Tomato performance in a protected structure: A review

Abstract

In the event of climate change, sheltered agriculture might offer plenty of opportunity for high-value vegetable crop production to occur during the "off" season. Tomato (*Solanumlycopersicum*L.) is one of the most significant high-value crops and a rich source of lycopene, β-carotene, phenols, flavonoids, and several vitamins. Growers can produce tomato fruit during the off-season and get higher prices in the market by using protected buildings like net houses, polyhouses, semi-high tunnels, and mulching.Through the modification of the natural environment, this technology has significantly improved productivity for areas with unfavourable weather conditions. In addition, it has extended the harvest period, increased yields, improved quality, increased production stability, and made fresh, high-quality produce available during the off-season, especially in Himalayan areas. From this study, it is pertinent to opine that tomato is high value vegetable crop in which protected cultivation is always advantage over open field cultivation.We highlight or briefly discussed the differences between growing tomatoes in an open field and under protection structure, as well as the growth characteristics, yield, and other quality parameters in this review.

Keywords:Tomato, Solanumlycopersicum, Protected cultivation, Open field condition, Yield

1. Introduction

Tomato (*Solanumlycopersicum*L.) is one of the most widely-grown greenhouse vegetables in the world (Viuda-Martos*et al.* 2014), and is highly demanded by fresh market. It plays a vital role in human health also (Li 2021). “Fresh tomato production was around 180 million tonnes worldwide in 2020. The top five tomato-producing nations are China, India, Pakistan, Turkey, and the United States, together generating more than 60% of the world's tomatoes. China is the country with the largest tomato production in the world, with an annual output of more than 65.15 million tonnes, accounting for one-third of the global tomato production”(Zhang et al.,

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2023).“Its output in India reached a peak in 2019–20 at 21.187 million tonnes (MT), and it has subsequently been in decline. It decreased to 20.69MT in 2021–2022 and 20.62MT in 2022–2023” (FAOSTAT, 2023). “Tomatoes are high in vitamin C, potassium, folate, and vitamin K, all of which are responsible for a variety of health benefits, including cancer prevention, heart health, and constipation prevention”(Megan 2017; Ramasamy 2018 andIslam 2019).“Furthermore, tomatoes have significant nutritional value and positive health impacts due to their potassium, ascorbic acid (Vitamin C), and lycopene levels.Tomato continues to be the most important vegetable in the world due to increasing commercial and dietary value, widespread production as well as model plant for research purpose”(kimura and Sinha 2008). Similarly, tomato is utilized as a fresh crop or processed into various forms such as paste, puree and juices.

“Tomatoes are planted both in the greenhouse and open fields. Therefore, developing a sustainable production system is essential for improved crop growth and a consistently high tomato yield” (Zang*et al.* 2023). “In the plains of India, tomato is mainly grown as Rabi crop.However, in the Himalayan region, it is mostly grownas summer season crop. In in trans-Himalayan region of Ladakh its production is limited due to harsh climate, short growing season and extreme temperature fluctuations. Hence, protected cultivation is a feasible answer for successful cultivation of tomato in this region” (Kanwar 2011).“With the innovative technique of protected cultivation, environmental conditions can be partially or completely controlled”. (Baghel*et al.* 2003;Navale*et al.* 2003 and Wani*et al.* 2011).Singh and Asrey (2005) “recommended that cultivation of tomato in a greenhouse would help to obtain high productivity and better return. The greenhouse environment encompasses climatic and nutritional elements, along with structural and mechanical conditions”. “If properly managed, it can significantly increase fruit quality and yield. Since the costs associated with greenhouse cultivation are generally higher, due to the initial investments in the structure”(Shamshiri*et al.* 2018). The protected cultivation of tomato is always aimed to obtain high yield, good quality crop, improved shelf life and year around availability of tomato fruit (Parvej*et al.* 2010; Gupta *et al.* 2017 and Sotelo-Cardona 2021).“The parameters of economic importance like fruit weight and yield are better under protected conditions but the nutritional parameters like vitamin C and lycopene content are higher in open conditions” (Rana *et al.* 2014). “Cultivation of tomatoes

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under protected structure protects tomato fruit from biotic and abiotic stresses especially, during the off-season.Alsoincreases yield by increasing fruits per plant, fruit weight, fruit length and fruit diameter" (Aberkain*et al.* 2006 and Parvej*et al.* 2010)."Under protected structures such as net houses and polyhouses, growers can produce tomato fruit during the off-season and receives higher prices in the market. If these structures are carefully maintained, it will increase productivity and net returns per unit area, and also keep pests away" (Ramasamy and Ravishankar 2018).Rana *et al.* (2014) "also observed that tomato crop grown extensively in the plastic greenhouses increase productivity". "The environmental factors affecting greenhouse tomato include air and root-zone temperatures, relative humidity (RH), light conditions (L), disease and insect intervention, as well as carbon dioxide" (Jones, 2013). "Microclimatic parameters are directly affected the fruit yield and quality of tomato" (Kittas*et al.* 2012 and Shamshiri*et al.* 2018). "Different techniques and methods of determinant and indeterminate varieties of tomato planting under open-field and greenhouse conditions are available in the textbooks" of Van Ploeg and Heuvelink (2005);Cherie (2010); Hochmuth and Hochmuth (2012)and Jones (2013).

The main obstacles to growing vegetables particularly tomato is climate change, shrinking agricultural land, water shortages, rising seed and input costs, a lack of qualified labour, market price volatility, the appearance of illnesses and insect resurgence, etc. In order to support the protected production of tomatoes and to recommend various scholars for upcoming research and development, this review paper has been painstakingly documented.

2. Performance of tomato under protected cultivation as compare to open field cultivation

Protected cultivation of vegetables endorses effective use of the soil nutrients, soil moisture, humidity, temperature, CO_2, light intensity etc., which results in increase the production and quality vegetables by delimiting biotic and abiotic stresses whereas in open cultivation plants suffer a great damage due to weeds, insects and diseases with limited use efficiency of natural resources and environment factors. Greenhouse is the present trends in Indian agriculture where the crop is raised under fully automated or partly artificially manipulated environment endorse higher production and productivity as compared to open filed cultivation (Navaleet*et al.*

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2003). Takteet*et al.* (2003) revealed that polythene sheet and shading nets avoids extreme sunshine, chilling, freezing, high wind and biotic stresses. Environmental factors like day and night temperature, air relative humidity, light intensity, light period, CO_2 concentration, water availability, nutrient availability, plant population, plant media etc. are significantly maintained in greenhouse for crop cultivation (Baghel*et al.* 2003 and Wani*et al.* 2011). There is drastic increase in the resource-use efficiency through protected crop cultivation in comparison to the conventional open field cultivation (Choudhary2016). Tomato production has undergone many changes in the way as it is being grown in different regions, since different limiting factors including climatic conditions, availability of water and nutrients, and quality and quantity of light must be taken into account to provide appropriate conditions for the optimal growth and development of the crop. Because of their sophisticated light-perception system, plants are able to modify and optimize their metabolism and performance in response to the specific environmental factors that are most common. As observed by Arsovski*et al.* (2012), that light affects many developmental and physiological processes which include germination (Bentsink and Koornneef 2008), flowering (Alvarez-Buylla 2010) and direction of growth (Pedmale 2010). The growing conditions especially light and temperature are also known to influence both composition and quality of tomato fruits. Ganesan (2002) “reported that plant height is better in polyhouses as compared to open field conditions”.“The environment in the polyhouse favour the growth and development of tomato plant through increased plant height, number of branches,stem grithand yield” (Mishra *et al.* 2003; Kang and Sidhu 2005 and Rana *et al.* 2014). “However, fruits harvested from open field had higher TSS, acidity, total sugar, ascorbic acid and the lycopene content than the fruits grown under protected conditions”(Loures2001 and Rana *et al.* 2014). “Therefore, both types of environmental conditions are favourable in some aspects. Protected cultivation had a significant impact in improving the crop productivity, employment and income generation. Furthermore, protected cultivation attains more stable income than open field cultivation” (Singh and Sirohi 2006; Singh *et al.* 2011; Mwangi 2012and Mehta *et al.* 2020).Therefore, it is necessary to grow tomatoes in protected environments like net houses, poly houses, and green houses, among others, in order to acquire high-quality produce and production throughout the off-season. Green houses have a great deal of potential to increase tomato yield (Chandra *et al.* 2000 and Dixit *et al.* 2018).

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3. Performance of capsicum for vegetative growth parameters

“An appropriate environmental condition inside polyhouse promotes robust cell division and cell enlargement in the terminal portion of the plant, which supports the maximum plant height, the greater number of leaves per plant, a greater number of branches per plant, and overall plant growth.In Tomato, a greater number of branches and better plant height reported in polyhouses as compared to open field conditions” (Ganesan2002 and Kanwar2011). “Total fruit bearing period was also prolonged under polyhouse. For that reason, total number of fruit harvests was more in polyhouse than open field” (Pandey *et al.* 2004 and Cargneluttie*t al.* 2004). Plant spacing and stem pruning are the two most important factors. Optimum plant spacing may help in proper utilization of land and high-quality fruits. However, stem pruning may influence the production of yield (Ara *et al.* 2007). Suitable day and night temperature, relative humidity and light intensity are available in polyhouse resulting in increasing yield by improving the vegetative characters in tomato (Adams *et al.* 2001). Foolad and Lin (2000) attempted to connect tomato vegetative development to cold tolerance during seed germination. They discovered that there was no connection between the two and suggested that distinct genes are engaged at these developmental stages. Therefore, it's possible that characteristics that affect fruit output at lower temperatures have little to do with growth during the vegetative stage.Ulukapi*et al.* (2009)reported that the average fruit weight and quality increased with fruit reduction on the stem, and accordinglythe plantyield increased. Leaf and side branch pruning has been shown to improve final output in a number of ways. According to Khoshkam*et al.* (2014), “training increases a plant's capacity to absorb sunlight, which is essential for its growth and development. It is also important to maintain adequate air movement around the plant to reduce risk of fungus and insect problems. A dense canopy of leaves shades the fruits, causing them to be pale”. Rana *et al.* (2014) “reported that tomato plants grown in polyhouse climate produced about 50% higher fruit yield than the tomato plants grown in open field conditions”. “The significantly higher yield in the plants grown under polyhouse condition over the plants grown in the open field was associated with the production of higher number of fruits with greater length and diameter and fruit weight than those in open field” (Kang and Sidhu 2005 and Parvej*et al.* 2010).

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Dixit *et al.* (2018) “reported that different combinations of organic manures i.e., FYM, Vermicompost and Poultry manure are the best treatment for better plant growth and flowering of tomato under protected structure”. Reddy *et al.* (2002); Patil *et al.* (2004) and Poul *et al.* (2004) “also reported that organic manure increase plant growth and yield”. “The use of FYM was found to be the most important variable and showed a significantly positive relationship with the yield of tomato under-protected and open-field conditions as reported” by Mehta *et al.* (2020).

4. Performance of tomato for yield parameters

Tomato yield is a function of the entire plant's growth rather than a single feature. A tomato plant will never produce a large amount of yield if it does not grow well. Thus, the relationship between plant form, physiology, and growth circumstances determines yield (Van der Ploeg and Heuvelink 2005). “Tomato yield in the tropics is much lower than that in the temperate zone due to several factors like high humidity, high temperature, excessive rainfall, disease and pest” (Opena 1985).Temperature has a major impact on crop phenological growth and output (Awal *et al.* 2003). Plants grown in greenhouse have favourable environmental conditions that enable more effective use of water and nutrients, ensuring that the crop's genetic potential is fully expressed for growth and production. However, decrease in temperature will also affect the growth and development of plant including biomass production, fruit growth and yield(Heuvelink1995 and Van der Ploeg and Heuvelink 2005). According to Adams *et al.* (2001), “trusses form more quickly at higher temperatures. Because of the shorter fruit growth period and faster initiation of new trusses at higher temperatures, early yields are higher” (De Koning 1989 and Adams *et al.* 2001). “Tomato plant grown under polyhouse was observed to be earlier in flowering and fruit setting by about 3 and 8 days, respectively when compared to the crop raised under open condition”(Ganesan 2002). “Microclimate inside protected structures influences the flowering and fruiting during winter months which is helpful for higher yield in tomato” (Rylski*et al.* 1994; Kang *et al.* 2005 and Parvej*et al.* 2010). Kumar and Arumugam (2010) “observed that the growth and yield parameters of different vegetables were significantly enhanced under protected over open field”. “Similar results were also observed” by Kumar *et al.* (2016).Parvej*et al.* (2010) “reported that under polyhouse plants had higher number of flower clusters/plant, flowers/cluster, flowers/plant, fruit clusters/plant, fruits/cluster and fruits/plant, and fruit length, fruit

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diameter, individual fruit weight, fruit weight/plant and fruit yield then open field condition.Also,tomato yield obtained from the polyhouse was 81 t/ha against 57 t/ha from the open field".Kanwar (2011) "reported that variety 'Shivalik' performed best with respect to yield followed by 'Pusa Rohini' under polyhouse conditions. Moreover, cultivation of tomato under the polyhouse produced 136.12% more yield per ha and 188.93% more fruits per plant compared to open field cultivation".Khadka and Adhikari (2021) "reported that not only yield but also gross return, gross margin and net profit from polyhouse farming of tomato was 60.14%, 68.25%, 74.32% and 69.97% respectively higher than that of open field farming".Kanthaswamy*et al.* (2000); Nagalakshmi *et al.* (2001); Gaikwad *et al.* (2002); Srivastava *et al.* (2002); Mishra *et al.* (2003) and Kang and Sidhu (2005) "reported that higher values of all the yield components and yield of tomato crop grown under polyhouse was due to the taller plants and much number of branches with greater Leaf area index attributed by warmer temperature". "Although lower amount of available PAR (Photosynthetically active radiation) under polyhouse could not affect the growth and yield of tomato" (Aberkain*et al.* 2006 and Marcelis *et al.* 2006)."Overall, to obtain higher yields under this production system, it is important to reduce the elevated temperature and increase the relative humidity inside the protective structures to be adapted for local growing conditions.The improved microclimate within the polyhouse, which included winter temperatures 4-9°C higher than in the adjacent open field, was primarily responsible for the early and higher output of several vegetable crops". (Cheema *et al.* 2004). Thus, the polyhouse environment may provide a new scope for commercial production of high value vegetable crops like tomato.

5. Performance of tomato for quality parameters

Plants grown in open conditions face unfavourable weather and biotic stresses, which leads to lower-quality yield production. In contrast, plants grown in greenhouses yield higher-quality produce because of favourable environmental conditions and lower rates of weeds, diseases, and pests. "Morphological development like plant height, number of branches per tomato plant, leaf area expansion rate and leaf area index were positively favoured due to the warmer environment inside the polyhouse" (Duhr and Dubas 1990; Miah, 2001 and Pandey *et al.* 2004). "Environmental factors, including light and temperature, may influence the chemical and nutritional composition of tomatoes, including lycopene, accounting

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for 80-90% of the total pigments presented in ripened tomato"(Garcia-Valverde*et al.* 2013). Hormonal action is influenced by environmental conditions, which can lead to early blooming, fruit setting, increased fruit production, and increased fruit count. Occurrence of various limiting factors like biotic and abiotic stresses can be minimized under protected structures (Sotelo-Cardona *et al.* 2021). Moreover, fruits produced in open field were more acidic (0.49%) than fruits produced in a protected environment (0.40%) (Rana *et al.* 2014). Frusciante *et al.* (2000) "reported that fruit grown open filed condition have higher ascorbic acid rather than fruit grown in protected environment condition. It may be a result of the lower photosynthetic activity of the plant (shading in protected environment) in this environment and lower carbohydrate accumulation in the fruits". Rana *et al.*(2014)"also observed that Genotype influenced the lycopene content of fruit, while the environment did not influence this characteristic"."Cherry tomatoes have also been earlier reported to contain higher content of lycopene than local ones under open conditions" (Raffo*et al.* 2006).

"Moreover, studies had shown that color shading structures improved tomato fruit quality and carotenoid content" (Sotelo-Cardona *et al.* 2021). "Because coloured shade nets enable a better use of the sun's energy due to the modulation of the radiation spectra that reach the crops, thus promoting physiological responses in plant and fruit development, including leaf area index, chlorophyll and carotenoid contents, tissue structure, fruit ripening, physiological disorders, nutritional quality, etc". (Ilic and Fallik 2017). "In contrast, during tomato production, high temperatures and high solar radiation may reduce lycopene and β-carotene levels resulting in fruit damage, sunscald and increasing unmarketable fruit yield" (Diaz-Perez 2014). Studies also reported that colour net houses provide a positive effect on tomato production in terms of improvement in morphometric parameters like taller plants,larger terminal leaflets compared to those plants grown under open field conditions.According to Gupta *et al.* (2017), "tomato varieties grown in open fields and poly houses have varying in flowering time.Phenological development governs the plant growth and productivity"."Days to flowering, fruiting and maturity of crop are the important phenological events which determine the productivity of a crop" (Parvej*et al.* 2010).

6. Conclusion

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From this study, it is pertinent to opine that tomato is high value vegetable crop in which protected cultivation is always advantage over open field cultivation. Naturally ventilated greenhouse cultivation endorses maximum plant height, number of leaves, number of branches per plant and overall vegetative growth intomato. Moreover, Improved yield parameters such as early flowering and fruiting, a greater number of flower and fruits per plant, better fruit set, early fruit ripening, maximum fruit size and weight, early first harvesting,total yield are increased in tomato with superior quality fruit are obtained under polyhouse growing.

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