



## **Factors Influencing Performance of Capsicum under Protected Cultivation: A Review**

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### **Authors' contributions**

*This article has been written in collaboration among all authors and each author contributed their specialization in this manuscript. Author KP designed the study, wrote the protocol and wrote the first draft of the manuscript. Author PPM has scrutinized the final writing. Authors JP and LKA managed the analyses of the study and correction in language. Author CJ managed the literature searches. All authors read and approved the final manuscript.*

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### **ABSTRACT**

Vegetables as the succulent pot herb are the most vulnerable to vagaries of climate change i.e. extreme weather events, such as elevated temperature, lengthy droughts, untimely rains, heavy rainfalls, violent storms, sea rising and resurgence of biotic stresses such as weeds, pathogens and their vectors, and insect pests. Adjoining to this, shrinking of cultivable land, limited natural resources, lower productivity, higher inputs cost, shortage of man power, low market price, hesitation among youth to choose farming as career etc. endorse the adoption of protected cultivation as the ultimatum to all these troublesome. In recent days, protected or greenhouse cultivation of high value vegetables like capsicum especially during offseason has been witnessed in increasing trends among small and marginal farmers as it is high value and low volume crop and produce higher yield in manifolds with superior quality. Protected structure not only delimits the abiotic and biotic stresses in capsicum cultivation but also accounts for higher economic remuneration to growers and provide a boost to their socio-economic development through

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adoption of improved package of practice such as mulching, drip irrigation, fertigation, training and pruning, better plant protection management, etc. Though, protected cultivation is remunerative but high initial investment, lack of technical guidance, non-availability of genuine building material for protected structure, torrential flood, cyclone etc. are major constraints and setbacks prevailed in developing countries like India for its adoption and commercialization. Therefore, this review covers all the aspects of protected cultivation in Capsicum to find an amicable solution through improved technologies.

**Keywords:** Climate change; greenhouse; biotic stresses; drip irrigation; fertigation; mulching.

## 1. INTRODUCTION

Capsicum (*Capsicum annuum* L. var. grossum Sendt;  $2n = 24$ ), christened as Bell pepper, Sweet pepper, Green pepper or *Shimla Mirch* is grown all over the world, encountered by Christopher Columbus in the Mexico and Central America region in 1493. It belongs to the Night shade family Solanaceae and is believed to be originated in the Tropical South America [1]. Capsicum renowned as highly remunerative vegetables and high value low volume crop cultivated natural and protected conditions in India [2]. It has special place in Indian foods because of its delicacy and pleasant flavour coupled with rich vitamins and minerals [3]. As far as nutritional aspects concern, 100 g of edible portion of capsicum fruits provides 24 Kcal of energy, 1.3 g of protein, 4.3 g of carbohydrate and 0.3 g of fat [4].

In India, it is considered as non-traditional category of vegetables and grown as Rabi and *Kharif* crop [5]. Protected cultivation is a cutting edge technology where partial to full control over environmental parameters can be achieved [6,7 and 8]. Capsicum is a cool season crop. Therefore it is quite cumbersome to get higher yields with desired quality fruits throughout the year under open conditions in most parts of India where tropical and subtropical climates prevailed more. But, protected structures like green house, shade net, poly house etc. make possible to cultivate capsicum even during the off-season for obtaining high quality fruits. Due to the medium height, lateral spreading and fruit set at comparatively lower temperature capsicum is very much suitable to greenhouse growing [9,10]. The protected cultivation of capsicum is always aimed to obtain high yield, good quality, improved shelf life and year around availability of pepper fruit [11]. Polyhouse cultivation of capsicum is witnessed as more profitable as compared to others protected structures [12]. It perform better under poly houses, poly-tunnels with plastic mulching [13,14].

Open field crop cultivation suffers various abiotic stress such as extreme solar radiation, high rainfall, high surface wind, weed competition and biotic stress such as insects and diseases [15]. The main objectives of cultivation of capsicum under protected structure is to protect against biotic and abiotic stresses especially, during the off-season. In India, capsicum cultivation is in primary stage of transfer and expansion in farmers' fields though it is highly profitable [16, 11,17,18,19,20]. Murthy et al. [20] opined that capsicum perform better under protected structure with respect to economic feasibility, higher yield, better fruit quality, superb appearance and ensure year round availability of capsicum.

Capsicum fruits with mild pungency, medium size tetra lobed fruits, longer shelf life, eye catching colour and superior taste are suitable for export market. However, due to the low productivity, the supply is inadequate in capsicum [21]. Climate change, shrinking of cultivable land, limited natural resources, higher inputs cost, shortage of man power, market price fluctuation, hesitation among youth to choose farming as career etc. always limit the cultivation of vegetables, capsicum in particular. It is pertinent to opine that protected cultivation delimits all these adverse factors for capsicum cultivation. Hence, by considering this as a future thrust, this review article has been documented meticulously to refer the different target personnel for further research and development thereof.

## 2. FACTORS INFLUENCING THE PERFORMANCE OF CAPSICUM

### 2.1 Temperature

Temperature is an important climatic factor which influences various physiological processes like germination, transpiration, respiration, photosynthesis, growth and flowering in plants [22]. The higher temperatures have more adverse influence on net photosynthesis than lower temperature leading to decreased

production of photosynthates above a certain temperature [23]. Temperature condition inside protected structures plays a pivotal role in growing of capsicum. Day temperature of 25-30°C and night temperature of 18-20°C suitable for growing of capsicum. If temperature exceeds 35°C or falls below 12°C, fruit setting is affected. 18°C night temperature inside greenhouse is most suitable for flowering and fruiting. Low night temperatures during growth and development of capsicum adversely affect the flower morphology, induce larger flowers with swollen ovaries, shorter styles and ultimately function of flowers than as compared to higher temperature growing condition [24,25]. Kato [26] opined that self-pollination in capsicum flower is affected with the large ovaries which push the anthers away from the stigmas. Number of pollen grains, pollen viability and vigour decrease with low night temperature which affects the capsicum production [27,28]. Improper pollination leads to small, deformed (flattened) fruits with few or no seeds are produced in capsicum when the plants suffers low night temperature [27,29]. Polowick and Sawhney [24] revealed that male sterile flowers with non-viable pollens are witnessed even when capsicum plants suffers non-extreme low day/night temperature of 18/15°C. Myster and Moe [30] opined that plant morphogenesis, internode length, plant height and leaf and shoot orientation are affected with differences between day and night temperatures. Fresh weight, number of leaf and fruit yield in bell pepper positively influenced by 24 hour mean temperature [31]. Generally, higher soil temperature of 2-3°C is observed under polyhouse as compared to open cultivation at all growth stages of crop as reported by Montero and Anton [32], Parvej et al. [33] and Bini Sam and Regeena [34]. Accumulation of carbohydrates in developing pollen before 3-4 days of anthesis is also affected with low night temperature injury [28]. Pressman et al. [35] researched that total plant biomass, plant heights, numbers of leaves of plants, sugar accumulation and other vegetative and reproductive parameters are greatly affected when plant exposed to low night temperature (LNT) as compared to optimal night temperature (ONT) and high day temperature (HDT) which can be prevented by markedly increasing daytime temperatures to 36±2°C. Basavaraja et al. [36], Sabir and Singh [37] and Gill [38] revealed that with occurrence of root zone temperature ranging 20-22°C vegetative growth parameters are improved in capsicum under polyhouse.

Vattakunnel and Sajitharani [39] recorded higher fruit length, number of fruits per plant, fruit yield per plant and total fruit yield in capsicum variety viz. Vellayani Athulya and Anugraha under polyhouse condition with an average air temperature of 24.88°C as compared to 3°C higher air temperature under open field condition during March to September. Higher air temperature accompanied with low humidity may cause dehydration in cells resulting permanent injury to the plant and cessation of growth which witnesses reduction in number of fruits per plant under open field condition [40]. Ganiger [41] reported that moderate air temperature ranges from 21.45°C to 27.71°C with prevalence of higher RH (88.50%) inside polyhouse endorse rapid multiplication of cells, better cellular elongation, higher vegetative growth and fruit yield in capsicum. Polyhouse has better protective ability against higher air temperature (3-4°C higher temperature than open field condition).

## **2.2 Relative Humidity**

The relative humidity increases the availability of net energy for crop growth and prolongs the survival of crops under moisture stress conditions, which leads to optimum utilization of nutrients. Higher relative humidity inside greenhouse is best suited for growing capsicum. Extreme fluctuation in relative humidity adversely affect the growth and development of the plant. It is crystal clear that higher RH is witnessed inside protected structure as compared to open condition. The various protected structures provide different level of relative humidity according to the insulation and ventilation capacity. Gill [38] recorded maximum humidity of 94.5% under walk-in tunnel followed by 90.1% under natural ventilated polyhouse and 88.5% under nethouse structure. Vattakunnel and Sajitharani [39] recorded higher Relative Humidity (RH) of 88.50% inside the poly house as compared to open field (86.70%). Relative humidity is inversely proportional to temperature under greenhouse where level of both can be manipulated according to requirement of crop plants. Capsicum plants perform better with high relative humidity of 80% as investigated by Basavaraja et al. [36], Sabir and Singh [37] and Gill [38]. Low humidity accompanied with higher air temperature may cause dehydration in cells resulting permanent injury to the plant and cessation of growth which witnesses reduction in number of fruits per plant under open field condition [40]. Ganiger [41] reported that

moderate air temperature ranges from 21.45°C to 27.71°C with prevalence of higher RH (88.50%) inside polyhouse endorse rapid multiplication of cells, better cellular elongation, higher vegetative growth and fruit yield in capsicum. Sabir and Singh [37] revealed that high relative humidity of about 80% positively influence plant growth and development in capsicum. However, excess temperature and relative humidity prevailing inside polyhouse aggravate the attack, development and spread of powdery mildew during the crop growth [42,43].

### 2.3 Light Intensity

Light is essential for the inevitable process like photosynthesis in plants. A certain light intensity influence rate of photosynthesis results in accumulation of dry matter content in plant body. Plant suffers compensation point due to minimum light intensity where the rates of photosynthesis and respiration are equal so that leaves do not gain or lose dry matter. Light has pivotal role in plant growth and development including morphology, phototropism and flowering. Long sun shine day produce more light intensity which increases stomata functioning leads to higher plant growth and development. Digital lux meter are used for measuring the light intensity by placing it over crop at 1 m height. Light intensity and photoperiod is manipulated in commercial greenhouses which is an important strategies to induce growth, flowering and fruiting in growing plants. Leite et al. [44] and Kittas et al. [45] revealed that the reflective aluminum shading nets lower summer temperatures and increases the winter temperature and it enhances conservation and reflection of solar energy which is efficiently trapped by plants canopies through photosynthesis. Nangare et al. [46] revealed that shade net house offers low light intensity as compared to open condition influence the quality, maturity as well as fruiting period and productivity in vegetable crops. Vattakunnel and Sajitharani [39] reported average light intensity inside poly house is 67.50 K. lux which is 21.90% lower than that of open condition (86.50 K. lux).

Capsicum performed better under polyhouse positively influenced by better light intensity as reported by Ilic et al. [47], Singh et al. [48], Ombodi et al. [49] and Gill [38]. Santana et al. [50] researched that growing of capsicum under photo-selective (red and blue) shading net house witnessed higher fruit yield and quality as compared to open field. Samanta and Hazra [51]

investigated that low fruit set and high incidence of bacterial wilt disease which are caused by high RH and low light intensity of 30,000 to 35,000 lux are main constraint of taking shade net house for sweet pepper cultivation. Samanta and Hazra [51] also reported that open field condition generates very high light intensity of 55,000 to 80,000 lux which is not congenial for fruit set in capsicum particularly for the red and yellow-fruited hybrids and fruit weight is increased when the plants face light intensity of 35,000 to 55,000 lux combined with the maximum/minimum temperature of 30 to 33°C/14 to 17°C under polyhouse condition which influences the flowering, fruit set and fruit development is most suitable for growing of capsicum.

### 2.4 Growing Media

In protected cultivation, the role of growing media is vital for successful raising of crops. In recent years, organic growing media such as cocopeat, vermicompost, FYM, rock wool, peat, perlite, vermiculite, soilrite etc., gaining importance as compared to soil which is the carrier of many harmful microbes and dwelling place of many insects and pests. Organic growing media are of natural origin rich in many macronutrients and micronutrients require for plant growths and developments. These hold adequate amount of water by draining excess water which suppress many fungal diseases and avoid water stagnation condition is a biggest advantage to vegetable crops as these are very susceptible to water logging condition. Growing media also improve the soil structure, biological and physical health of soil along with supply nutrients to plants in constant and steady manner. Kumar and Kohli [52] revealed that application of vermicompost as media in capsicum improve soil conditions, provides macro- and micro-nutrients which enhance plant metabolic processes and growth, synthesis and accumulates metabolites in plant tissues. Bijeta et al. [53] investigated maximum plant height, maximum fruit length, average fruit weight, fruit yield, early flowering, minimum days to marketable maturity and maximum harvest duration in capsicum with growing media i.e. Soil + Cocopeat + Vermicompost + FYM in proportion of 2:1:0.5:0.5 whereas, maximum overall growth is obtained with cocopeat, vermicompost and FYM. Roy et al. [54] inferred that plant growth parameters are improved with application of vermicompost alone and admixed with FYM and green manure in capsicum. Gungor and Yildirim [55] researched that fruit size and weight

significantly increased in capsicum growing in polythene bags with growing media peat: Perlite: Sand in a proportion of 1:1:1 while peat media positively influence the higher Vitamin C, Total Soluble Solids (TSS), number of fruits and yield. Hala et al. [56] reported that organic growing media are turned to nontoxic substance with the presence of earthworm which endorse higher economic return by improving plant growth. Bijeta et al. [53] and Llaven et al. [57] investigated highest number of fruits per plant and fruit breadth in bell pepper when grown with Soil + Cocopeat + Vermicompost (2:1:1) as growing media.

## **2.5 Plant Spacing and Density**

Both, plant spacing and density are correlated with each other. With increase in spacing, plant density decreases and vice versa. Wider plant spacing produce short and robust plant due to less competition between the plant for light, water, nutrients etc., but it may aggravate more weeds infestation. In case of closer plant spacing results in taller plants produced due to heavy competition among plants for natural resources but the weeds population is comparatively less. Generally, high density method is adopted in greenhouse for efficient use of natural resources and inputs to increase productivity. Resources such as water, nutrients, space and light are effectively utilized by better root spread in wider spacing of planting as reported by Ganjare et al. [58], Malik et al. [59], Roy et al. [54] and Kumar [60].

In capsicum, proper spacing endorse healthy competition among the plants result in production of marketable yield with superior quality and makes inter-cultural operations less tedious under polyhouse. Dharmatti and Kulkarni [61] and Sharma and Peshin [62] opined that increase in plant spacing result in increase in fruit and seed yield in capsicum. Singh and Naik [63] reported that plant spacing 50 cm x 30 cm and 50 cm x 40 cm produce maximum fruit yields in sweet pepper and highest net returns is recorded with 50 kg N/ha and 150 kg P<sub>2</sub> O<sub>5</sub>/ha with spacing of 50 cm x 40 cm. Guo et al. [64] revealed that plant population of 4.5 plants/m<sup>2</sup> yields higher than plant population of 2.25 plants/m<sup>2</sup>. Savic et al. [65] revealed that highest yield and lowest yield per plant is obtained with closer spacing and vice versa in capsicum. Gaye et al. [66] reported that increase in plant population results in decrease of vegetative and reproductive yield in capsicum. Cebula [67]

reported that plant spacing of 80 cm x 30 cm produce highest yield and the plant spacing of 80 cm x 71.7 cm produce higher fruit size in capsicum. Maya et al. [68] revealed higher fruit weight with closest spacing of 60 cm x 30 cm and higher levels of N and P of sweet pepper cv. California Wonder. Jovicich et al. [69] investigated that capsicum plants grown with population of 2 plants/m<sup>2</sup> produce higher total marketable yield and bigger fruit per plant. Patel et al. [70], Chaudhary and Singh [71] reported that the 60 cm x 50 cm plant spacing significantly produce maximum fruit yield per ha over 75cm x 50 cm spacing. Dasgan and Abak [72] reported that the plant spacing of 80cm x 30 cm and three shoots per plant is economical for cultivation of capsicum. Mantur et al. [73] reported that plant spacing of 45 cm x 30 cm produce maximum capsicum fruit yield, numbers of fruits per plant with high mean fruit weight as compared to 45 cm x 45 cm during summer season. Lee and Liao [74] researched that higher proportion of large sized capsicum fruits with highest marketable fruit yield is commenced with plant population of six plants per basket. Zende [75] and Kumar and Chandra [76] revealed that excellent quality and higher fruit yield in capsicum with closer spacing of 45 cm x 30 cm under polyhouse condition. Plant spacing of 45 cm x 45 cm witnessed good yield per unit area leading to the higher yield in capsicum cultivation [77]. Maniutiu et al. [78] reported that a significant increase in capsicum yield is obtained in 40000 plants/ha over 30000 plants/ha. Lone [79] revealed that the early flower initiation, early fruit setting, early first picking, higher fruit length, fruit breadth, fruit weight, shelf life, pericarp thickness, number of fruits per plant and fruit yield per plant are witnessed with wider spacing of 60 cm x 45 cm. But maximum fruit yield, net returns and benefit: Cost ratio of 1:1.39 is witnessed with plant spacing 45 cm x 30 cm in capsicum production under NVPH. Kumar and Chandra [76] revealed that 45 cm x 30 cm of spacing endorse greater flower count, fruit count, yield and higher benefit in Indra hybrid of capsicum under polyhouse condition. Ngullie and Biswas [80] reported that significantly maximum plant height and number of structural branches, fruit length, fruit diameter, fruit circumference, individual fruit weight and overall fruit yield are obtained with plant spacing of 45 cm x 60 cm in capsicum grown under low-cost polyhouse. Edgar et al. [81] recommended that the plant spacing 40 cm x 40 cm produce highest fruits yield per plant in cultivation of green pepper.

## **2.6 Training and Pruning**

Training and pruning in plants suppress apical dominance and facilitate lateral spreading, increase the number of branches, flower and fruits, maintain plant frame work, keep balance between vegetative and reproductive growth cycle, increase stem crotch angle, better light penetration to fruiting branches etc. In capsicum, training and pruning is operated 30 days after transplanting (DAT). The main stem of plant is tied with hessian string to train and the string is then tied to GI wire grid fixed on the top of the plants. Each newly emerged stems are trained along with the strings. Capsicum plants are pruned to retain 2 to 4 branches per plants according to purpose of adopting the pruning methods. Two branches pruned capsicum plants produce big size fruit with superb quality suitable for export purpose whereas, 4 branches pruned plants produce more number of fruits and higher yields. The tip of the plant is pruned at 5<sup>th</sup> or 6<sup>th</sup> node to allow 2 branches per plant and are allowed to grow. These two branches again pruned to have four branches per plant at an interval of 8-10 days of 1<sup>st</sup> pruning. One strong branch and one weak branch is allowed at every node to balance the diversion of food. Esiyok et al. [82] recommended pruning for obtaining a proper balance between fruit number and fruit size. Guo et al. [64] revealed that capsicum with 2 stems/plant yields higher than plant with 4 stem/plant. Cebula [67] reported that capsicum plant with two shoots/plant produce highest yield and the plant with two shoots/plant produce higher fruit size. Jovicich et al. [69] investigated that capsicum plants grown with four stems/plant produce higher total marketable yield and bigger fruit per plant. Saen and Pathom [83] revealed that four branch pruning increased plant height, fruit weight and fruit length in bell pepper variety CA-778. Thapa [84] reported that pruned yellow pepper plants produce more number of fruits and higher yield as compare to non-pruned plants. Capsicum plants trained with 2 stems per plant and fertigation dose of 350:350:350 kg/ha witness higher yield as reported by Cavero et al. [85], Dasgan and Kazim [86], Manohar Lal et al. [87], Ahirwar and Hedau [88] and Awal in et al. [89]. Similarly, combinations of fertigation @ 250:250:250 kg/ha and 4 stem pruning method recorded highest fruit yield per 1000 m<sup>2</sup> in capsicum as investigated by Xu et al. [90], Bowen [91], Tiwari et al. [92], Rwiza and Kisetu [93] in capsicum. Shoot pruning has vital role in inducing heavy vegetative growth and fruit yield in coloured capsicum as reported by Shaw and

Cantliffe [94] and Maniutiu et al. [78]. Dasgan and Kazim [86] and Maniutiu et al. [78] reported that capsicum plant is pruned according to number of branches (1 to 4) are to be retained. Different pruning system in capsicum such as two stem, three or four stems per plant is beneficial for easy training practices, allow HDP, produce larger fruits, early ripening, early picking and higher yields as revealed by Dasgan and Kazim [86], Alam [95], Awal in et al. [89]. Jovicich et al. [96] and Zende [75] researched better fruit set, early fruit ripening, high yield and large sized fruit are witnessed in capsicum under greenhouse. Lee and Liao [74] reported that double-stem capsicum plants endorse bigger sized fruits and highest marketable fruit yield. Lee and Liao [74] researched that higher proportion of large sized capsicum fruits with highest marketable fruit yield is commenced with double-stem per plant. Kumar and Chandra [76] revealed that 45 cm x 30 cm of spacing with 4 shoot per plant endorse greater flower count, fruit count, yield and higher benefit in Indra hybrid of capsicum under polyhouse condition.

## **2.7 Mulching**

Plasticulture is gaining momentum in recent modern farming in which different colour plastic mulch such as black, silver, red, white mulch are in use according to different purposes. Mulching is important intercultural operation performed in growing plants especially in Horticultural crops. It checks weeds growth, conserve soil moisture, regulate soil and air temperature, avoid soil crust formation and soil erosion adopted in both protected and open cultivation. Black mulch as a plasticulture reduces nutrient leaching loss, raise soil temperatures, control weeds and enhances yield in crop plants [97]. Mehta et al. [98] opined that black plastic much increases soil temperature, control weed plants and conserve of soil moisture.

In horticultural crops, 30-100 micron thickness with different durability mulch materials are used. Infra-red mulch produce higher soil temperature followed by black and silver plastic mulch. Root zone temperatures is affected by color of the mulch [99]. Ham et al. [100] revealed higher soil temperature under plastic mulches during winter months (Dec, Jan and Feb). Henry and Barbara [101] revealed 1<sup>o</sup>C higher soil temperature is witnessed under black mulch than white mulch. White and black mulch generate higher soil temperature of 5-8<sup>o</sup>C and 1-4<sup>o</sup>C respectively, than open condition [102]. White plastic is never

recommended in grown plant as generate higher 90°F soil temperature which may be detrimental growth and development instead it is only used for soil solarization. Color plastic mulches decrease the surface soil temperature by 2 to 3°C during summer and increase soil temperature by 3 to 5°C during winter inside greenhouse which endorse offseason growing of high value vegetables especially capsicum [103]. Silver and yellow mulch induce the plant survival and yield as these retard soil temperature. Jakhdhar [104] researched that black mulch generates 2.2 to 3.4°C higher soil temperature and significantly increased the yield of 20.7 to 29.8% as compared to bare soil.

Bowen and Frey [105] reported that bigger and more productive capsicum fruit with thicker pericarp and higher water content are produced when cultivated by using polyethylene mulch. Maximum number of fruits per plant, fruit weight, early and marketable fruit yield and total fruit yield are recorded in capsicum under polyhouse with black polythene mulching [106]. Kumar and Verma [107] researched that maximum plant height, flower number, fruit number, fruit set percent and yield per plant or per square meter are obtained with black polythene mulching along with fertigation in capsicum production under polyhouse. Gill [38] obtained high productivity of capsicum under NVPH with silver black polyethylene mulch (30 micron thickness) due to less weed infestation and improvement in soil moisture conservation.

## 2.8 Fertigation

Drip irrigation with fertigation is the most important component of precision farming endorse water and nutrient use efficiency, reduces water and nutrients loss along with enhances the crop yields. Fertigation is the precise application of water soluble nutrients with irrigation water direct to the plant root zone which helps in dispensing adequate amount of nutrient at appropriate concentration for growth and development of plants.

Goh and Haynes [108] and Salisbury and Ross [109] reported many metabolic intermediates are produced resulting earliness in reproductive phase due to fertigation. Patel and Rajput [110] reported that plants acquire water and nutrients demand through fertigation by mixing water and nutrients at right concentration is the most efficiency method of nutrient management. Silber et al. [111] reported that fertigation is responsible

for enhanced uptake of plant nutrients which has positive correlation with yield. Xu et al. [112] revealed that fertigation of Phosphorus at high frequency may overcome the deficiency. Locascio [113] revealed that precision, uniformity and use efficiency in nutrients application is achieved through fertigation with drip irrigation directly to root rhizosphere. Adoption of drip irrigation maximizes the water use efficiency (60-200%), water saving (20-60%), nutrients use efficiency (20-33%) through fertigation in addition improve the yield (7-25%) and quality of crop as against conventional methods [114]. Drip irrigation with fertigation increases the water use efficiency, fertilizer use efficiency and yield as against conventional methods of irrigation and fertilizer application [115].

Marschner [116], Xu et al. [90], Bowen [105], Tiwari et al. [92] and Rwiza and Kisetu [93] revealed that fertigation in capsicum has positive effect in improving fruit parameters results in higher yield per unit area under polyhouse. Gowda et al. [117] researched that the fertigation of 75 per cent nitrogen, phosphorus plus 100 per cent potassium along with inoculation of Azotobacter, Azospirillum, PSB and VAM witness maximum plant height, number of branches per plant, leaf area and dry matter production per plant in capsicum. Tumbare and Bhoite [118] reported capsicum performed better with respect to higher B: C ratio of 2.17 when N, P, K water soluble fertilizers is applied through fertigation. Santos et al. [119] investigated maximum plant height, leaf area, leaf dry matter, number of green fruit and fruit production are obtained with the application of water soluble fertilizers in bell pepper under plastic tunnels as compare to field conditions. Antony and Singhdupe [120] investigated maximum height, number of branches and yield in bell pepper with 100% drip irrigation as compared to conventional methods. Silber et al. [121] investigated that blossom end rot disease incidence in capsicum may reduce with increase in fertigation frequency. Mantur et al. [73] reported higher fruit weight, fruit yield per plant and fruit yield per m<sup>2</sup> in capsicum with N application during summer and *Kharif*. Solaimalai et al. [122] opined nutrient use efficiency as high as 90% witnessed and low leaching loss of 10% under fertigation as compared to 40 to 60% and 50% respectively, under conventional method. Chaudhary et al. [123] reported that growth parameters are improved with the application of nitrogen @ 200 kg N/ha in capsicum hybrid Indra. Gupta et al. [124] concluded that drip irrigation at 80% ET water along with fertigation

of 80% recommended NPK significantly improve the growth and yield attributes which achieves maximum fruit yield (366.48 q/ha) and B:C ratio (3.33:1) in Capsicum var. Nishat-1. Kumar and Verma [107] researched that maximum plant height, flower number, fruit number, fruit set percent and yield per plant or per square meter are obtained with fertigation of 250 kg NPK per hectare and black polythene mulching in capsicum production under polyhouse. IW/CPE ratio of 0.75 with 60 cm plant spacing, witness better dry matter accumulation, number of fruits per plant, fruit size, early yield, total yield, WUE and benefit cost ratio in capsicum cultivation under protected cultivation [125]. Brahma et al. [126] revealed that drip irrigation at 100% ET along with fertigation of 100% recommended N and K, significantly improve the growth attributes, yield attributes, ascorbic acid content and cost benefit ratio (1:1.72) in capsicum. Khan et al. [127] revealed that higher doses of NPK significantly increase quantity and quality of capsicum such as ascorbic acid content and capsanthin content. This is due to availability of soluble plant nutrients in soil throughout the active growth and development phase as reported by Bassiony et al. [128]. Vegetative growth parameters such as plant height and number of leaves are positively influenced by sole application of NPK at 250 kg NPK ha<sup>-1</sup> in capsicum [129]. Gupta et al. [115] recommended combination of 80 % ET through drip and 80 % RDF application with fertigation in capsicum var Nishat 1 witnessed higher yield, quality and water and fertilizer use efficiencies. Sanchita et al. [130] investigated that 61.09% increased yield, highest ascorbic acid content and highest cost benefit ratio (1:1.72) in capsicum are witnessed with fertigation of 100% recommended N and K. Ciba [131] revealed maximum plant height, number of primary and secondary branches, number of flowers/plant and yield attributing characters in capsicum under drip fertigation 100% RDF in addition with Bio stimulants. Kaushal et al. [132] reported maximum benefit-cost ratio (2.93 without subsidy) and (3.05 with maximum subsidy) in capsicum under low tunnel with combination of drip irrigation (IW/CPE ratio of 0.75) and low tunnel height (60 cm). Growth, yield and quality attributing characters in capsicum are improved with RDF of 150 kg/ha, 120 kg/ha, 60 kg/ha and 40 t/ha N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O and FYM respectively as reported by Malik et al. [58]. Shivakumar et al. [133] reported maximum chlorophyll content in leaves and fruit with spacing of 45 cm x 30 cm and RDF of 150 kg each NPK/ha + 30 t/ha FYM

in capsicum. Higher yield is witnessed when capsicum plants are grown with Black Polythene mulch of 25 micron thickness and fertigation of 100 per cent RDF under polyhouse [48,134,135]. Mohammad Hossein et al., [136] reported highest fruit volume and plant yield obtained in sweet pepper (*Capsicum annum* L.) with fertilization with 50 kg N/ha under open condition. Sabli et al. [137] researched that higher leaf area, total dry matter production, number of fruits/plant and higher fertilizer use efficiency are witnessed in bell pepper with fertigation of N and K. Bhuvneshwari et al., [138] found maximum plant height in capsicum with application of 75kg N and 60 Kg K per ha. Kanwar et al., [139] revealed positive effect of fertigation of 100% of RDF with black polyethylene mulch on fruit length (cm) in sweet pepper. Nagre et al. [140] reported maximum number of fruits per plant, average fruit weight and fruit yield per plant in capsicum var. Indira when grown under Soil: compost: sand media with fertigation @ 150:150:150 kg/ha NPK in addition basal dose of 50 kg/ha NPK and black polythene mulch. Pandey et al. [141] investigated that maximum yield, net income, water saving minimal disease and total irrigation time are witnessed in capsicum with drip irrigation and fertigation as compare to conventional methods. Biwalkar et al. [142] reported maximum fruit length, fruit width, fruit girth and pericarp thickness in yellow colour variety Syngenta Red of capsicum with combination of fertigation 120% and irrigation 100%. Sharma [143] reported that higher plant height, fruit length, fruit breadth fruits per plant and fruit yield per plant witness in capsicum with application 50 % more recommended dose as compare to other doses of NPK. Thenmozhi and Kottiswaran [135] investigated that capsicum plants grown under polyhouse with 50 micron black Polythene mulch and 80 per cent RDF as fertigation witnessed highest N, P and K fertilizer use efficiency). Kumar et al. [144] investigated that adoption of fertigation @ 25: 25: 25 kg NPK per 1000 m<sup>2</sup> and four shoot training system in addition with application *Trichoderma viride*, PSB (*Bacillus megaterium*), Azotobactor, *Pseudomonas fluorescens*, vermicompost and micro-nutrients at the time of planting produce higher yield and better net returns in capsicum.

## 2.9 Biotic Stresses

The constant and indiscriminate use of chemical pesticides has downgraded the soil health, imbalanced the ecology and increased the toxicity content of fresh fruits and vegetables. At



present world, the plants are most vulnerable to various insect and diseases due to appearance of pest resurgence problem. Various biotic factors like insects, diseases and nematodes are the major challenges in open field cultivation. Thrips a destructive pest of Capsicum pierce and collapse the plant cells resulting in the formation of deformed flowers, leaves, stems, shoots, and fruits besides causing the greatest threat to many crops, through the thrips vectored tomato spotted wilt virus (TSWV). In addition mite, aphid and fruit borer infect Capsicum under protected cultivation. Bacterial wilt is one of the major diseases of capsicum under protected cultivation with symptoms of rapid wilting and death of plants without yellowing or spotting of leaves. Damping off and powdery mildew are also found major diseases. Among nematodes, root-knot nematode (*Meloidogyne incognita*) is one of the most economically damaging plant-parasitic nematodes causing the development of root-knot galls that drain the plant's photosynthate and nutrients [145]. But most of the following studies by different scientists reveal encouraging result in protected cultivation as compared to the open field and it is the way forward. Adjoining to this higher production and superior quality vegetables can be achieved under protected cultivation. Bhatnagar et al. [146] reported that the incidence of leaf blight and fruit rot are less inside the greenhouse as compared to open fields. Takte et al. [147] investigated that high value crops are protected from various stresses like extreme atmosphere and insect-pests under plastic films and shade houses which also influence the crop production by ventilation. Singh et al. [10], Singh et al. [148], Singh and Sirohi [149], Yosepha [150] and Gill [38] researched that there is lesser insect-pest infestation in capsicum when grown under protected conditions. Minimum diseases are recorded under polyhouses which protect crop against major biotic and abiotic stresses, excessive rainfall and provide controlled environment as reported by Singh et al. [10,151]. Singh et al. [148] reported that high tunnel protect the capsicum crop against heavy rainfall, hails, cold wind and high humidity and also against bacterial wilt in plant and fruits as compared to open field cultivation. Kohnic et al. [152] revealed that significant decrease in infestation of aphids and thrips (*Frankliniella occidentalis*) in pepper production in greenhouses. Yosepha et al. [150] revealed that the yellow net is responsible for significantly lower infestation of aphids, thrips and incidence of viral disease as compared to other colour net in sweet pepper cultivation. Kaur et al. [153]

revealed that root-knot nematode population is low at the time transplanting, increases gradually in capsicum cultivation under net house. Anwar et al. [154] investigated that nine species of plant-parasitic nematodes viz., *Aphelenchus avenae*, *Helicotylenchus dihystra*, *Hoplolaimus columbus*, *Meloidogyne javanica*, *M. incognita*, *Pratylenchus penetrans*, *Radopholus smillis*, *Tylenchorhynchus claytoni* and *Xiphinema* sp. attack bell pepper cultivation under plastic tunnels and highlighted the integrated pest management approach to tackle these nematodes.

Owing to growing consumer demands for healthy and green produce, Integrated Pest Management (IPM) programmes using biorational pesticides are being increasingly used in greenhouse production. The use of good agricultural practices (GAP) and IPM are being increasingly advocated in protected cultivation [155]. Biorational pesticides such as agricultural spray oils and azadirachtin have been shown to be effective against the most common pests of protected cultivation [156,157,158].

### 3. CONCLUSION

With this review article, the following conclusions have been inferred;

- Protected cultivation is always advantage over open field cultivation for high value low volume crop like capsicum.
- Climatic condition such as day temperature of 25-30°C, night temperature of 18-20°C, 80% relative humidity and light intensity of 35,000 to 55,000 lux inside polyhouse endorse better performance of capsicum.
- Majority of researchers recommended a best media i.e. Soil + Cocopeat + Vermicompost + FYM in proportion of 2:1:0.5:0.5, feasible spacing i.e. 45-60 cm x 30-45 cm, suitable training method i.e. 2 stems per plant, black-silver mulch as an effective mulching material, fertigation of 100 % RDF @150:150:150 kg NPK/ha along with application of 30 t/ha FYM during final media preparation with integrated pest management encourages higher vegetative growth, yield and quality parameters, suffers less insects and disease attack in capsicum under polyhouse.
- Further research and development is utmost necessary in protected cultivation of capsicum particularly to delimit the

precarious effect of climate change in coming years.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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