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Training systems in *Capsicum*: Effects on growth and yield under protected cultivation

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ABSTRACT

Capsicum (*Capsicum annuum* L.) is an important vegetable crop valued for its attractive fruit colours, nutritional properties, flavour and commercial demand. The crop is increasingly produced under protected conditions, where environmental factors can be managed more precisely and high-quality fruits can be produced for an extended period. However, vigorous vegetative growth, continuous branching and heavy fruit load can result in excessive canopy density, poor light distribution and competition among shoots and fruits. Training and pruning are therefore important practices for managing plant architecture and maintaining a suitable balance between vegetative and reproductive growth. Different systems such as single-shoot, two-shoot, three-shoot and four-shoot training regulate the number and arrangement of productive stems and consequently influence light interception, canopy structure, flowering, fruit development and assimilate distribution. The response to shoot number varies with cultivar, plant density, light availability, growing system and crop duration. Fewer stems may provide better conditions for individual fruit development, whereas additional stems can increase the number of productive sites and total fruit production when adequate resources are available. Excessive shoot retention, however, may increase competition and reduce light penetration, while severe pruning may decrease productive leaf area and fruit-bearing sites. Training can also influence fruit quality characteristics such as total soluble solids, vitamin C, and carotenoids through changes in fruit load and canopy microclimate. Therefore, the selection of a suitable training system is important for achieving a desirable balance among plant growth, yield and fruit quality. This review discusses the principles and major systems of training in capsicum and summarizes their effects on growth, flowering, yield components, fruit quality, canopy environment and practical crop management under protected cultivation.

Keywords: *Capsicum*, Training, Pruning, Shoot number, Protected cultivation, Canopy management, Yield, Fruit quality

1. Introduction

Capsicum (*Capsicum annuum* L.) is an important vegetable crop belonging to the family Solanaceae and is cultivated widely for fresh consumption, processing and culinary use. *Capsicum* is particularly valued for its attractive green, yellow, orange and red fruits, distinctive flavour and nutritional properties. The fruit contains vitamins, minerals and several bioactive compounds, including vitamin C, vitamin E, carotenoids, flavonoids and phenolic compounds, which contribute to its nutritional and functional value (Younes *et al.*, 2024) [1].

Protected cultivation provides a favourable environment for high-value vegetable crops by allowing better management of temperature, humidity, irrigation, nutrition and other environmental factors. It also helps reduce the direct effect of unfavourable weather conditions and can improve the uniformity and quality of produce. Recent reviews have highlighted protected cultivation as an important approach for increasing productivity and improving quality of horticultural crops under changing environmental conditions (Singh *et al.*, 2024) [2].

Capsicum responds well to protected cultivation because of its relatively long crop duration and high productivity potential. However, greenhouse conditions may promote vigorous vegetative growth and continuous branching. If the developing shoots are not properly managed, a dense canopy may develop, causing overlapping leaves, reduced light penetration and restricted air movement. Such conditions can affect flowering, fruit development and harvesting operations. In India, technical and labour-related constraints are also important considerations in successful protected capsicum production (Atheequlla *et al.*, 2023) [3].

Training and pruning are therefore important canopy-management practices in protected capsicum. Training directs the plant into a suitable architecture and provides support to productive branches, while pruning involves the selective removal of unwanted shoots or plant parts. Proper canopy management can improve the

distribution of light, facilitate crop operations and help maintain a balance between vegetative and reproductive growth (Barot *et al.*, 2023) [4].

Different training systems are used in protected cultivation of capsicum, including single-shoot, two-shoot, three-shoot and four-shoot systems. The number of retained stems influences the number of productive growing points, canopy density, fruit-bearing sites and resource distribution within the plant. Research has shown that shoot number can influence both crop growth and yield, but the optimum number of stems depends on the production environment (Yoon *et al.*, 2021) [5].

Thus, training should not be considered simply as a method of supporting the plant. It is an important component of canopy management that influences plant architecture, light interception, fruit load and source-sink relationships. The present review discusses the major training systems in capsicum and their effects on growth, yield and fruit quality under protected cultivation.

2. Training and pruning in Capsicum

Training: Training refers to directing the main shoot and selected branches into a desired plant structure. In protected capsicum production, the stems are generally supported using twines, wires or other structures so that the plant remains upright and the productive branches are properly distributed.

Pruning: Pruning refers to the selective removal of unwanted shoots, leaves, flowers or fruits. In capsicum, shoot pruning is mainly used to control the number of productive stems and remove weak or unnecessary branches. The purpose is not to remove as much plant material as possible but to develop a canopy that contains sufficient productive leaves and an appropriate number of fruit-bearing shoots.

Training and pruning are closely related practices. Training determines the arrangement of the selected stems, whereas pruning controls unwanted vegetative growth. Together, they help regulate canopy density, light penetration and fruit load.

3. Need and importance of training

Capsicum has a branching growth habit and can produce several lateral shoots after the main shoot branches. If these shoots are allowed to develop without management, the plant may become excessively dense. Such conditions can reduce light availability inside the canopy and increase competition among leaves, shoots and fruits.

The major purposes of training in capsicum are:

- To maintain a suitable plant architecture
- To regulate the number of productive stems
- To improve light distribution within the canopy
- To improve air movement around leaves and fruits
- To support branches carrying heavy fruits
- To distribute fruits more uniformly
- To facilitate spraying and harvesting
- To reduce unnecessary competition among shoots and fruits
- To maintain a suitable balance between vegetative and reproductive growth.

The importance of canopy management becomes greater under protected conditions because crops are often maintained for a long period and have continuous vegetative and reproductive activity.

4. Principles of training in Capsicum

- Training should begin at an early stage so that the desired plant structure can be developed before excessive branching occurs. Strong and healthy shoots should be selected as productive stems, while weak or poorly positioned shoots should be removed.

- The selected stems should be distributed properly around the supporting structure. Excessive overlapping of stems and leaves should be avoided because it can restrict light penetration and air movement.
- Pruning should be carried out carefully and regularly. Large shoots should not be removed unnecessarily because excessive pruning can reduce photosynthetic leaf area. At the same time, unwanted lateral shoots should not be allowed to grow excessively because they can become strong competitors for assimilates.
- The intensity of training should also be adjusted according to cultivar vigour, planting density and environmental conditions. A system suitable for a vigorous cultivar under high-light conditions may not give the same response under low-light or high-density conditions.

5. Major training systems in Capsicum

5.1 Single-shoot training

In single-shoot training, one main productive shoot is retained and unwanted lateral shoots are removed. The system produces a relatively simple plant structure with a limited number of productive growing points. The major advantage of single-stem training is that the available assimilates are distributed among a smaller number of productive sites. This can favour individual fruit development and fruit quality. Halshoy *et al.* (2025) [6] found that one-stem plants produced superior average fruit weight and favourable vitamin C and TSS values compared with the other training treatments evaluated under greenhouse conditions. However, maintaining only one shoot reduces the number of fruit-bearing sites per plant. Therefore, single-shoot training may not always produce the highest total yield. Its usefulness depends on whether the production objective is larger fruits, quality improvement or maximum total production.

5.2 Two-shoot training

Two-shoot training is one of the commonly used systems in protected capsicum. Two strong shoots are selected after the initial branching and are maintained as the main productive stems. Other unwanted shoots are removed regularly. The system provides a balance between canopy openness and the number of productive stems. It retains more productive sites than a single-shoot system while avoiding excessive branching.

Yoon *et al.* (2021) [5] compared two and three-shoot capsicum plants under greenhouse conditions with supplemental lighting. Two-shoot plants produced larger fruits, whereas increasing the number of stems increased total fruit production. This indicates that two-shoot training can favour individual fruit development when compared with a higher shoot number.

5.3 Three-shoot training

Three-shoot training maintains three productive stems on each plant. It provides an intermediate canopy structure between two and four-shoot systems. Increasing the number of stems generally increases the number of growing points and potential fruit-bearing sites. However, the additional stems also increase competition for light and assimilates.

Flores-Velazquez *et al.* (2022) [7] evaluated two- and three-stem systems in greenhouse-grown capsicum and found that shoot number affected fruit production and fruit characteristics. The response differed with cultivar, demonstrating that shoot number should be considered together with genetic characteristics.

5.4 Four-shoot training

Four-shoot training maintains four productive stems after controlled branching. It provides a greater number of fruit-bearing sites while keeping the plant structure organized. Four-shoot training can be useful when the crop has sufficient light, nutrition and growing space to support a greater number of productive stems.

Kumar *et al.* (2018) [8] evaluated two-, three- and four-shoot training systems under protected conditions and found that training influenced plant growth, flowering, fruit characteristics and yield. However, four shoots require regular management because unwanted lateral shoots may continue to develop. If canopy density becomes excessive, the additional stems may increase competition and reduce fruit size.



One-Shoot



Two-Shoot



Three-Shoot



Four-Shoot

6. Effect of training systems on plant growth

Training modifies the architecture of capsicum by changing the number of shoots, leaves and growing points. Shoot number can therefore influence plant height, leaf development, branching and biomass distribution.

A lower number of stems generally produces a more open plant structure, while increasing shoot number creates more growing points and may increase total leaf number. However, the leaves associated with additional stems may become smaller when resources and light are limited.

Hwang *et al.* (2023) [9] studied the effects of shoot number and supplemental lighting using greenhouse capsicum and three-dimensional canopy modelling. Their study showed that shoot number altered plant height, leaf characteristics and canopy light interception. Plants with more stems had greater competition for light and produced smaller leaves under some conditions.

7. Effect on flowering and fruit set

Flowering and fruit set are important steps in determining the final yield of capsicum. Training influences these processes by modifying the number and distribution of reproductive shoots. When the plant has excessive vegetative growth, assimilates may be distributed among a large number of growing points. Controlled training can reduce unnecessary vegetative competition and provide a more organized structure for reproductive growth.

Awalin *et al.* (2017) [10] reported that shoot pruning influenced growth and yield-related characteristics of capsicum, indicating that shoot management can alter the balance between vegetative and reproductive development. Severe pruning may remove productive sites, while insufficient pruning may create excessive competition. Therefore, moderate canopy regulation is generally more appropriate than excessive shoot removal.

8. Effect on number of fruits, fruit weight and yield

The number of fruits and fruit weight are closely affected by the number of productive shoots and fruit-bearing sites. More shoots may increase the number of fruits, but excessive fruit load can increase competition for assimilates and reduce individual fruit weight.

Gawade *et al.* (2025) [11] reported that unpruned plants produced more fruits per plant, whereas four-shoot training recorded higher overall yield. Yoon *et al.* (2021) [5] observed greater fruit weight in two-stem plants than in three-stem plants, indicating that fewer stems can allow better assimilate distribution to individual fruits. Parniani *et al.* (2022) [12] also reported that fruit-load regulation through pruning influenced fruit development and quality. Similarly, Kumar *et al.* (2018) [8] found that different training systems produced different responses in fruit number, fruit size and yield under protected conditions. Therefore, the optimum shoot number is influenced by the growing environment and crop management. Thus, proper training should maintain a balance between fruit number and fruit weight to obtain higher yield with good-sized fruits.

9. Training under hydroponic and soilless systems

Hydroponic and soilless systems provide precise control over water and nutrient availability and can support vigorous crop growth. This high growth potential makes canopy management particularly important.

Under such systems, plants may continue producing shoots and fruits for an extended period. Without appropriate training, the resulting canopy can become difficult to manage and may reduce light distribution.

Training systems should therefore be evaluated specifically under hydroponic conditions because responses observed in soil-based greenhouse cultivation may not always be directly applicable. Differences in nutrient availability, root-zone conditions and plant vigour can alter the optimum number of stems.

10. Factors determining the suitable training system

The optimum training system varies with production conditions. Important factors include:

10.1 Cultivar

Cultivars differ in vigour, branching habit, fruit size and crop duration. Therefore, the same shoot number may not give the same response in different cultivars.

10.2 Plant density

Higher planting density produces greater canopy competition. Training should therefore be adjusted according to the number of plants and shoot present per unit area.

10.3 Light availability

Stem number should match available light. Under low-light conditions, excessive shoots may increase competition, whereas sufficient light can support a larger productive canopy.

10.4 Crop duration

Long-duration crops require regular canopy management. Training systems should therefore be practical for repeated shoot removal throughout the crop cycle.

10.5 Growing system

Soil, substrate and hydroponic systems can produce different levels of plant vigour. The training system should be selected according to the growing system.

10.6 Labour availability

Training and pruning require regular labour. A system should therefore be evaluated not only for yield but also for the labour required to maintain it.

23. Conclusion

Training and pruning play an important role in regulating plant architecture, fruit load and yield of protected capsicum. Studies indicate that different training systems influence fruit number, fruit weight and total yield differently, with fewer shoots generally favouring larger fruits and increased shoot number favouring more fruit-bearing sites. Therefore, an appropriate training system should maintain a balance between vegetative growth, fruit number and fruit size for obtaining higher yield and better fruit quality under protected conditions.

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