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Protected Cultivation of Horticultural Crops: A Comprehensive Review

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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

Horticultural crops grown under protection are becoming more and more significant in modern agriculture, offering a number of benefits such as increased yields, better quality, and protection from pests and bad weather. This comprehensive review aims to demonstrate protected cultivation

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methods as they currently exist and explore their future applications in horticulture. The first part of the examination covers the many types of protected production structures, including high tunnels, shade houses, and greenhouses, along with their advantages and disadvantages. The significance of protected farming in tackling concerns associated with worldwide food security is further underscored by preserving crop productivity throughout the year and limiting dependence on seasonal variations. This review looks more closely at the effects of protected cultivation methods on the growth and development of horticultural crops. These methods include improved crop morphogenesis, precipitation control, and the optimisation of environmental parameters like temperature, humidity, and carbon dioxide levels. Furthermore, the utilisation of advanced technologies like hydroponics, aeroponics, and vertical farming in protected growing systems is examined and its capacity to optimise crop yield while minimising resource consumption is emphasised. The difficulties and limitations associated with adopting protected cultivation are also examined in the study, including the need for artificial inputs, energy requirements, and financial considerations. It talks about environmentally friendly and sustainable ways to reduce these problems and preserve ecological balance, like switching to organic farming methods and using renewable energy sources. Future trends and developments in protected cultivation are covered in detail in the study's final section. These include the application of artificial intelligence, the adoption of smart farming technologies, and the employment of precision agriculture techniques. Higher yields and higher-quality horticultural crop output could be the outcome of these developments, which further optimise resource utilisation, improve automation, and better crop monitoring and management.

Keywords: Protected cultivation; food security; hydroponics; greenhouses.

1. INTRODUCTION

Protected farming is the practice of growing crops in a whole or partially enclosed area, like a high tunnel, greenhouse, or shade house [1]. The primary objective of protected farming is to optimise environmental factors while establishing a controlled microclimate that shields the crops from inclement weather, pests, and disease [2]. It involves applying structures, materials, and technologies that provide protective barriers and environmental control over temperature, humidity, light, and other variables [3]. This method extends the growing season, enhances crop yield and quality, enables year-round or off-season farming, and reduces reliance on external factors. A variety of horticultural crops, including fruits, vegetables, flowers, and herbs, are grown through protected agriculture [4].

In the current dynamic environment, crop quality and yield are significantly impacted by both biotic and abiotic stressors [5]. Extreme temperatures, sunshine, water availability, relative humidity, weeds, nutritional shortages, wind velocity, carbon dioxide concentration, illnesses, and insect pests are some of the difficulties faced by North Indian horticulture crop production [6]. Protected agricultural practices have proven effective in reducing these limitations, particularly in regions with harsh weather [7]. Protected farming involves cultivating superior crops outside of their usual growth seasons by using structures such as greenhouses [8]. This approach reduces transit times and increases farmer profitability by delivering fresh product, particularly in periurban areas [9]. Buildings with greenhouses are covered with transparent materials, such as polythene or glass, which act as selective radiation filters. Short-wavelength solar light can flow through, but long-wavelength solar energy is trapped inside [10]. The building thus suffers a greenhouse effect, which boosts inside temperatures by absorbing solar energy [11]. Plant photosynthetic rate, transpiration, stomatal aperture, and leaf temperature are all impacted by the rising temperature [12]. By controlling the greenhouse climate, it is possible to alter the physiological conditions of plants [13]. For instance, when the greenhouse is closed at night, plant respiration raises CO_2 levels. This extra CO_2 is used for photosynthesis early in the morning of the following day. The greenhouse's improved nutrition, increased warmth, relative humidity, and CO_2 levels all promote faster development and greater yield [14]. In order to regulate the temperature inside a greenhouse, cooling mechanisms such as fan pad systems, ventilation, and fogging can be employed [15]. These techniques optimise the potential yield of vegetable crops and enable the year-round production of targeted crops. Planting closer together and with a higher plant density can further improve yields under protected farming

[16]. Open-field and covered agriculture require different management approaches. Peri-urban areas now significantly rely on multistory crop production in greenhouses to supply the need for fresh food, strawberries, flowers, and fruit tree nurseries [17]. Protection farming systems employ a wide range of methods, including fertigation, mulching, drip irrigation, naturally ventilated polyhouses, and more [18]. Furthermore, in the Northern Plains of India, walk-in polytunnels have become increasingly popular as a useful technique for growing cucurbits, tomatoes and cucumbers as well as for building nurseries during the off-season [19].

1.1 The Purpose of Protective Cultivation

- Stores are protected against biotic variables like pests and the volume of complaints they receive, as well as from abiotic stress (physical or resulting from non-living organisms) like temperature, water scarcity or excess, hot or cold swelling, etc.
- Water consumption decreased and weed growth controlled
- Enhancing productivity in relation to area. Decreased usage of fungicides in agricultural goods.
- Supporting premium, superior horticulture produce.
- High-value crop adaptation, multiplication, and addition of crops that are reputed to flourish in specific regions.
- Products produced from year-round flower, vegetable, or fruit crops
- Produced from superior genetic transplantation without any complaints.
- Innovative methods for cultivating protected crops for decorative plants
- Adapting farming practices for indoor greenhouse flower cultivation

Growing veggies in greenhouses is a relatively new practice in India, and it's being used more and more to make luxury goods that can be exported in the off-season. A floriculture unit can only succeed if it produces ornaments with exceptional efficiency, a focus on export, and exquisite artistry. In order to ensure consistency in output quality and quantity while keeping prices within manageable bounds, greenhouse growers must embrace the most recent technological advancements.

Studies on the standardisation of farming technology, including cost-effective greenhouse utilisation. It is always preferable and more fruitful to grow carnations, tuberoses, gerberas, and roses rather than other flowers [11].

1.2 Advances in the Production of Protected Vegetable Crops

Vegetables are a significant source of nutrition and have been consumed for decades. By supporting or exploiting creative scenarios of guarded civilisation technology for the production of horticultural crops with an eye towards their wallets, many producers in the country's peri-urban areas can successfully diversify their traditional husbandry. The year-round need for high-value vegetables such slicing tomatoes, coloured peppers, and parthenocarpic cucumbers, among others, will be satisfied, as well as the emerging demand for uncommon and unusual off-season horticultural produce.

The other industry that requires total diversification from the current nursery caregiving system is high-quality vegetable nurseries. Due to their financial constraints, low-cost or medium-sized producers have straightforward organisational structures. Vegetable polyhouse civilisation breaks the seasonal hedge and prolongs crop duration compared to open field circumstances by overcoming biotic and abiotic constraints. When compared to open field settings, poly homes produced the highest number of fruit weights and yield. On the poly house, some protected technologies showed decreased net return and BC; nonetheless, an open field showed the lowest values.

1.3 New Trends in Protected Cultivation's seed Production

These days, growing efficiently begins with the seeds, and those grown in polyhouse structures are immune from diseases and pests that are often seen in open-air farming. A wide variety of buildings are employed in the production of seeds: among the main structures are walk-in tunnels, inexpensive poly-houses, insect-proof net homes, climate-controlled greenhouses, semi-controlled greenhouses, naturally ventilated greenhouses, and plastic low tunnels.

2. GLASSHOUSES WITH CLIMATES THAT ARE PARTLY CONTROLLED

High-value exotic crops are grown in poly houses, also known as glasshouses, which provide semi-climate control or temperature

regulation and allow for longer growing seasons and larger yields. In an open field, the growing season is shorter otherwise. High-value foods such as parthenocarpic cucumbers, sweet peppers, cherries, and sliced tomato products can be grown in these structures. When compared to seeds grown in open fields or under other structures, the initial or starting point of construction and ongoing costs of comparable glasshouses are the main obstacles to using this type of building. This is because the cost of seed is substantially higher. However, seed output and quality are always significantly higher under similar setups [20].

3. SHEDS WITH NATURAL VENTILATION

Greenhouses are an excellent place to grow a wide range of fruits and vegetables, including parthenocarpic cucumbers, summer squash, muskmelon, and tomatoes, for seed because of their natural aeration. On the other hand, compared to greenhouses with climate control or semi-climate control, less time is needed for growing and seed production [21].

4. MANUFACTURING FOR COMMERCIAL USE

Net buildings that are resistant to insects can be used to grow cucurbits, which include sweet pepper, tomato, and brinjal seeds. These structures can protect crops against viruses and other insects such as fruit borer bugs during the wet and post-rainy seasons [22]. In comparison to other greenhouse types, not only is the seed yield consistently lower, but the production expenses are also much lower [23].

5. PRODUCTION OF SEEDS

Walk-in tunnels can be used for the production of cucurbit seeds, which include those for bottle gourds, bitter gourds, summer squash, muskmelon, and watermelon [24]. High tunnels are used to warm the soil for agricultural development and extend the growing season in temperate regions of the world [25].

5.1 The Situation of Protected Agricultural Crop Cultivation now and its Future Prospects the Position of Protected Cultivation Worldwide Global Adoption

Particularly in regions with severe weather or limited fertile land, protected farming techniques, such high tunnels and greenhouses, are becoming more and more prevalent [26] (Fig 1).

Variety in Crops: There are many different types of horticultural crops growing there, such as flowers, fruits, vegetables, and decorative plants [27].

Technological Advancements: Industrialised countries have invested heavily in state-of-the-art controlled environment agriculture technologies, including automated climate control, hydroponics, and vertical farming [28].

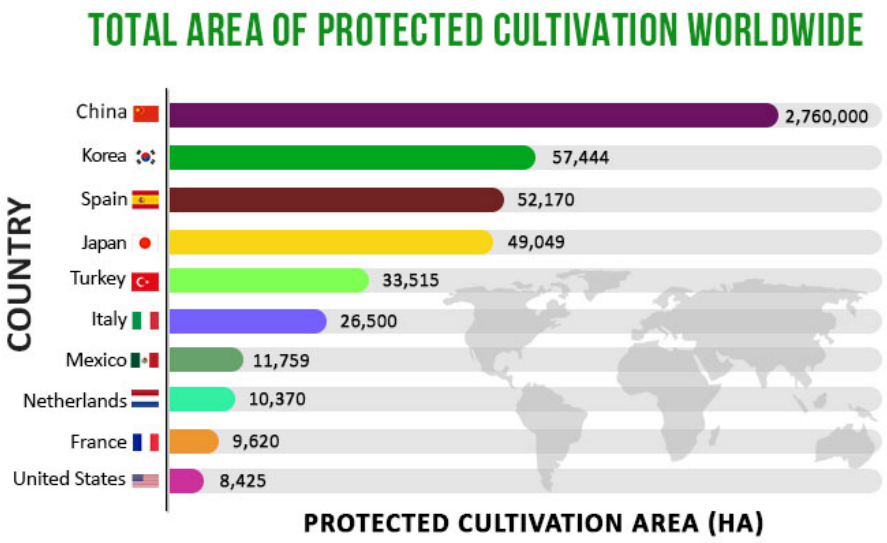

Fig 1. Position of protected cultivation worldwide

Sustainable Practices: Within protected areas, a greater focus is being made on organic and sustainable production techniques in an effort to reduce the environmental impact of agriculture [29].

Market Expansion: Due to the expanding need for services, technology, and equipment related to protected cultivation, businesses now have opportunities [30].

5.2 Indian Protected Agricultural Status

Rapid Growth: In recent years, India's adoption of protected farming practices has steadily increased as a result of the need to meet the nation's growing demand for fresh and off-season items [31].

Good environment: Protected agriculture, which extends growing seasons and protects crops from poor weather, thrives in India because to its diverse environment, which includes strong monsoons and exceptionally high temperatures [32].

Diversity in Horticulture: India cultivates a diverse range of horticulture crops, including exotic fruits, flowers, and vegetables, using protected farming techniques [33].

Government Initiatives: The Indian government has introduced a number of programs and incentives to encourage farmers to adopt greenhouse and polyhouse technology as well as protected farming [34]. Even with the growth, challenges remain, including the high initial investment cost, small-scale farmers' lack of technical know-how, and sustainability concerns [35].

Research and Innovation: One of the main priorities of Indian agricultural institutes and research organisations is the development of region-specific technology for protected farming and boosting crop yield [36].

Export Prospects: Protected farming has helped India's horticultural exports because some crops are now sold in international markets [37].

6. UPCOMING PROSPECTS

Protected farming seems to have a promising future. As the population increases and the amount of arable land accessible diminishes, protected agriculture offers a sustainable solution to meet the growing demand for horticultural products [38]. It enhances crop quality, allows for year-round farming, and reduces the demand for water and pesticides.

7. ADVANCES IN TECHNOLOGY FOR PROTECTED AGRICULTURE

Drones for crop monitoring, robotics for harvesting, precision agricultural methods, and the usage of Internet of Things (IoT) solutions for data collecting and analysis are a few cutting-edge technologies in protected cultivation [39, 40]. Growing contribution of protected agriculture to world food supply: In order to supply enough food to fulfil the world's demand, protected farming is required [41]. It makes it possible to grow superior crops in areas with unfavourable weather conditions.

Furthermore, it boosts crop yield, lowers losses following harvest, and guarantees a steady supply of fresh vegetables all year long. Prospects and obstacles for sustainable agriculture Protected horticulture has numerous advantages, but it also has drawbacks. These consist of the initial setup expenses, energy usage, appropriate upkeep, and guaranteeing the ideal climate for agricultural growth [42]. However, there is a chance to overcome these obstacles and increase the use of protected agriculture thanks to technological advancements and growing public knowledge of sustainable farming methods.

8. SIGNIFICANT PESTS

Vegetable crops grown in greenhouses around the world are vulnerable to a variety of diseases and pest infestations because of the favourable circumstances that exist within. Huge losses may arise from greenhouse pests. The main causes of agricultural losses are arthropod pests such nematodes, fungi, bacteria, thrips, and aphids, as well as diseases caused by bacteria, fungi, and viruses. The percentage of losses produced by a virus can vary from 5% to 90%, depending on several factors such as the virus strain, crop variety, age of the plant at infection time, and temperature during disease development [43, 44]. Severe tomato mosaic virus (ToMV) losses have been reported in susceptible pepper varieties [45].

Numerous plant hosts are afflicted by the virus known as tomato infectious chlorosis virus

(TICV). Orange County calculated in 1993 that the global tomato industry would lose $2 million. While western flower thrips in UK glasshouses caused 90% of the crop loss, the tomato yellow leaf curl virus, which is propagated by whiteflies, boosted crop loss to 100% in Mediterranean locations [46]. Reports state that certain significant crop losses in greenhouse vegetable crops are attributable to the Pythium species. Botrytis species can cause large post-harvest losses when plant products are transported or stored [47, 48].

9. IPM AND PROTECTED FARMING

Biological management has gained popularity recently due to customer demands for food free of residues and pests that are resistant to artificial pesticides used to control greenhouse pests. Because of this, integrated pest management (IPM) techniques for long-term crop protection have been developed [49, 50, 51]. IPM minimises adverse impacts on the environment, non-target animals, and human health while preventing pest damage. It involves integrating all relevant plant protection strategies to keep pests below commercially significant levels while preserving consumer health, environmental sustainability, and farmer profitability. Controlling diseases and insects is crucial to growing plants that are healthy, pest-free, and undamaged since they represent a severe threat to greenhouse production. So, a greenhouse IPM plan should include a bio-intensive strategy that includes sanitation, mechanical barriers, scouting, GAP protocols, biocontrol, and specialised pesticides as needed. These days, almost all greenhouse vegetable crops such as lettuce, tomatoes, cucumbers, sweet peppers, brinjal, and others are cultivated in many regions of the world using integrated pest management (IPM) [52, 53, 54].

10. AUTOMATED SYSTEMS IN PROTECTED FARMING

In order to maintain some robotic duties, automation is a helpful technology. The strategy for technological protection covers a variety of machinery. Encouraging the production of valuable crops like tomatoes, sweet peppers, and cucumbers, along with a range of trimmed plants and flowers like roses, gerberas, and chrysanthemums, protected development is a high-risk, high-reward creative method.

In Western social orders, this kind of creation has encountered difficulties such as expanding creation offices, growing labour costs, increasing difficulty in locating workers with the necessary skills, health issues resulting from heavy and monotonous work, and escalating competition in the national and international business sectors. Precise farming methods, which handle plants as a single organism, are also gaining traction since they provide greater control over the type and quantity of crop yielded while making optimal use of available resources. Because of the ongoing demands on human work, this has led to a far more realistic push for computerisation and sophisticated mechanics. Mechanisation has been developed as a modern requirement for different processes, including harvesting [55, 56, 57].

11. ISSUES OR CHALLENGES WITH INDIA'S PROTECTED FARMING

Though it has a long history, protected vegetable farming is still relatively new in India. The enormous potential of growing protected vegetables has received very little attention.

The following limitations and issues add to the difficulty of cultivation:

1. Vegetables like sweet peppers, cucumbers, tomatoes, and cherry tomatoes are important, but no particular breeding has been done to develop types or hybrids that are best suited for growth in greenhouses or other protected environments. Indian farmers are discouraged from purchasing exotic seeds due to their high cost.
2. Some of these vegetable varieties are available for purchase domestically, but they don't meet the standards of premium or export markets.
3. Indian producers should not utilise climate-controlled greenhouses because they are costly initially and require constant upkeep.
4. To maintain the heating and cooling systems in the greenhouses, a more consistent power supply is required in many parts of the nation.
5. Certain plants, such as sweet pepper in Delhi's winter climate, may produce less when exposed to intense sunlight during critical periods.
6. Not much has been done to standardise the designs of greenhouses and other covered structures, despite the nation's varied agro-climatic zones.

7. Potential methods for producing vegetables under various protected structures have not been investigated for the country's various agroclimatic zones.
8. It is challenging to find the resources needed to meet the prerequisites. In addition, greenhouses lack the proper instruments to control the atmosphere.
9. There are currently no dedicated studies being carried out on protecting vegetable plants.
10. It is challenging to supply markets with high-quality products due to the lack of packaging and on-farm value-added components.

12. CONCLUSION

Protected farming is the practice of cultivating crops in a regulated setting where temperature, humidity, and light levels may be changed to suit each crop's specific requirements. In this controlled environment, overall productivity is increased and healthier plants are encouraged. In addition to forced-vent greenhouses, other protected farming techniques include plastic tunnels, insect-proof net houses, naturally ventilated poly houses, raised beds, trellising, drip irrigation, and more. These methods can be used separately or in combination to create a favourable growing environment that shields plants from harsh weather, extends the growing season, or allows for the production of crops outside of the regular growing season. When raised beds and mulch films are added, drip irrigation reduces evaporation losses and offers benefits including improved soil moisture retention and weed control.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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