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Protected Vegetable Crop Production for Long-term Sustainable Food Security

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A protected culture strategy that offers a fully regulated environment decreases a number of biotic and abiotic stressors. Thinking about protected farming is necessary given the rising food need. The most effective way for meeting the goals of protected horticulture is the greenhouse. The cultivation of many greenhouses has become an important Indian agricultural policy. As a result of the greater productivity levels, these technologies are not only opening doors for producers with larger landholdings, but also for those with smaller holdings. Protected agriculture has provided a new way to produce more in a small space as a result of land holding restrictions, fast urbanisation, falling crop yield, declining biodiversity, and an ever-increasing population. Demand for food, particularly vegetables, has increased significantly as a result of these factors.

Keywords: Protected vegetable; protected horticulture; crop production; food security.

1. INTRODUCTION

India's economy has always been centred around agriculture, but the last 50 years have shown us that there is a link between agricultural practises and prosperity. A combination of noteworthy achievements and missed opportunities may be seen in the path of agricultural growth [1]. In order to ensure food security for the impoverished, preserve self-sufficiency, and export superior fruits and vegetables, India's agricultural industry must consistently boost its productivity, profitability, and respectability through the use of innovative and efficient production technology. One such area is protected cultivation technique, which is utilized sparingly in India but widely in wealthier countries. The wide variations in geography and weather conditions across the nation allow for a wide variety of cropping patterns [2]. Extreme weather events including floods, droughts, and other climatic abnormalities are very common in India and can cause agricultural losses or damages that are expensive for farmers. Over the past ten years, the demand for high-quality agricultural products has grown concurrently. This gives Indian farmers better options to employ protected agriculture techniques according to their region and the compatibility of the crops. High-quality seedlings, export-quality cut flowers, and exotic (non-native) and off-season crops are all produced in commercial greenhouses. The financial rewards from high-value agricultural goods can be greatly increased when they are grown in greenhouses [3]. To avoid residues from affecting agricultural yield, chemical herbicides and insecticides should only be applied sparingly to crops growing in protected areas [2].

The majority of greenhouses are utilized as rain shelters, particularly in the northeastern and coastal districts of India which receive a lot of rain. The majority of vegetables cultivated under protected culture include radish, cucumber, broccoli, red cabbage, yellow and red bell peppers, tomatoes, and green vegetables. In the northern plains of the country, most vegetable kinds cultivated there are open-pollinated and grown in two growing seasons, during the summer and the rainy season. In India, the main method of producing vegetables is open-field farming. Many diseases and pests commonly afflict crops grown in open spaces, which lowers production and results in low-quality food [4]. However, many vegetables are oversaturated in the marketplaces during their peak season, and sometimes vegetable producers are even losing money on their crops. In contrast to other parts of the nation, the same veggies are sold at astronomically high prices during the off-season. Due to the continuous shift in consumer tastes towards high-quality, off-season food and the continued development of availability, the demand for off-season veggies is rapidly increasing in several of the country's main cities [4].

The harsh winters and intense summers of the north Indian plains make it necessary to maintain a balance throughout the year. Furthermore, there is usually a severely inadequate supply of water in these areas. A tiny degree of protection against biotic stressors and meteorological aberrations greatly increases the productivity of horticultural crops under such climatic circumstances [5]. The growing population, climate change, declining land holdings, rising demand for premium fresh horticultural food, and mounting pressure on natural resources like

water and land have forced us to adopt modern crop production techniques like protected cultivation [6]. Currently, only 70,000 hectares of land are utilized for the protected cultivation of horticultural crops, and a large portion of that area—especially in northern India—is not utilized for this purpose successfully [7]. Plastic tunnels saw a significant rise of 60.5% between 2007 and 2012. Covered by plastic tunnels, protected horticulture occupied 4.3% of the total area in 2012.

2. PROTECTED CULTIVATION: DEFINITION

Cropping strategies that partially or entirely manage the microclimate surrounding the plant body throughout growth, according to the needs of the species being cultivated, are known as protective farming practices (Mehta & Savita, [8], Mishra *et al*., [9]. The many kinds of protective farming techniques have been adopted according to the current climate. A greenhouse or polyhouse is particularly helpful for year-round food growing in temperate climates. Protected agriculture, sometimes referred to as controlled environment agriculture (CEA), is extremely productive, environmentally friendly, and sparing with regard to water and land use [10].

3. PRESENT SCENARIOS SURROUNDING PROTECTED CULTIVATION

India was first introduced to highly advanced protected vegetable growing and alternative high-value agricultural manufacturing through the Indo-Israel greenhouse cultivation project, which was started at the New Delhi-based facility. Indian Agricultural Research Institute (IARI) in 1998, not long after diplomatic relations were established with that nation [11]. At the end of the five-year project, in 2003, the Israeli consultants departed the Asian nation; nonetheless, IARI remained to manage the career and abilities of the Center for Protected Cultivation Technology (CPCT) [12]. It has, within the past ten years, managed to refine and up market the system to scale back prices, besides coming up with greenhouse structure to suit native conditions. By the end of the 20th century, there were over 100 ha of greenhouse space in Asia and over 275,000 square feet worldwide [13]. This room ought to have grown by 10%, at the very least, over the past ten years. Andhra Pradesh is one of the states that continually increased the area under protected agriculture between 2007 and 2012. Maharashtra and Gujarat. Punjab, West Bengal, Tamil Nadu, and Haryana. Up till 2012, protected cultivation covered a total area of 5,730,23 hectares in Maharashtra and 4,720,72 hectares in Gujarat, respectively. Approximately 30,000 acres of land are currently covered in protected cultivation in our nation. Leading states with protected cultivation include Punjab, TN, UK, MH, KT, HP, and N-E States. The most significant crops that have reached full maturity within the protected cultivation are tomatoes, capsicum, melons, roses, gerbera daisies, carnations, and chrysanthemums [8].

3.1 Why Protected Cultivation?

The production of vegetables in open fields is hampered by a number of factors, including high insect pest infestation pressure [14], fungal diseases (Sringarm *et al*., 2013), heavy rain, thunderstorms, excessive solar radiation, temperatures, and humidity levels above plant growth optimums. According to Trivedi and Singh [15], the main determining element in horticulture crops is the environment. Protected cultivation is utilised to reduce the impact of the environment. The sustainable method for growing vegetables in unfavourable weather is protected cultivation. In addition to being shielded from harsh weather conditions, vegetables grown in protected areas produce vegetables of superior form, size, and colour (Sringarm *et al*., 2013). It is possible to alter the microclimate inside the polyhouse. A UV opaque covering material for poly houses helps to prevent insects from entering the house because some insects need UV light for their eyesight purposes. As a result, insecticide usage is minimal. Due to the favourable interior microclimate and greater price, vegetable production is higher than in open fields. The term "protected cultivation" refers to a variety of tools and techniques, such as windbreaks, irrigation soil mulches, etc., as well as buildings like greenhouses, tunnels, and row covers that alter the surrounding environment to increase productivity year-round (Trivedi and Singh, 2015). It will further extend the harvest season, boost yield, improve quality, and maintain frequent availability of commodities. It is a standard production strategy that relies on tillage, manure, fertiliser application, and irrigation timing

to control the kind of root medium. Light, temperature, air quality, and relative humidity have no bearing on crop production in an open field situation. One of the solutions for the aforementioned factors is greenhouse production.

4. TYPES OF PROTECTED STRUCTURES USED FOR VEGETABLE CULTIVATION

4.1 Climate Controlled Greenhouse

In order to produce crops with the best development and productivity, greenhouses are framed or inflated buildings coated in transparent or translucent material that are large enough. These are best suited for year-round growing of high value commodities like vegetables and flowers. The greenhouse is equipped with cooling pads and exhaust fans in the summer to reduce the temperature. Heaters are offered in the winter to increase the temperature. The allowable range for the night time temperature is 12–13^{0}C.

4.2 Zero Energy Naturally Ventilated Greenhouse

The shielded structures without climate control equipment are known as naturally ventilated greenhouses. Through insect-proof netting, mostly at the top and sides, it is naturally ventilated. They are basic, reasonably priced greenhouses with a manually operated system for natural ventilation. These greenhouses can be used safely and effectively to grow cucumber, tomato, and capsicum all year long for 8 to 9 months.

4.3 Shade Net House

Perforated plastic shade nets are used to block sun radiation and stop the scorching or wilting of leaves brought on by rising temperatures. Shade net's primary goal is to somewhat reduce temperature and radiation during the hot summer months of May through September. Shade nets are offered in a variety of shade levels, from 25-75%. Shade net homes are suited for locations where the average daytime temperature is 28–30^{o}C and the night time temperature does not fall below 15–18°C.

4.4 Insect-Proof Net House

It can be created as a temporary or permanent building and is inexpensive. The building is covered in a 40–50 mesh UV–stabilized insect– and rust–resistant nylon or metal net. The primary function of the building is to act as a barrier against the entry of disease-carrying insects and other pests. Pesticide consumption is reduced in fresh vegetable cultivation while using insect-proof net houses. Tomato, chilli, sweet pepper, and other crops can be raised using this technique, but in order to grow them in insect proof net houses, it is necessary to cultivate virus-free, healthy seedlings of the crop either in a greenhouse or by covering the nursery beds with insect proof net.

4.5 Walk-In-Tunnel

Walk-in tunnels are transparent UV stabilised (150-200 micron) polyethylene walls covered in GI pipes, plastic pipes, or bamboo that are bent semi-spherically. The centre is kept between 6 and 6.5 feet in height and 4.0 and 4.5 feet in width. Depending on the situation, the structure's length may change. The walk-in tunnels are simple to put together and take apart thanks to the use of prefabricated structures. Nut-bolts are used to assemble the entire structure; welding is not necessary. Walk-in tunnel constructions are made to support trellising loads of 15 to 25 kg per square metre.

4.6 Low Tunnels

Low tunnels are pliable, transparent covers placed above GI wire hoops. The hoops are covered with or stretched over transparent plastic that is 25–50 microns thick and 2 m wide. The sides are then fastened by burying them in dirt. Low tunnels are transient and often do not rise over 1.0 m. The flexible galvanised iron hoops (4-6 mm thick) are manually fastened at a distance of 3–4 m on trenches immediately following sowing. Keep the hoop's two ends' width to 1.0 metres. Row length can vary based on the situation.

5. SYSTEM OF PRODUCTION FOR VEGETABLES GROWN UNDER PROTECTED CULTIVATION

Geoponics or soil system: Crops are produced on natural soil under protected cultivation under this approach [16]. Its drawbacks include an increased risk of disease and insect infestation in the soil. But by far the most often used cultivation system is this one [17].

Soilless cultivation: Since nearly methyl bromide is used as a soil disinfectant in between crop cycles, the adoption of the soilless farming technology has grown dramatically in the last

several decades (Krishna *et al*., 2023). In a similar vein, a growing variety of substrates are being developed with the aim of improving quality and production for plants cultivated in soil [17]. A variety of substrates are employed as soilless media to shield crops from various soil illnesses, including coconut fiber, perlite, vermiculite, rock wool, peanut hulls, rice hulls, and coco peat. Compared to agricultural soil, the solid components of soilless growth media (hydroponics and aeroponics), either alone or in combinations, may offer a better environment for plants [18]. To cultivate Indian veggies using this approach, there isn't a sufficient resource available, thus most farmers end up cultivating "exotic vegetables" with imported seeds. The carbon footprint of what is supposed to be a low-carbon farming approach is increased because many of the parts needed to construct these growth systems must also be imported. Currently, India imports over 85% of its exotic vegetable production, resulting in an annual growth rate of 15-20%.

In India, hydroponic farming is still relatively new. This subject of farming in the future is being worked on by only few research organizations. Scientists at the Bidhan Chandra Krishi Viswavidyalaya in Nadia first succeeded in their small-scale hydroponically vertical farming efforts. Scientists have also succeeded in producing potato tubers in soilless environments in C.P.R.I., Shimla, Himachal Pradesh, and P.A.U., Ludhiana. Scientists at C.P.C.T., IARI, New Delhi, and C.I.S.H., Lucknow are experimenting with hydroponic farming for crops including capsicum, cucumber, and tomatoes. Hydroponics provides less than 1% of India's entire food supply. However, the hydroponic market for fruits and vegetables is predicted to grow from its starting market value of USD 2544.15 thousand in 2018 to a market value of USD 11,195.74 thousand by 2027. The market is projected to expand at a compound annual growth rate (CAGR) of 13.53% between 2020 and 2027. The fact that Indian manufacturers can achieve better production costs, that there are customers for their output in the USA, EU, Far and Middle East, and that India has strong land, sea, and air connections all support these projections. Furthermore, it is anticipated that the global adoption rate of urban hydroponic farming systems would increase significantly in the wake of the coronavirus epidemic, as a growing number of people have come to have negative opinions about eating outside.

Temperature maintenance: While a variety of crops may be produced in a broad range of temperatures, each crop needs a particular range of temperatures for optimal growth and development. Under protected cultivation, it's feasible.

5.1 Training and Pruning Methods in Protected Cultivation

- **Training**

Training is the process of giving a plant a specific form by stalking, tying, or supporting it in a specific way over a trellis or pergola, or by removing or trimming some of its parts. Training describes the methodical elimination of parts to create a suitable shape for the plant that can support a big crop load.

- **Objectives**

- Regulates the form of plants.
- Proper distribution of fruit-bearing components • Insect and disease control
- Make it easier for sunlight to be reflected off of every component of the plant.
- Create a balance between a plant's vegetative and reproductive growth.

- **Principles**

- Training should begin at the very young age of the plant;
- In plants with considerable apical dominance, the terminal bud should be removed to encourage the growth of side branches.
- Drooping branches need to be removed.

- **Pruning**

Pruning is the process of removing any extra or unneeded/unproductive branches, shoots, or other sections of a plant in order to allow the remaining portion to grow properly or in accordance with the pruner's preferences.

- **Prudent**: Removal of portions, such as roots, leaves, flowers, fruit, etc., to provide a good and high-quality harvest.

- **Objective**

- To eliminate weak shoots and diseased, damaged, or insect-infested portions of the plant.
- To thin out fruits and flowers

Table 1. Crops grown under protected cultivation

Vegetables	Tomato, Coloured Capsicum (Yellow and Red Bell Peppers), Cucumber, Broccoli, Red Cabbage, Leafy vegetables, Radish, etc.	
Crop Cycle		
Crops	**Periods/ Crop Cycle**	
	Transplanting	**Harvesting**
Tomato	August-September	April- May
	April- May	July- August
	February	May- June
Cucumber/ Cauliflower/ Leafy vegetables/ Okra	November-December	March – April
	April- May	October-November

- To increase plant production that depends on fresh growth.
- It guarantees that bearing shoots have access to sunshine.

➢ **Principle of Pruning**

- Pruning should be finished well before the flowering season.
- After pruning, use Bordeaux paste to prevent the spread of disease.
- Remove any diseased, damaged, or insect-infested shoots.
- Avoid injury to plant while pruning.

5.2 Criteria for Crop Classification for Protected Cultivation

Most suitable for sheltered cultivation are vegetable crops with a high value, limited shelf life, and tiny size. Cucumber, tomato, and sweet pepper are grown throughout India, especially in the hills. But green vegetables can also be grown in sheltered environments [19].At high altitudes, it is possible to produce vegetables like cabbage, cauliflower, tomato, brinjal, capsicum, beans, peas, and coriander (Kumar et al., 2020) well under protected conditions (Table 1).

5.3 Individual Crops' Responses to Protected Cultivation

Tomato: For a high production and superior quality, tomatoes need a comparatively chilly, dry environment [20]. Pollen bursting problems arise at temperatures below 10°C, whereas higher temperatures cause tomato fruit drops prematurely [21]. The decreased temperatures mostly had an impact on agricultural productivity because of problems with fertilization and lower fruit output. Fruits with thigh temperatures are sometimes severely damaged or distorted, making them unmarketable, while red types typically turn more orange. If the temperature in the protected cultivation is maintained, these issues can be resolved. Poor fruit set results from temperatures above 30°C because they might dry up the stigma and pollen grains [22].

Coriander: In a naturally ventilated polyhouse, coriander establishes and grows effectively, producing more biomass, according to Isaac S.R. [23].

Cucumber: Growing cucumbers in PE bags with sand, perlite, and volcanic scoria as substrates produced better results than growing them in soil. According to Singh et al. [24], the most practical and cost-effective greenhouses for growing cucumbers year-round in India's northern plains were those with natural ventilation.

Sweet pepper: In a greenhouse with natural ventilation and little energy consumption, it may be cultivated effectively. One of the most often produced vegetables in greenhouses, capsicum has better yields [25].

Brinjal: Thanks to the emergence of parthenocarpic hybrids, brinjal may now be grown in protected environments [26].

5.4 Scope of Cultivating Vegetables under Protected System

By the end of the 20th century, there were over 100 ha of greenhouse space in Asia and over 275,000 square feet worldwide (Kang *et al*., 2013). India’s protected agriculture landscape Indian horticulture has a vast range of applications (Patil *et al*., 2023). In India, the following promising fields have a lot of potential for protected cultivation:

- **Cultivation in an unfavorable agro-climate**: Most of India's uncultivated land is beneath unsuitable terrain, such as deserts and dry, uncultivated fallow regions. For the locals, even a little percentage of this land turned over to greenhouse farming might result in large financial gains.
- **Greenhouses surrounding large cities**: Fresh vegetables and flowers are in high demand all year round in big cities. Large cities also have a need for expensive and off-season crops (Patil et al., 2023). Greenhouse cultivation is therefore encouraged to meet urban needs.
- **Export of farming turn out**: Globally, agricultural products—especially cut flowers—have a sizable market. Export promotion would surely benefit from protected export-oriented commodity production and greenhouse farming (Pattnaik & Mohanty, 2021).
- **Greenhouses (GH) for plant propagation**: Nowadays, greenhouse technology is considered a suitable method for growing seedlings and cuttings that require a controlled environment for their development. The GH facility may improve the product's production quality and capabilities (Patil *et al*., 2023).
- **Biotechnology greenhouse technology**: Tissue culture materials ought to proliferate rapidly. Aquiculture or Nutrient Film Technique (NFT) is needed to provide controlled environmental conditions for plant growth (Patil *et al*., 2023).
- **A greenhouse for the growth of unusual and medicinal plants**: Several distinctive species, such as intensively grown orchids, and other medicinal herbs may be found in India. The greenhouse may give the perfect kind of environmental conditions for the intensive production of some plants [27-35].

5.5 Significance of Cultivating Vegetables under Protected System

- Due to the availability of the necessary plant environmental conditions, four to five crops can be cultivated in a greenhouse throughout the year.
- Produce of superior quality can be acquired since it is cultivated in an appropriately managed environment.
- In a greenhouse, equipment for the effective use of various inputs, such as water, fertilizer, seeds, and plant protection agents, can be well-maintained.
- Because the growing area is enclosed, pest and disease management may be done effectively.
- A large percentage of seedlings germinate in greenhouses.
- Plantlets can be acclimated using the tissue culture approach within a greenhouse.
- Crop production timetables for horticulture and agriculture can be arranged to take advantage of of the market needs
- Peat mass, vermiculate, rice hulls, and compost—different types of growing medium used in intensive agriculture—can all be used successfully in greenhouses.
- Produce of international standards and export quality can be grown in greenhouses.
- Using the trapped heat, it is possible to dry gathered produce and do associated tasks when the crops are not being produced.
- Using computers and artificial intelligence techniques, greenhouses can be automated for irrigation, application of other inputs, and environmental controls.
- Self-employment for young people with education

5.6 Future Thrust

Protected agriculture will help educated unemployed youth find many opportunities for self-employment, but it will also strengthen the national economy by promoting the sale of premium produce in both domestic and international markets (Choudhary & Verma, 2018). In addition to providing excellent water and nutrient consumption efficiency, enclosed vegetable production has the potential to increase productivity over open field agriculture by a factor of three to five under the country's varied agroclimatic conditions [28]. This technique has great potential, especially in the peri-urban and metropolitan areas around the country's major cities, which are becoming a fast growing market for fresh produce.

Vegetable farming utilizing agribusiness models, the targeting of many specialized markets in the nation's main cities consistently draws the

attention of vegetable producers, encouraging them to move from traditional crop-growing methods to such new alternatives. The warm, sunny days and cool nights in the hot, arid region of India, despite several challenges, make it an ideal place to cultivate cucurbits, including cucumber, watermelon, muskmelon, longmelon, bottle gourd, ridge gourd, tinda, summer squash, etc. Meghwal *et al*., [29]. Under such conditions, cucurbit cultivation yields a meager yield of inferior product. The poor output of cucurbits in hot, dry areas can be enhanced by utilizing innovative techniques including drip irrigation and fertigation, low tunnel technology, spraying micronutrients, and integrated crop management (ICM). Vegetables are still usually cultivated with little technical input, thus new methods like tunnel cultivation are needed to increase output, productivity, and cucurbit quality. Low tunnel technique has the potential to increase the profitability of cucurbit agriculture during the off-season. The utilization of inexpensive covered structures, especially low tunnels with little alterations, may become an alternative for the effective development of cucurbits in dry conditions [30,31, 36-39].

6. CONCLUSION

Protected crop production is a good technique for the agricultural community since it is a financially worthwhile endeavor. It is safe to consume the veggies because less chemicals are used in their cultivation. A friendly atmosphere for off-season growing and excellent results are also provided by this strategy. The rising demand for vegetables from a growing population and for sustainable food security may thus be met by this technology through long-term production systems.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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