natural Resource Management

Doi: HTTPS://DOI.ORG/10.23910/2/2025.6466a

Influence of Two Shoots and Four Shoots Training Techniques on Growth, Yield and Quality of Capsicum under Protected Cultivation (*Capsicum annuum* var. *grossum* Sendt.)

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Article History

Received on 27th June, 2025
Received in revised form on 24th August, 2025
Accepted in final form on 08th September, 2025
Published on 20th September, 2025

Abstract

The present study was conducted during *kharif* (June to September, 2022) at the Centre of Excellence for Vegetables, KVK, Malegaon, Baramati, Maharashtra, India to evaluate the interaction effects of three training techniques (two shoots, four shoots and unpruned control) and two capsicum hybrids commercial capsicum hybrid-1 (yellow) and commercial capsicum hybrid-2 (red) on growth, yield and quality under a polyhouse. Among the training techniques, two shoot system significantly influenced plant growth and flowering characteristics. Although unpruned plants produced a higher number of fruits per plant, the four shoot training technique recorded the highest fruit yield per plant, per plot and per hectare. Between the two hybrids, Commercial capsicum hybrid-1 outperformed Commercial capsicum hybrid-2 across all growth, yield and quality parameters. In terms of interaction effects, the two shoot + Commercial capsicum hybrid-1 combination resulted in the tallest plants (179.01 cm), earliest flowering (19.79 days) and earliest 50% flowering (31.07 days). The maximum number of fruits plant^{-1} (23.71) was observed in unpruned+Commercial capsicum hybrid-1. However, two shoot+Commercial capsicum hybrid-1 recorded highest average fruit weight (198.74 g), polar diameter (10.03 cm), equatorial diameter (9.39 cm) and pericarp thickness (0.90 cm). The four shoot+Commercial capsicum hybrid-1 treatment recorded highest yield plant^{-1} (2.85 kg), m^{-2} (17.10 kg), plot^{-1} (30.51 kg) and (115.98 t) ha^{-1} with excellent quality fruits. In contrast, the lowest yield was recorded in unpruned +Commercial capsicum hybrid-2. The four shoot training system combined with the Commercial capsicum hybrid-1 proved most effective for maximizing growth, yield and quality of colored capsicum under protected cultivation conditions.

Keywords: Capsicum, training techniques, two shoots, four shoots, yield, quality

1. Introduction

Bell pepper (*Capsicum annuum* var. *grossum* Sendt.) is a widely cultivated crop belonging to the *Solanaceae* family, known for its high nutritional, therapeutic, and commercial value. It is commonly referred to as sweet pepper, capsicum, or *Shimla Mirch* in different parts of the world. The genus *Capsicum* consists of species with a diploid chromosome number of 2n=2x=24, while its wild progenitor, *C. annuum* var. *glabriusculum*, is a tetraploid with 2n=4x=48 chromosomes. This genetic diversity offers a valuable resource for breeding and genetic improvement. Bell peppers are not only integral to culinary practices worldwide but also valued for their health-promoting properties. They are rich sources of essential vitamins, particularly vitamin A (8493 IU) and vitamin C (283 mg), as well as key minerals and phytonutrients. These nutritional compounds, especially carotenoids, flavonoids, and other antioxidants, contribute to various health benefits including antioxidant activity, anti-inflammatory effects, anticancer potential, and mood regulation (Carrizo et al., 2016).

Globally, bell pepper is extensively cultivated in countries such as China, Mexico, and Indonesia, which are among the top producers. In India, bell pepper cultivation spans approximately 46,000 ha with an annual production of around 288,000 mt (Anonymous, 2021). It is grown in both open-field conditions and protected cultivation environments across several Indian states, including Maharashtra, Himachal Pradesh and Karnataka (Sood et al., 2009). However, open-field cultivation of bell pepper is constrained by climatic limitations, especially in terms of temperature, humidity, and seasonal variability. These challenges have necessitated the adoption of protected cultivation methods, such as

polyhouses and shade net houses, which provide controlled environmental conditions that support year-round cultivation.

Protected cultivation plays a pivotal role in enhancing the productivity, fruit quality, and resource use efficiency of bell pepper crops. It enables growers to regulate critical growth parameters such as temperature, humidity and light, thereby extending the growing season and allowing for off season production. Moreover, it facilitates the cultivation of high value vegetables with better input use efficiency and marketable quality (Chaudhary, 2016).

Under protected cultivation systems, training and pruning techniques have emerged as crucial agronomic interventions that significantly influence the growth habit, canopy structure and overall performance of capsicum plants. Bell pepper exhibits a dichotomous branching habit and responds well to systematic training and pruning practices Singh and Kaur (2018). Training typically involves supporting the plant on vertical twines or strings tied to overhead structures, which enhances aeration and light penetration. Pruning involves the removal or regulation of vegetative shoots to encourage balanced growth and higher reproductive output. Specifically, pruning the plant to two or four main shoots has been found to regulate canopy density, reduce pest and disease incidence, and improve fruit size, uniformity, and yield (Maniutiu et al., 2010).

Several studies have demonstrated the benefits of shoot training under protected conditions, including improved fruit development, reduced intra-plant competition, lower relative humidity within the canopy, and minimized incidence of pests and diseases (Dasgan and Kazim, 2003; Norris and Kogan, 2005). Therefore, the current study was undertaken to evaluate the interaction effects of three training techniques two-shoot, four-shoot and unpruned control on the performance of two commercial capsicum hybrids (yellow hybrid-1 and red hybrid-2) under polyhouse conditions. The goal was to assess their impact on plant growth, fruit yield, and quality attributes, providing insights for optimizing cultivation practices in protected environments Waiba et al. (2021).

2. Materials and Methods

The present study was conducted during *kharif* (June to September, 2022) at Centre of Excellence for Vegetables, Krishi Vigyan Kendra (KVK), Baramati. The study involved two indeterminate capsicum hybrids, Commercial capsicum hybrid-2 (Red) and Commercial capsicum hybrid-1 (Yellow) evaluated under protected conditions. The seedlings were raised in pro trays using sterilized soilless media (cocopeat:vermiculite:perlite in 3:1:1 ratio). Carbendazim (1 g l^{-1}) was applied at a weekly interval to prevent fungal infections. Healthy seedlings were transplanted in the month of May in a ventilated net house (27×9×3 m^3) on raised beds (1 m wide) at a spacing of 45×45 cm^2. Pinching was performed post transplanting, prior to flowering, to encourage branching. The experiment followed a factorial completely randomized design (FCRD) with six treatments and four replications. Treatments included two hybrids (Commercial capsicum hybrid-1, Commercial capsicum hybrid-2) and three training levels two shoots, four shoots and unpruned (control). The plants were pruned 25–30 days after transplanting to retain either two or four stems, depending on the treatment. Capsicum was a natural dichotomous branching, occurring around 15–30 DAT, guided pruning. Pruning continued at 8–10 day intervals to improve fruit size and fruit quality. Plants were trained using plastic twines (two or four per plant) tied to overhead GI wire grids for vertical support and canopy management.

3. Results and Discussion

3.1. Plant height (cm)

Plant height was significantly influenced by training intensities (Table 1). The tallest plants were recorded under the two-shoot training system (P_1) at height of 173.96 cm, significantly higher than four shoot (P_2) at 161.13 cm and unpruned control (P_3) recorded height of 149.91 cm Singh et al. (2004). Among capsicum hybrids, the hybrid Commercial capsicum hybrid-1 (C_1) recorded significantly greater plant height (163.81 cm) compared to Commercial capsicum hybrid-2 (C_2) at a height of 159.52 cm. Interaction effect showed the interaction between training levels and hybrids significantly affected plant height. The highest plant height was observed in treatment T_1 two Shoots+Commercial capsicum hybrid-1 (179.01 cm), followed by treatment T_2 two shoots+commercial capsicum hybrid-2 (168.92 cm). The four shoots+Commercial capsicum hybrid-1 (T_3) recorded moderate height (161.42 cm), while the lowest height was recorded in treatment T_6 unpruned+commercial capsicum hybrid-2 (148.81 cm). The increased height in pruned treatments might be attributed to the redirection of nutrients toward apical growth due to removal of lateral branches Singh and Kaur (2018).

3.2. Number of days to first flowering

Days to first flowering (Table 1) showed significant variation in days to first flowering across training levels. Plants trained to two shoots (P_1) flowered earliest (20.99 days), significantly earliest than those trained to four shoots (P_2) (24.39 days) and unpruned plants (P_3 control^{-1}) (28.98 days). Unpruned plants taken the longest to initiate flowering. The capsicum hybrid Commercial capsicum hybrid-1 (C_1) recorded early flowering (23.77 days) compared to hybrid Commercial capsicum hybrid-2 (C_2) (25.80 days), indicating a quicker transition to flowering in hybrid Commercial capsicum hybrid-1 (C_1). The interaction effect of training and hybrid combinations significantly affected flowering time. The earliest flowering occurred in treatment T_1 Two shoots+Commercial capsicum hybrid-1 (19.79 days), followed by treatment T_2 Two shoots+Commercial capsicum hybrid-2 (22.18 days) and treatment T_3 Four shoots+Commercial capsicum hybrid-1

Table1: Effect of different training techniques on plant height, number of days to first flowering, days to 50% flowering number of fruits plant^{-1}, average fruit weight, Diameter, pericarp thickness, yield and yield related attribute of capsicum under protected cultivation in different training levels

Treatment	PH (cm)	NF	DF	NFP	AFW (g)	PD (cm)	ED (cm)	PT (cm)	YPT (kg)	Yield m^{-2} (kg)	Yield plot^{-1} (kg)	Yield ha^{-1} (t)
A. Training level (Factor 1)												
P_1	173.96	20.99	33.99	14.75	196.99	9.64	9.24	0.87	1.57	9.44	23.67	90.01
P_2	161.13	24.39	40.42	19.34	180.52	9.08	8.11	0.82	2.47	14.81	28.85	109.70
P_3	149.91	28.98	45.17	21.70	149.91	6.43	6.34	0.74	1.47	8.82	20.31	77.26
SEm±	1.38	0.83	1.41	0.78	5.44	0.36	0.35	0.01	0.09	0.55	0.48	1.83
CD (*p*=0.05)	4.11	2.46	4.18	2.32	16.16	1.06	1.04	0.04	0.27	1.64	1.43	5.43
B. Capsicum hybrids (Factor 2)												
C_1	163.81	23.77	37.86	21.39	180.25	8.82	8.33	0.82	1.99	11.98	25.35	96.40
C_2	159.52	25.80	41.85	15.80	171.37	7.94	7.46	0.79	1.68	10.06	23.20	88.25
SEm±	1.10	0.67	1.15	0.64	4.44	0.29	0.29	0.01	0.07	0.45	0.39	1.49
CD (*p*=0.05)	3.27	2.01	3.41	1.90	NS	0.86	0.85	0.03	0.22	1.34	1.17	4.43
C. Interaction effect												
T_1	179.01	19.79	31.07	19.27	198.86	10.03	9.39	0.90	1.61	9.65	25.22	95.87
T_2	168.92	22.18	36.90	10.24	195.12	9.25	9.08	0.84	1.54	9.24	22.13	84.16
T_3	161.42	23.24	39.30	21.19	187.74	9.83	9.05	0.82	2.85	17.10	30.51	115.98
T_4	160.83	25.53	41.53	17.49	173.30	8.33	7.18	0.81	2.09	12.53	27.20	103.42
T_5	151.01	28.27	43.20	23.71	154.15	6.60	6.56	0.75	1.53	9.21	20.34	77.35
T_6	148.81	29.69	47.13	19.69	145.68	6.25	6.12	0.72	1.41	8.43	20.29	77.17
SEm±	1.90	1.17	1.99	1.11	7.69	0.50	0.50	0.02	0.13	0.78	0.68	2.59
CD (*p*=0.05)	5.66	NS	NS	3.29	NS	NS	NS	NS	0.39	2.31	2.01	7.68

PH (cm): Plant height (cm); NF: Number of days to first flowering (DAT); DF: Days to 50% flowering (DAT); NFP: Number of fruits plant^{-1}; AFW (g): Average fruit weight (g); PD: Polar diameter (cm), ED: Equatorial diameter (cm); PT.: Pericarp thickness (cm); YPt: Yield plant^{-1} (kg); P_1: Two shoots; P_2: Four shoots; P_3: Un-pruned (Control); C_1: Commercial capsicum hybrid-1; C_2: Commercial capsicum hybrid-2; T_1: Two shoots+Commercial capsicum hybrid-1; T_2: Two shoots+Commercial capsicum hybrid-2; T_3: Four shoots+Commercial capsicum hybrid-1; T_4: Four shoots+Commercial capsicum hybrid-2; T_5:Un-pruned (control)+Commercial capsicum hybrid-1; T_6: Un-pruned (control)+Commercial capsicum hybrid-2

(23.24 days). The unpruned treatments (T_5 Commercial capsicum hybrid-1 and T_6 Commercial capsicum hybrid-2) had the longest times to flowering 28.27 and 29.69 days. Earlier flowering in two shoot treatments was likely due to better resource allocation and enhanced photosynthesis activity Kurubetta and Patil (2009).

3.3. Days to 50% flowering

Days required to 50% flowering varied significantly with training levels. The plants trained to two shoots (P_1) recorded less number of days (33.99 days), followed by four shoots (P_2) (40.42 days), while unpruned plants (P_3) took the longest (45.17 days). The capsicum hybrid Commercial capsicum hybrid-1 (C_1) reached 50% flowering earlier (37.86 days) than Commercial capsicum hybrid-2 (C_2) (41.85 days), likely due to genetic differences. Among the interaction effect training hybrid combinations significantly influenced flowering. The earliest 50% flowering occurred in treatment T_1 Two shoots+Commercial capsicum hybrid-1 (31.07 days), followed by treatment T_2 two shoots+Commercial capsicum hybrid-2 (36.90 days). T_3 and T_4 (Four shoots+Commercial capsicum hybrid-1 Commercial capsicum hybrid-2^{-1}) took 39.30 and 41.53 days. Unpruned treatments T_5 and T_6 showed the highest number of days (43.20 and 47.13 days). Early flowering might be linked to higher pigment content and photosynthesis Maitra et al., (2024) and Alam et al. (2016).

3.4. Number of fruit plant^{-1}

For Number of fruits plant^{-1} the unpruned plants (P_3) recorded the highest fruit plant^{-1} (21.70), followed by four shoots

(P_2) (19.34) and two shoots (P_1) (14.75). The higher yield in unpruned plants was due to more fruit bearing shoots Singh and Kaur, (2018). The capsicum hybrid Commercial capsicum hybrid-1 (C_1) produced a greater number of fruit (21.39) than Commercial capsicum hybrid-2 (C_2) (15.80), likely due to genetic factors Maboko et al. (2012). Interaction effect of hybrid combinations significantly affected number of fruit plant^{-1} (Table 1). The highest yield was recorded in treatment T_5 unpruned+commercial capsicum hybrid-1 (23.71) and treatment T_3 Four shoots+commercial capsicum hybrid-1 (21.19) performed similarly to treatment T_5 and outperformed two shoot treatments. The lowest number of fruit plant^{-1} were in treatment T_1 Two shoots+commercial capsicum hybrid-1 (19.27) and treatment T_2 Two shoots+commercial capsicum hybrid-2 (10.24) Singh et al. (2004), Prasanth et al. (2024).

3.5. Average fruit weight (g)

The average fruit weight (g) showed significant differences across the training levels (Table 1). The highest weight was recorded in two shoot plants (P_1) (196.99 g), followed by four shoots (P_2) (180.52 g), while unpruned plants (P_3) recorded lowest weight (149.91 g). The capsicum hybrids Commercial capsicum hybrid-1 (C_1) produced heavier fruits (180.25 g) than Commercial capsicum hybrid-2 (C_2) (171.37 g), likely due to genetic differences (Kurubetta and Patil, 2008; Manoj and Venugopal, 2018). The interaction effect also recorded the highest average fruit weight was in treatment T_1 Two shoots+Commercial capsicum hybrid-1 (198.86 g), followed by treatment T_2: Two shoots+Commercial capsicum hybrid-2 (195.12 g). The lowest was in treatment T_6: Unpruned+Commercial capsicum hybrid-2 (145.68 g). The fourshoot treatments showed 187.74 g (Commercial capsicum hybrid-1) and 173.30 g (Commercial capsicum hybrid-2). While interaction effects were statistically insignificant for higher fruit counts plant^{-1} tended to reduce individual fruit weight due to limited metabolite supply Shukla et al. (2019), Maitra et al. (2024).

3.6. Polar diameter (cm)

Significant differences were (Table 1) recorded in polar diameter across training levels. The highest Polar diameter was in two shoots (P_1) (9.64 cm), closely followed by four shoots (P_2) (9.08 cm). The lowest polar diameter was recorded in unpruned plants (P_3) (6.43 cm). The capsicum hybrid Commercial capsicum hybrid-1 (C_1) recorded a larger polar diameter (8.82 cm) than Commercial capsicum hybrid-2 (C_2) (7.94 cm) Manoj and Venugopal (2018). The interaction effect showed maximum polar diameter in treatment T_1: Two shoots+Commercial capsicum hybrid-1 (10.03 cm), followed by treatment T_3: Four shoots+Commercial capsicum hybrid-1 (9.83 cm). The lowest was recorded in treatment T_6: Unpruned+Commercial capsicum hybrid-2 (6.25 cm). Fewer shoots allowed better nutrient distribution, leading to larger fruits Shukla et al. (2019).

3.7. Equatorial diameter (cm)

For equatorial diameter training level showed significant variation, the highest was in two shoots (P_1) (9.24 cm), followed by four shoots (P_2) (8.11 cm), while unpruned plants (P_3) had the lowest (6.34 cm) Alsadon et al. (2013). The capsicum hybrid Commercial capsicum hybrid-1 (C_1) showed a larger equatorial diameter (8.33 cm) than Commercial capsicum hybrid-2 (C_2) (7.46 cm), with yellow fruits outperforming red. The interaction effects were recorded statistically non-significant. The highest equatorial diameter was in treatment T_1: Two shoots+Commercial capsicum hybrid-1 (9.39 cm) followed by treatment T_2: (9.08 cm) and treatment T_3: Four shoots+Commercial capsicum hybrid-1 (9.05 cm). The lowest was in treatment T_6: Unpruned+commercial capsicum hybrid-2 (6.12 cm). Fewer shoots likely improved nutrient distribution, enhancing fruit size. Two shoot training led to the largest fruits, closely followed by four shoots Maitra et al. (2024).

3.8. Pericarp thickness (mm)

The pericarp thickness was a key to quality trait in capsicum, directly linked to shelf life and fruit firmness. The pericarp thickness recorded significant variation. Two shoots (P_1) recorded the highest (0.87 cm), followed by four shoots (P_2) (0.82 cm) and unpruned plants (P_3) had the lowest (0.74 cm). The capsicum hybrid Commercial capsicum hybrid-1 (C_1) showed higher pericarp thickness (0.82 cm) than Commercial capsicum hybrid-2 (C_2) (0.79 cm). The thicker pericarp in commercial capsicum hybrid-1 contributed to better shelf life by reducing moisture loss. In interaction effect (Table 1) the maximum thickness was recorded in treatment T_1: Two shoots+commercial capsicum hybrid-1 (0.90 cm), followed by treatment T_2 (0.84 cm) and treatment T_3: Four shoots+commercial capsicum hybrid-1 (0.82 cm). The lowest thickness was recorded in treatment T_6: Unpruned+commercial capsicum hybrid-2 (0.72 cm). Less number of shoots improved nutrient distribution, enhancing pericarp development and fruit quality Pathare et al. (2025).

3.9. Yield plant^{-1} (kg)

Yield was a key indicator of crop productivity, influenced by multiple factors. In present study, the yield attributes were central to evaluating capsicum performance under protected conditions. The training level factor (Table 1) showed significant yield differences. The highest yield plant^{-1} was recorded in four shoot training (P_2) (2.47 kg), followed by two shoots (P_1) (1.57 kg) and unpruned plants (P_3) (1.47 kg) Singh and Kaur (2018). The factor 2 capsicum hybrid Commercial capsicum hybrid-1 (C_1) outperformed Commercial capsicum hybrid-2 (C_2), recorded yield 1.99 kg vs. 1.68 kg plant^{-1}. The hybrid commercial capsicum hybrid-1 recorded superior performance to maximum number of fruits, fruit size and weight of fruit (Manoj and Venugopal, 2018). The significant variation was observed across combinations in interaction effect. The treatment T_3: four shoots+commercial capsicum hybrid-1 gave the highest yield (2.85 kg), followed

by treatment T_4 (2.09 kg). Two shoot combinations (T_1, T_2) recorded yield 1.61 kg and 1.54 kg, respectively. The lowest yield was recorded in unpruned treatments: T_5 (1.53 kg) followed by T_6 (1.41 kg), due to smaller fruits, lower fruit weight. Overall, pruning improved yield potential by optimizing fruit set and plant microclimate Jon et al. (2022) Pramanik et al. (2020).

3.10. Yield m^{-2} (kg)

Significantly variation was recorded in factor training level showed that fruit yield m^{-2} . The highest yield was recorded in four shoot trained plants (P_2) (14.81 kg), followed by two shoot (P_1) (9.44 kg), and unpruned (P_3) (8.82 kg). (Table 1) The capsicum Hybrid the yellow hybrid Commercial capsicum hybrid-1 (C_1) recorded significantly more (11.98 kg m^{-2}) than the red hybrid Commercial capsicum hybrid-2 (C_2) (10.06 kg), due to superior traits like fruit number, size, and weight Manoj and Venugopal (2018); Singh and Kaur (2018). In interaction effect significant yield differences were observed across treatments. The treatment T_3: Four shoots+commercial capsicum hybrid-1 recorded the highest yield (17.10 kg m^{-2}), followed by T_4 (12.53 kg). The two shoot trained Commercial capsicum hybrid-1 and Commercial capsicum hybrid-2 produced 9.65 kg and 9.24 kg m^{-2}, respectively Maniutiu et al. (2010). Lowest yield was recorded in unpruned treatments: T_6 (9.21 kg) followed by T_5 (8.43 kg), likely due to smaller fruits, lower weight and dense foliage that hindered microclimate and increased disease incidence. Overall, pruning (especially four-shoot training) improved yield by enhancing plant architecture and excellent fruit quality Waiba et al. (2021).

3.11. Yield plot^{-1} (kg)

In factor training level, the fruit yield plot^{-1} differed significantly, the four shoot training system (P_2) produced the highest yield (28.85 kg), followed by two shoot (P_1) (23.67 kg) and unpruned control (P_3) (20.31 kg) (Table 1). The capsicum hybrid Commercial capsicum hybrid-1 (C_1) outperformed Commercial capsicum hybrid-2 (C_2) with yield 25.35 kg vs. 23.20 kg plot^{-1}. The hybrid Commercial capsicum hybrid-1 superiority was due to better yield traits like maximum number of fruits, better size and higher weight Manoj and Venugopal (2018). The interaction effect significant differed across the treatments. The treatments T_3 (Four shoots+commercial capsicum hybrid-1) recorded highest yield (30.51 kg), followed by T_4 (27.20 kg). In two shoot trained system hybrid Commercial capsicum hybrid-1 and Commercial capsicum hybrid-2 recorded 25.22 kg and 22.13 kg yield Ahirwar and Hedau (2015). Lowest yield was recorded in unpruned treatments T_6 (20.29 kg) followed by T_5 (20.34 kg), possibly due to unfavorable microclimate. Overall, trained plants, especially under four shoot training system, performed better Manoj and Venugopal (2018), Prasanth et al. (2024).

3.12. Yield ha^{-1} (t)

The Yield ha^{-1} (t) demonstrated statistically significant variations in yield associated with different training methods. The four-shoot trained plants (P_2) had the highest yield (109.70 t ha^{-1}), followed by two shoot (P_1) (90.01 t ha^{-1}), and unpruned control (P_3) (77.26 t ha^{-1}). The hybrid Commercial capsicum hybrid-1 (C_1) recorded significantly more yield (96.40 t ha^{-1}) than Commercial capsicum hybrid-2 (C_2) (88.25 t ha^{-1}), due to superior yield traits like maximum number of fruits, size, and weight (Manoj and Venugopal, 2018). In interaction effect the yield varied significantly across combinations. The treatment T_3 (Four shoots+commercial capsicum hybrid-1) recorded the highest yield (115.98 t ha^{-1}), followed by treatment T_4 (103.42 t ha^{-1}). The two shoot training system in Commercial capsicum hybrid-1 and Commercial capsicum hybrid-2 recorded 95.87 t ha^{-1} and 84.16 t ha^{-1}. The lowest yield was found in unpruned treatments T_5 (77.35 t ha^{-1}) and T_6 (77.17 t ha^{-1}), likely due to dense foliage and poor microclimate. Overall, pruned plants, especially with four shoots treatment showed better yield potential Wani et al. (2011).

3.13. Benefit-cost ratio (B:C ratio)

The highest benefit-cost ratio (2.51) was observed in treatment T_3 (Four shoots+ Commercial capsicum hybrid-1), followed by treatment T_4 (Four shoots+Commercial capsicum hybrid-2) at 2.16.

4. Conclusion

The four shoot system of training performed better overall in both growth, yield and quality. Among hybrids, Commercial capsicum hybrid-1 outperformed Commercial capsicum hybrid-2 in plant height, fruit size, pericarp thickness and early flowering. The highest yield was recorded in T_3 (Four shoots+ Commercial capsicum hybrid-1). Thus, four-shoot training was recommended for higher yield and better quality in colored capsicum hybrids to get more monetary returns.

5. Funding Details

The authors gratefully acknowledge Centre of Excellence for Vegetables, KVK, Malegaon, Baramati, Dist. Pune, Maharashtra (413 115) India for providing the facilities and necessary support to conduct this research.

6. Acknowledgment

The authors sincerely acknowledge the support and facilities provided by Krishi Vigyan Kendra (KVK), Baramati, which were instrumental in conducting this research. We also extend our gratitude to the technical staff and field assistants for their valuable help during the experimentation.

7. References

Ahirwar, C.S., Hedau, N., 2015. Effect of shoot pruning on yield and quality attribute of a winter capsicum (*Capsicum annum* L.) crops in hills protected condition. Asian Journal of Bio Science 10(1), 1–5. DOI : 10.15740/HAS/AJBS/10.1/1-5.

Alam, M., Islam, N., Ahmad, S., Hossen, M., Islam, M., 2016.

Effect of different staking methods and stem pruning on yield and quality of summer tomato. Bangladesh Journal of Agricultural Research 41(3) 419–432. Available from: https://www.cabidigitallibrary.org/doi/pdf/10.5555/20163341323.

Alsadon, M., Wahb-Allah, H., Abdel-Razzak., Ibrahim, T., 2013. Effects of pruning systems on growth, fruit yield and quality traits of three greenhouse-grown bell pepper (*Capsicum annuum* L.) cultivars. Australian Journal of Crop Science 7(9), 1309–1316. Available from: https://www.cropj.com/alsadon_7_9_2013_1309_1316.pdf.

Anonymous, 2021. National Horticulture Board, Area, Production and Productivity of horticultural crops for the year, 2020–21. Available from: https://nhb.gov.in/Statistics.aspx.

Carrizo, G.C., Barfuss, M.H.J., Sehr, E.M., Barboza, G.E., Samuel, R., Moscone, E.A., Ehrendorfer, F., 2016 Phylogenetic relationships, diversification and expansion of chili peppers (Capsicum, *Solanaceae*). Annals of Botany 118, 35–51. doi: 10.1093/aob/mcw079.

Chaudhary, A.S., Singh, R.L., 2016. Effect of spacing, nitrogen and phosphorus on growth and yield of capsicum hybrid. Haryana Journal of Horticulture 381(2), 124–125. Available from: https://researchjournal.co.in/upload/assignments/3_12-14.pdf

Dasgan, H.Y., Kazim, A., 2003. Effects of plant density and number of shoots on yield and fruit characteristics of peppers grown in glasshouses. Turkish Journal of Agriculture and Forestry 27(1), 29–35. Available from: https://journals.tubitak.gov.tr/agriculture/vol27/iss1/5/.

Jon, A., Vijay, B., Samir, E.T., Deepanshu, Vishal, P., 2022. Performance of capsicum (*Capsicum annuum* L.) varieties in naturally ventilated polyhouse condition. Environment and Ecology 40(4A), 2252–2257. Available from: https://www.cabidigitallibrary.org/doi/pdf/10.5555/20230054216.

Jovicich, E., Cantliffe, D.J., Stofella, P.J., 2004. Fruit yield, quality of greenhouse grown bell pepper as influenced by density, containers and trellis system. Horticulture Technology 14(4), 507–513. Available from: https://era.dpi.qld.gov.au/id/eprint/14892/1/horttech-article-p507.pdf.

Kurubetta, Y., Patil, A.A., 2009. Performance of coloured Capsicum hybrids under different protected structures. Karnataka Journal of Agriculture Science 22(5), 1058–1061. Available from: https://www.scribd.com/document/181121742/Coloured-Capsicum-Hybrids-in Protected-Cultivation.

Maboko, M.M., Du Plooy, C.P., Chiloane, S., 2012. Effect of plant population, stem and flower pruning on hydroponically grown sweet pepper in a shade net structure. African Journal of Agricultural Research 7(11), 1742–1748. DOI: 10.5897/AJAR11.2078.

Maitra, S., Sairam, M., Santosh, T., Gaikwad, D.J., Sahoo, U., 2024. Growth, productivity and quality of colored capsicum (*Capsicum annuum* L.) as influenced by hybrids and plant growth regulators under controlled environment conditions. Research on Crops 25(2), 328–335. DOI: 10.31830/2348-7542.2024.ROC-1079.

Maniutiu, D., Sima, R., Apahide, A.S., Apahidean, M., Ficior, D., 2010. The influence of plant density and shoot pruning on yield of bell pepper cultivated in plastic tunnel. Bulletin UASVM Horticulture 67(1), 259–263. Available from: https://www.researchgate.net/publication/267372377_The_Influence_of_Plant_Density_and_Shoot_Pruning_on_Yield_of_Bell_Pepper_Cultivated_in_Plastic_Tunnel.

Manoj, P., Venugopal, S., 2018. Evaluation of capsicum hybrids under protected condition. Journal of Farm Science 31(1), 120–122. Available from: https://epubs.icar.org.in/ejournal/index.php/JFS/about/index.

Norris, R.F., Kogan, M., 2005. Ecology of interactions between weeds and arthropods. Annual Review of Entomology 50, 479–503. DOI: 10.1146/annurev.ento.49.061802.123218.

Pathare, A.M., Pawase, P.A., Bora, P.P., Rout, S., Bashir, O., Sharma, E., Roy, S., 2025. Advances in packaging technologies for capsicum: Enhancing shelf life and post-harvest quality through packaging film and coating technologies. Trends in Food Science & Technology 163, 105140. Available from: https://doi.org /10.1016/j.tifs.2025.105140.

Pramanik, K., Mohapatra, P.P., Pradhan, J., Acharya, L.K., Jena, C., 2020. Factors influencing performance of capsicum under protected cultivation: a review. International Journal of Environment and Climate Change 10(12), 572–588. DOI: 10.9734/ijecc/2020/v10i1230339.

Prasanth, S.R., Surendrakumar, A.R., Kavitha, K., Nagarajan, K., Venkatesan, Ravikumar, R., 2024. Engineering properties of colored capsicum crop for innovative robotic harvesting solutions in protected agriculture. Journal of Applied Horticulture 26(1), 73–77. https://doi.org/10.37855/jah.2024.v26i01.14.

Shukla, C., Acharya, S.K., Bhakar, S.R., Jamrey, P.K., 2019. Effect of different micro climate on the physiological parameters and yield of capsicum. Horticulture International Journal 3(2), 61–65. DOI: 10.15406/hij.2019.03.00113.

Singh, I., Kaur, A., 2018. Effect of pruning systems on growth and yield traits of greenhouse grown bell pepper (*Capsicum annuum* L. var. *grossum*). Indian Journal of Agriculture Research 52(4), 414–418. doi: 10.18805/IJARe.A-4997.

Singh, D., Kaur, S., Dhillon, T.S., Singh, P., Hundal, J.S., Singh, G.J., 2004. Protected cultivation of sweet pepper hybrids under net-house in Indian conditions. Acta Horticulture 659(68), 515–521. DOI: 10.17660/ActaHortic.2004.659.68.

Sood, S., Sood, R., Sagar, V., Sharma, K.C., 2009. Genetic variation

and association analysis for fruit yield, agronomic and quality characters in bell pepper. International Journal of Vegetable Science 15, 272–84. Available from: https://doi.org/10.1080/19315260902875822.

Waiba, K.M., Sharma, P., Kumar, K.I., Chauhan, S., 2021. Studies of genetic variability of tomato (*Solanum lycopersicum* L.) hybrids under protected environment. International Journal of Bio-resource and Stress Management 12(4), 264–270. Available from: https://ojs.pphouse.org/index.php/IJBSM/article/view/4105/1572.

Wani, K.P., Singh, P.K., Amin, A., Mushtaq, F., Zahoor, A.D., 2011. Protected cultivation of tomato, capsicum and cucumber under Kashmir valley conditions. Asian Journal of Science and Technology 1(4), 56–61. Available from: https://www.journalajst.com/protected-cultivation-tomato-capsicum-and-cucumber-under-kashmir-valley-conditions.