Review Article

A comprehensive review on Protected Cultivation of Horticultural Crops: Present status and future prospects

Abstract

Protected cultivation of horticultural crops has emerged as a crucial technique in modern agriculture, offering numerous benefits such as increased yield, enhanced quality, and protection against adverse climatic conditions and pests. This comprehensive review aims to present the current status of protected cultivation practices and explore its future prospects in horticulture. The review begins by discussing the various types of protected cultivation structures, including greenhouses, high tunnels, and shade houses, along with their advantages and limitations. It then highlights the significance of protected cultivation in addressing global food security challenges by ensuring year-round crop production and reducing dependence on seasonal variations. The review further explores the impact of protected cultivation techniques on the growth and development of horticultural crops, including improved crop morphogenesis, precipitation management, and the optimization of environmental factors such as temperature, humidity, and carbon dioxide levels. Furthermore, the utilization of advanced technologies like hydroponics, aeroponics, and vertical farming within protected cultivation systems is examined, with an emphasis on their potential for maximizing crop productivity while minimizing resource consumption. Moreover, the paper delves into the challenges and constraints faced in implementing protected cultivation, including cost considerations, energy requirements, and the use of synthetic inputs. It discusses sustainable and environmentally friendly approaches, such as utilizing renewable energy sources and adopting organic farming practices, to mitigate these challenges and promote ecological balance. Lastly, the review discusses some future prospects and trends in protected cultivation, including the integration of precision agriculture techniques, the use of artificial intelligence, and the adoption of smart farming technologies. These advancements have the potential to further optimize resource utilization, improve automation, and enhance crop monitoring and management, ultimately leading to greater yield and quality improvements in horticultural crop production.

Keywords: Environmentally Friendly, Food Security, Greenhouses, Hydroponics, Protected Cultivation and Vertical Farming

Introduction:

Protected cultivation refers to the practice of growing crops in an enclosed or partially enclosed environment, such as greenhouses, shade houses, or high tunnels [1]. The primary purpose of protected cultivation is to create a controlled microclimate that shields the crops from adverse weather conditions, pests, and diseases, while optimizing environmental factors [2]. It involves the use of structures, materials, and technologies that provide a protective barrier and allow for manipulation of temperature, humidity, light, and other environmental variables [3]. This method enables year-round or out-of-season cultivation, extends the growing season, increases crop quality and yield, and reduces reliance on external factors. Protected cultivation is widely employed in the production of various horticultural crops, including vegetables, fruits, flowers, and herbs [4].

The impact of abiotic and biotic stresses under the present changing climate significantly affects crop production and quality [5]. In North Indian conditions, horticultural crop production faces challenges such as extreme temperatures, sunlight, water availability, relative humidity, weeds, nutrient deficiencies, wind velocity, carbon dioxide concentration, and diseases and insect pest incidences [6]. To address these constraints, protected cultivation techniques have proven to be a viable solution, especially in hostile climatic conditions [7]. Protected cultivation involves growing crops with improved quality outside of their regular growing seasons, utilizing structures like greenhouses [8]. This practice increases profitability for farmers and reduces transportation time, ensuring the delivery of fresh produce, particularly in peri-urban areas [9]. Greenhouses are structures covered with transparent materials, such as polythene or glass, which act as selective radiation filters. They allow short-wavelength solar radiation to pass through while trapping long-wavelength radiation inside [10]. This creates a greenhouse effect, trapping solar energy and raising the temperature inside the structure [11]. The elevated temperature affects leaf temperature, transpiration, stomatal aperture, and the photosynthetic rate of plants [12]. Controlling the greenhouse environment allows manipulation of the physiological conditions of the plants [13]. For instance, closing the greenhouse at night leads to an increase in CO_2 levels resulting from plant respiration. This elevated CO_2 is then utilized for photosynthesis during the early morning hours of the following day. The increased temperature, relative humidity, CO_2 levels, and improved nutrition within the greenhouse promote fast growth and increased production [14]. The temperature within a greenhouse can be regulated by incorporating cooling systems such as ventilation, fogging, or fan pad systems [15]. These technologies

enable year-round production of desired vegetable crops and maximize their yield potential. Closer planting and higher plant density under protected cultivation further enhance yields [16]. Management practices for protected cultivation differ from open-field production. In peri-urban areas, multistoried crop cultivation in greenhouses has become imperative to meet the demand for fresh vegetables, strawberries, flowers, and fruit tree nurseries [17]. Various techniques, such as naturally-ventilated polyhouses, drip irrigation, fertigation, and mulching, are employed in protected cultivation systems [18]. Additionally, walk-in polytunnels have recently emerged as profitable technologies in the Northern plains of India, proving their suitability for growing crops like tomatoes, capsicum, cucurbits, and establishing nurseries during the off-season [19].

Global and Indian scenario of protected cultivation of horticultural crops

The global area under protected cultivation of horticultural crops was estimated to be around 623,302 hectares in 2023 with China accounting for the largest share (45%), according to the latest data from the Food and Agriculture Organization of the United Nations (FAO) [20]. Other major producers include Turkey, Spain, Italy, and Japan [21]. In India, the area under protected cultivation of horticultural crops is around 11 thousand hectares. The leading states are Maharashtra, Gujarat, Himachal Pradesh, Karnataka, and Punjab [22]. Protected cultivation of horticultural crops results in higher yields and better quality produce compared to open field cultivation [23]. The average yield of tomatoes under protected cultivation is around 30-40 kg/m2, while the average yield of tomatoes in open field cultivation is around 10-15 kg/m2. The global production of horticultural crops under protected cultivation is estimated to be around 150 million tonnes. The major crops produced under protected cultivation include vegetables (tomatoes, cucumbers, peppers, lettuce, etc.), fruits (strawberries, raspberries, blueberries, etc.) [24], and flowers (roses, gerberas, carnations, etc.) [25]. In India, the major horticultural crops produced under protected cultivation include tomatoes, cucumbers, capsicums, roses, and gerberas [25]. According to the Food and Agriculture Organization of the United Nations (FAO), the global area under protected cultivation was estimated to be 2.76 million hectares in 2020. China is the world leader in protected cultivation, with over 4 million hectares under production.

Present status and future prospects of protected cultivation of horticultural crops

Global Status of Protected Cultivation:

Widespread Adoption: Protected cultivation techniques, such as greenhouses and high tunnels, have gained widespread adoption across the globe, particularly in regions with extreme climates or limited arable land [26].

Variety of Crops: It is used to grow a wide range of horticultural crops, including vegetables, fruits, flowers, and ornamental plants [27].

Technological Advancements: Developed countries have invested heavily in modern technologies for controlled environment agriculture, including automated climate control, hydroponics, and vertical farming [28].

Sustainable Practices: There's a growing emphasis on sustainable and organic practices within protected cultivation to reduce the environmental footprint of agriculture [29].

Market Expansion: The market for protected cultivation equipment, technology, and services has grown, offering opportunities for businesses [30].

Indian Status of Protected Cultivation:

Rapid Growth: In India, the adoption of protected cultivation methods has been steadily increasing in recent years, driven by the need to meet the growing demand for fresh and off-season produce [31].

Favorable Climate: India's diverse climate, with extreme temperatures and monsoon patterns, makes it well-suited for protected cultivation to extend growing seasons and protect crops from adverse weather conditions [32].

Horticultural Diversity: A wide variety of horticultural crops, including vegetables, flowers, and exotic fruits, are grown using protected cultivation techniques in India [33].

Government Initiatives: The Indian government has introduced various schemes and incentives to promote protected cultivation, encouraging farmers to adopt greenhouse and polyhouse technologies [34].

Challenges: Despite growth, there are still challenges, including the high initial investment cost, technical knowledge gaps among small-scale farmers, and sustainability concerns [35].

Research and Innovation: Indian agricultural institutions and research organizations are actively involved in developing region-specific technologies for protected cultivation and improving crop productivity [36].

Export Opportunities: Protected cultivation has also opened up opportunities for India's horticultural exports, with certain crops being exported to international markets [37].

Future prospects

The future of protected cultivation looks promising. As the population increases and available arable land decreases, protected cultivation offers a sustainable solution to meet the growing demand for horticultural crops [38]. It allows for year-round production, increases crop quality, and reduces water and pesticide usage. Emerging technologies in protected cultivation: Some emerging technologies in protected cultivation include the use of drones for crop monitoring, robotics for harvesting, precision agriculture techniques [39], and the integration of Internet of Things (IoT) solutions for data collection and analysis [40]. Expanding role of protected cultivation in meeting global food demands: Protected cultivation plays a crucial role in meeting global food demands [41]. It allows for the production of high-quality crops in regions with unfavorable climatic conditions. Additionally, it reduces post-harvest losses, enhances crop productivity, and ensures a consistent supply of fresh produce throughout the year. Challenges and opportunities in protected cultivation: While protected cultivation offers numerous opportunities, it also faces some challenges. These include initial setup costs, energy consumption, proper maintenance, and ensuring optimal environmental conditions for crop growth [42]. However, advancements in technology and increasing awareness about sustainable farming practices present opportunities for overcoming these challenges and expanding the use of protected cultivation.

Types of protected structures

There are a variety of protected cultivation structures available, ranging from simple net houses to sophisticated greenhouses. The type of structure chosen depends on the crop being grown, the climate, and the budget available.

Net houses: Net houses are the simplest and most affordable type of protected structure. They are made of a net mesh that protects the crop from pests, diseases, and birds [43].

Polyhouses: Polyhouses are made of a plastic film that provides better protection from the elements than net houses. They can also be heated and cooled to create a more controlled environment [44].

Greenhouses: Greenhouses are the most sophisticated type of protected structure. They are made of glass or polycarbonate and can be equipped with a variety of environmental control systems [45].

Major horticultural crops grown under protected cultivation

A wide range of horticultural crops can be grown under protected cultivation, including:

Vegetables: tomato, capsicum, cucumber, eggplant, lettuce, leafy greens, zucchini and melon and [46].

Fruits: grapes, apple, pear, peach, plum, cherry strawberry and other berry crops [47].

Flowers: rose, carnation, gerbera, anthurium, lilium, orchids and chrysanthemum [48].

Technological advancements in protected cultivation

There have been a number of technological advancements in protected cultivation in recent years. These include [49]:

Precision agriculture technologies: Precision agriculture technologies, such as sensors, drones, and artificial intelligence, are being used to optimize crop production and reduce inputs.

Renewable energy sources: Renewable energy sources, such as solar and wind power, are being used to power protected cultivation facilities.

Integrated pest management practices: Integrated pest management (IPM) practices are being used to reduce the use of pesticides and fertilizers in protected cultivation.

Suitable Horticultural Crops for Protected Cultivation

A wide range of horticultural crops are suitable for protected cultivation. Some of the crops commonly grown in protected environments include:

1. Tomatoes: Tomatoes are one of the most popular crops for protected cultivation. Greenhouses provide optimal conditions for their growth, ensuring higher yields and better quality fruit compared to open field production [50].

2. Cucumbers: Cucumbers thrive in protected environments, especially in greenhouses or high tunnels. The controlled climate and protection from pests and diseases contribute to higher yields and improved fruit quality [51].

3. Peppers: Both sweet and hot peppers are well-suited for protected cultivation. Greenhouses offer the ideal conditions for pepper plants, allowing for extended growing seasons and increased production [52].

4. Lettuce and Leafy Greens: Leafy greens, including lettuce, spinach, kale, and arugula, can be grown year-round in protected environments. Greenhouses provide protection from extreme temperatures and allow for more precise control over moisture levels [53].

5. Fruits: Grapes, apple, pear, peach, plum, cherry and Strawberries are commonly grown in greenhouses or high tunnels, as these structures provide protection from rain, pests, and diseases. This allows for better fruit quality and extended harvest periods [54].

6. Flowers: Many varieties of flowers, such as roses, chrysanthemums, and gerberas, are suitable for protected cultivation. Greenhouses offer stable conditions and protection from wind and rain, resulting in higher-quality blooms. Example as rose, carnation, gerbera, anthurium, lilium, orchids, chrysanthemum [55].

7. Herbs: Herbs like basil, cilantro, mint, and parsley are amenable to protected cultivation. Controlled environments ensure consistent growth, higher yields, and better quality herbs [56].

8. Melons: Certain varieties of melons, such as muskmelons and cantaloupes, can be successfully grown in protected environments. Greenhouses provide optimal temperature and humidity control, leading to improved fruit quality [57].

9. Beans: Some types of beans, such as green beans and runner beans, can be grown in protected structures. These environments offer protection from adverse weather conditions and pests, resulting in increased productivity. It's important to note that the suitability of specific crops for protected cultivation may vary depending on factors such as regional climate, market demand, and available resources. Farmer preferences and local conditions should be considered when selecting crops for protected cultivation [58].

Future prospects of protected cultivation of horticultural crops

Protected cultivation is expected to play an increasingly important role in meeting the global demand for fresh, high-quality horticultural produce in the coming years [59]. This is due to a number of factors, including:

- The growing population and urbanization

- The increasing demand for healthy and nutritious food
- The need to produce food in a sustainable manner

Advantages of protected cultivation:

1. Provides favorable microclimate conditions for the plants: Protected cultivation allows for the creation of an optimal growing environment by controlling temperature, humidity, and light conditions. This ensures that plants receive the ideal conditions for growth and development [60].

2. Cultivation in all seasons even under extreme conditions is possible: With protected cultivation, crops can be grown year-round, regardless of the external climatic conditions. This allows for consistent production and a more reliable food supply [61].

3. High yield with better quality per unit area: The controlled environment of protected cultivation promotes higher yields per unit area. Additionally, the crops tend to have improved quality, including characteristics such as size, color, flavor, and nutritional value [62].

4. Longer production cycle: Protected cultivation extends the production cycle by protecting crops from adverse weather conditions. This enables farmers to harvest crops for a longer duration, increasing overall output [63].

5. Needs less irrigation due to moisture conservation: Protected structures reduce water evaporation, leading to better moisture conservation. This, in turn, reduces the water requirements of crops and promotes water efficiency [64].

6. More suitable for off-season/high-value crops: Protected cultivation is particularly beneficial for growing off-season crops when their production is limited in open fields. This allows for the cultivation of high-value crops when market prices are higher [65].

7. Hygienic production due to fewer sprays of toxic pesticides: In protected cultivation, the controlled environment helps reduce the incidence of pests and diseases. As a result, farmers can minimize the use of harmful pesticides, leading to cleaner and more hygienic crop production [66].

8. Better disease and pest control: Protected cultivation provides a physical barrier that prevents insects, pests, and diseases from directly accessing crops. This reduces the likelihood of infestations and allows for more effective pest control measures [67].

9. Helps in early raising of nursery: Protected cultivation facilitates the early establishment of seedlings and nursery plants. This contributes to quicker crop development and enables farmers to have a head start in the growing season [68].

10. Protection from wind, rain, snow, birds, hail, etc.: Protected structures shield crops from various environmental factors, such as wind, rain, snow, birds, and hail. This protection minimizes crop damage and ensures a higher level of harvestable yield [69].

11. Generates self-employment for educated youth: The field of protected cultivation requires specialized knowledge and skills, creating opportunities for educated individuals to engage in self-employment. This can contribute to rural development and job creation [70].

Factors affecting the adoption of protected cultivation of horticultural crops

Several factors influence the adoption of protected cultivation of horticultural crops. These include:

1. Cost: The initial investment and ongoing costs associated with setting up and maintaining protected cultivation structures can be significant. This includes expenses for infrastructure, equipment, materials, and specialized technologies. The affordability of these investments can dictate the willingness of farmers to adopt protected cultivation methods [71].

2. Knowledge and Skills: Adopting protected cultivation techniques requires specific knowledge and skills that may be different from traditional open-field farming practices. Farmers need to understand concepts such as climate control, irrigation systems, pest management, and crop nutrition within a protected environment. Lack of sufficient knowledge and skills can hinder adoption [72].

3. Market Demand and Profitability: The potential profitability and market demand for horticultural crops grown using protected cultivation techniques play a crucial role in adoption. Farmers need assurance that they can sell their produce at favorable prices, offsetting the additional costs associated with protected cultivation. Market research and analysis are essential in determining the viability and demand for these crops [73].

4. Climate and Environmental Conditions: The suitability of local climatic and environmental conditions for protected cultivation is another factor influencing adoption. Protected structures can provide insulation against extreme weather conditions, but they also

require adequate sunlight, water availability, and suitable temperature ranges. Assessing whether local conditions align with the requirements of protected cultivation is vital [74].

5. Access to Resources: The availability and accessibility of resources such as land, water, energy, and skilled labor are crucial for successful adoption. Adequate land space, a reliable water source, and access to electricity or alternative energy sources are necessary for setting up and operating protected cultivation systems [75]. The availability of skilled labor or the ability to train personnel is also essential.

6. Government Support and Policies: Supportive government policies, subsidies, incentives, or technical assistance can significantly encourage the adoption of protected cultivation. These initiatives help farmers manage the initial investment costs, provide training and knowledge-sharing platforms, and create a conducive environment for transitioning to protected cultivation methods [76].

7. Risk Management: Farmers may be cautious about adopting protected cultivation due to perceived risks and uncertainties. Factors such as crop failure, disease outbreaks, pest infestations, or market fluctuations can impact profitability. Risk management strategies, including crop insurance, technical support, and access to information, can help mitigate these concerns and encourage adoption. Overall, the adoption of protected cultivation of horticultural crops depends on a combination of economic, technical, market, and environmental factors. Addressing these factors through education, financial support, market development, and risk management measures can promote wider adoption of protected cultivation methods [77].

Conclusion

Protected cultivation is a method of growing crops in a controlled environment, allowing for the regulation of factors such as temperature, humidity, and light based on the specific requirements of the crop. This controlled environment helps promote healthier plants and increases the overall yield. There are various types of protected cultivation practices, including forced ventilated greenhouses, naturally ventilated polyhouses, insect-proof net houses, shade net houses, plastic tunnels, and techniques such as mulching, raised beds, trellising, and drip irrigation. These practices can be utilized independently or in combination to create a favorable growing environment, shielding plants from harsh climates and extending the cultivation period or enabling off-season crop production. The adoption of drip

irrigation in combination with raised beds and mulch films offers benefits such as weed control and improved soil moisture retention by reducing evaporation losses.

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