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Trends in Greenhouse Production Technology with Special Reference to Protected Cultivation of Horticultural Crops

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Abstract

Greenhouse is an important application scenario of modern agriculture. With the improvement of people's life quality, the demand for vegetables, fruits, flowers and has also increased, and the amount of greenhouses has developed rapidly. Greenhouse adopts artificial technical means to change natural light and temperature conditions, and to create environmental factors to optimize the growth of animals and plants, so that greenhouse crops can grow throughout the year and the weather. Compared with traditional planting methods, the greenhouse is more automated, intelligent, and mechanized. Greenhouse farming (Protected cultivation) refers to the practice of growing crops in an enclosed or partially enclosed environment, such as greenhouses, shade houses, or high tunnels. 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. 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. The benefits of greenhouses are high production per unit area because the genetic potential of the crop can be completely exploited, vegetables and nurseries can be grown off-season that obtain high market prices, good quality products and it is easy to protect the crops from pests, diseases and extreme climatic conditions. Greenhouse farming is a highly intensive industry that needs considerable labour and capital inputs. Because of this, all factors important for a successful enterprisers should be carefully considered by potential growers.

Keywords: Greenhouse technology, Protected cultivation, Smart greenhouse farming, Controlled environment agriculture.

1. Introduction

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 (Chandana et al., 2023). 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 (Patil et al., 2023). To avoid residues from affecting agricultural yield, chemical herbicides and insecticides should only be applied sparingly to crops growing in protected areas (Chandana et al., 2023).

Protected cultivation is one of the best and efficient way of raising seasonal and off-seasonal crops under a controlled environmental condition by applying scientific approach. Vegetable and flower crops offer a great deal of potential to create jobs, use land productively, and earn foreign currency through boosting export. Protected cultivation can help in the reduction of greenhouse gas emissions and the overall environmental impact by reducing the environmental hazard and by uplifting food production (Gruda et al., 2019). Greenhouse is a system for modification and management of environmental factors that allows plants to be grown in suitable climates that may not be well suited for their growth and development. In brief, a greenhouse farming optimizes growing conditions and protects the crops from extreme weather events, pests and diseases and enables effective crop managements. Greenhouses are important in agriculture, horticulture and botanical science (Samapika et al., 2020; Tiwari, 2003; Rajender et al., 2017). The modern greenhouse is used for the production of vegetables, flowers, fruits and any other plants that require controlled environment for survival. Protected cultivation involves growing crops with improved quality outside of their regular growing seasons, utilizing structures like greenhouses (Sabir & Singh, 2013). This practice increases profitability for farmers and reduces transportation time, ensuring the delivery of fresh produce, particularly in periurban areas (Paradiso & Proietti, 2022).

2. Importance of protected cultivation

Climate change is becoming an increasingly significant global problem that can no longer be ignored. The main underlying cause is anthropogenic, i.e., unsustainable use of fossil fuels, forest degradation for industrialization, and rapid urbanization with an overpopulation (Mukherjee et al., 2016).

- Crop is shielded from cold, wind, storm, rain and frost
- Due to controlled conditions there's higher germination, plant growth and crops mature quicker
- Improved quality & amount of manufacture with long period of time
- Use of water is optimized and there's reduction in its consumption by 40-50%
- Effective utilization of inputs
- Incidence of sickness and pests is reduced or eliminated
- Crops will be full-grown throughout the year.
- Best technology for industrial production of high worth crops like flowers, medicinal plants, etc.
- Can be used for star drying of farm manufacture
- Involvement of labor pool will be reduced
- Crop cultivation underneath inclement weather conditions

- Certain crops cultivated year spherical to satisfy the market demands.
- High worth and top quality, even organic, crops full grown for export markets
- Income from little land holdings exaggerated many fold.
- Successful nurseries from seeds or by vegetative propagation ready as and once necessary
- More Self-employment opportunities for educated youth on farm
- Manipulation of microclimate and bug proof feature of the greenhouse for plant breeding and, thus, the evolution of recent varieties and production of seeds.

3. Global and Indian scenario

Horticulture sector is the most lucrative venture providing vast employment opportunities and increased earnings to the farmers in India and at global level. India is at second place in the production of various horticultural crops in the world. Protected cultivation is the modern approach to cultivate horticultural crops in a manner that it can provide high quality produce with increased quantity. Greenhouse/poly house/net houses is most commanding technology under varying climate for round the year and off time vegetable and flower production.

Global Commercial Greenhouse Market size was valued at USD 39.6 Billion in 2023 and is expected to reach USD 68.7 Billion by 2028, growing at a CAGR of 11.6% during the forecast period 2023-2028. Several important factors augment the demand for commercial greenhouse solutions and services on a global scale. Commercial greenhouses provide the opportunity to lengthen growing seasons, lessen the effects of unfavourable weather, and ensure reliable crop harvests. Additionally, as consumer's awareness of the provenance and quality of their food grows, the transparency and traceability provided by greenhouse-grown products find a significant market resonance (CGMR, 2023).

The world underneath greenhouse cultivation reportable by the tip of twentieth century was regarding one hundred 10 ha in Asian nation and world over 275,000 area unit (Kang et al., 2013). Throughout last decade this space should have increased by 10 % if less. The states that have consistently expanded the area under protected cultivation for the period of 2007-2012 are Andhra Pradesh. Gujarat, Maharashtra. Haryana, Punjab, Tamil Nadu and West Bengal. Maharashtra and Gujarat had a cumulative area of 5,730.23 hectares and 4,720.72 hectares respectively under the protected cultivation till 2012. There are more than 55 countries currently within the world wherever cultivation of crops is underneath taken on a poster scale under cover, and it's ceaselessly growing at a quick rate internationally (Paramveer et al., 2020).

At present, only ~50,000 ha are under protected cultivation in India, followed China was 2 million hectares. There is a need to increase 4 times the area (~2,00,000 ha) under protected cultivation in the next 4-5 years. Production under protected cultivation not only providing high water and nutrient use efficiency but it can easily increase productivity and production by 3-5 folds over open/outdoor field cultivation (Government of India Ministry of Agriculture and Farmers Welfare Department of Agriculture, 2020). The total production of vegetables under protected cultivation is 138 million tons at present and to be increased to 250 million tons by the year 2024-2025 which may be achieved through bringing additional area under vegetable crops, using hybrid seeds, use of improved agro-techniques like protected structures (Sindhu &Chatterjee, 2020).

Many thousand acres square measure currently underneath glass the United States and equally giant space in England and Kingdom of The Netherlands, wherever gardening underneath glass was practiced over a

century past. During the past three decades, a large greenhouse industry has been developing rapidly in Spain. In a region called Almeria in southeastern Spain along the Mediterranean Sea, there is the largest concentration of greenhouses (more than 26,000 ha) producing mostly vegetables for Europe (Patowary, 2013).

Protected cultivation of horticultural crops results in higher yields and better quality produce compared to open field cultivation (Ameta et al., 2019). The average yield of tomatoes under protected cultivation is around 30-40 kg/m^2, while the average yield of tomatoes in open field cultivation is around 10-15 kg/m^2. 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.) and flowers (roses, gerberas, carnations, etc.) (Fernández et al., 2018). In India, the major horticultural crops produced under protected cultivation include tomatoes, cucumbers, capsicums, roses, and gerberas (Pachiyappan, 2022).

In the present scenario of perpetual demand of vegetables and shrinking land holding drastically, protected cultivation is the best alternative and drudgery less approach or using land and other resources more efficiently. In protected environment (greenhouse, glasshouse or polyhouse), the natural environment is modified to suitable conditions for optimum plant growth which ultimately provides quality vegetables.

Growing vegetables under protected environment is a fascinating art. It is expensive. In India, the structure of the greenhouse depends on the economic condition of the growers/farmers. Vegetable cultivation in low-and medium-cost greenhouse is a technical reality in India and is the need of the hour. Such production system has not only extended the growing season of vegetables and their availability but also encouraged to grow vegetables suitable for export. The seed production of vegetables production in India. Priorities must be focused to raise vegetables throughout the year by using greenhouse technology to complete the foreign markets.

Indian horticulture has a huge potential. If democratically organized, India's prospective fields with a great possibility for protected farming are:

- **Cultivation in difficult agro-climates:** The bulk of uncultivated land in India is under problematic circumstances such as barren, uncultivated fallow lands and deserts. Even a part of this space placed under greenhouse horticulture may yield significant dividends for the locals.
- **Greenhouses in and around major cities:** There is a year-round high demand for new veggies and ornamentals in major cities. Large cities also have a need for off-season and high-priced commodities. Thus, greenhouse cultivation is pushed to meet urban needs.

Protected Cultivation of (a) Tomato (b) Cucumber (c) Gerbera

- **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 offseason produce (Kumar & Singh, 2020).

- **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 (Kumar et al., 2019).
- **Horticultural Diversity:** A wide variety of horticultural crops, including vegetables, flowers, and exotic fruits, are grown using protected cultivation techniques in India (Asati &Yadav, 2004).
- **Greenhouse technology for biotechnology:** Material created by tissue culture should be propagated at a high pace. Controlled environmental conditions, such as aquiculture, hydroponic or aeroponics, are required for plant growth.

Hardening of Tissue Culture Raised Plants

Hydroponic Production System

- **Government Initiatives:** The Indian government has introduced various schemes and incentives to promote protected cultivation, encouraging farmers to adopt greenhouse and polyhouse technologies (Pachiyappan et al., 2022).
- **Challenges:** Despite growth, there are still challenges, including the high initial investment cost, technical knowledge gaps among small scale farmers, and sustainability concerns (Abegunde et al., 2019).
- **Research and Innovation:** Indian agricultural institutions and research organizations are actively involved in developing region-specific technologies for protected cultivation and improving crop productivity (Raina et al., 2009).
- **Horticulture produce Export Opportunities:** Protected cultivation has also opened up opportunities for India's horticultural exports, with certain crops being exported to international markets (Sengar & Rani, 2020). Promotions of greenhouse cultivation/protected growing of export homeward crops would undoubtedly aid in export promotion.

4. Greenhouse Structures

Greenhouses are structures covered with transparent materials, such as polythene, polycarbonate or glass, which act as selective radiation filters. They allow short-wavelength solar radiation to pass through while trapping long-wavelength radiation inside. This creates a greenhouse effect, trapping solar energy and raising the temperature inside the structure (Gorjian et al., 2021). The elevated temperature affects leaf temperature, transpiration, stomatal aperture, and the photosynthetic rate of plants (Pallas, 1967). Controlling the greenhouse environment allows manipulation of the physiological conditions of the plants (Paradiso & Proietti, 2022). The CO_2 released by the plants at night is also trapped inside, which increases the rate of photosynthesis at day time. The evaporation form the soul and plants also raises the humidity inside. The ultra-mode devices are also used for controlling the environment inside.

4.1. Greenhouse Classifications and types: Classification and types of GH is done based on different parameters such as: cost investment, shape of GH, roof of GH, utility of GH, GH construction materials, GH covering materials, GH climate control mechanism, etc. (Castilla & Baeza, 2013). The type and size of GH is a function of location, use, climate, purpose, topography, soil characteristic, water quantity and quality, labour availability affects the choice of GH, etc. (Agricdemy, 2020). On the basis of cost the greenhouses can be classified as:

- **Low Cost:** The low-cost greenhouses are constructed from locally available materials i.e. bamboo, wood etc. is used for construction of frame and glazed with stabilized polyethylene sheet. There is no environmental control in this type of greenhouses.
- **Medium Cost:** In case of medium cost greenhouses the frame may be made from Galvanized Iron/Mild steel pipes. But the problem associated with MS pipes is rusting after some time, which also damages the covering sheet. These greenhouses are also glazed with UV stabilized polyethylene sheet.
- **High Cost:** The high- cost greenhouses are made from aluminum/GI pipes, glazed with double layer poly ethylene sheet or poly carbonate. The environment inside the greenhouses is fully controlled and operation is also automated. There are sensors and controllers for temperature, humidity and soil moisture.



Low Cost Medium Cost High Cost

On the bases of height of greenhouses these may be classified as portable low tunnels and high tunnels. The portable low tunnels are of height 1 m and used to raise the seedlings of various crops. On the basis of cooling system the greenhouses may be classified as

1. Without cooling system
2. Passive cooing system

a. Natural ventilation
b. Shading type

3. Active cooling system

a. Forced ventilation and
b. Evaporative cooling

4.2. Indian standards for greenhouse

The BIS has formulated following standards with respect to greenhouse technology (Waaijenberg, 2006; BIS 1997).

- IS14462:1997-Recommended for layout, design and construction of greenhouse structures.
- IS14485:1998 – Recommendation for heating, cooling and ventilation of greenhouse.
- **SP 7 : 1983 -** National Building Code of India
- **SP30 : 1986 -** National Electrical Code of India
- 875: Code of practice for design loads (other than earth quake)' for buildings and structures
- **(Part 3) : 1987 -** Wind loads (second revision)
- **(Part 4) : 1987 -** Snow load (second revision)

- **2508 : 1984 -** Low density polyethylene films (second revision)
- **3034 : 1993 -** Code of practice for fire safety of industrial buildings: Electrical generating and distributing stations (second revision)

4.3. Leading Greenhouse companies: Leading companies in this market include well-established, financially stable solution providers of commercial greenhouse products and service providers. These companies have been operating in the market for several years and possess a diversified service portfolio, state-of-the-art laboratory &technologies, and strong global sales and marketing networks. Prominent companies in this market include Richel Group (France), Argus Control Systems Limited (Canada), Certhon (Netherlands), Logiqs. B.V. (Netherlands), Berry Global Group, Inc (US), Signify Holding (Netherlands), Heliospectra AB (Sweden), Plastika Kritis S.A. (Greece), Everlight Electronics Co., Ltd. (Taiwan), TopGreenhouses (Israel), Saveer Biotech Limited, India and other many more. Saveer Biotech Limited is an Indian Science and Technological firm that was founded in 1978 as a turnkey solution provider in the field of Hi-Tech Greenhouses and Scientific Research Infrastructures to give clients the greatest technology integration and quality solutions for their crops. Saveer Biotech design, manufacture, and commission projects on a turnkey basis, ensuring that end customers receive a fully operating facility. As a result, Saveer are constantly expanding product line by developing cutting-edge technology solutions such as Centre for Excellences for Horticulture, Automated Nursery, Seedling facilities, Climate Controlled Agriculture, Soilless Crop Production-Hydroponics & Aeroponics System, Speed Breeding facilities, Plant Tissue Culture, Phytotron, Plant Growth Chambers, Artificial PAR spectrum lights, Vertical farming, and many others.

5. Crops Grown under Protected Cultivation

- **Vegetables:** Tomato, Coloured Capsicum (Yellow and Red Bell Peppers), Cucumber, Broccoli, Red Cabbage, Leafy vegetables, and exotic vegetables, etc.
- **Flowers:** Chrysanthemum, Anthurium, Carnation, Gerbera, Rose, Lilium, Orchid, Gladiolus, etc.
- **Fruits:** Strawberry, Raspberry and other soft fruits.
- **Seedling and Nurseries:** Vegetables, Flowers, Tissue Culture, Clonal for Forestry, Fruit Grafting (like Lemon, Citrus, Mango, Pomegranate, Guava, Litchi, etc.).

6. Technological advancements in protected cultivation

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

- **Precision Agriculture Technologies:** Precision agriculture technologies, such as sensors, drones, and artificial intelligence, are being used to optimize crop production and reduce inputs. Agriculture also uses drones for crop health assessment, irrigation, crop monitoring, pesticide spraying, crop cultivation, and soil analysis. Precision agriculture is one of the most well-known applications of IoT ((Internet of Things)) in agriculture, and many organizations are using this technique worldwide. (Mizik, 2023; Raj, 2022).
- **Smart greenhouse:** Growing plants in a greenhouse is a method to help improve the yield of vegetables, fruits, and crops. Greenhouses control environmental parameters through manual intervention or control mechanisms. A competent greenhouse can be designed with the help of IoT, which intelligently monitors and manages the climate, eliminating the need for manual intervention.

It is necessary to use different sensors that measure the environmental parameters required by the plant to control the environment in an intelligent greenhouse (Ullah, 2022; Benghanem et al., 2023; Marın et al., 2023).

- **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.

7. Future prospects

There is a great need throughout India for effective greenhouse facility to boost vegetable production. The need exists in vegetable research institutes and laboratories to standardize greenhouse production technologies. There are potentials and opportunities in various agro climatic zones in India for commercial use of greenhouses in vegetable production. In temperate climates, vegetable farmers can substantially increase their income if they can start early vegetable production under protected conditions. Vegetables raised in open fields would reach market later than greenhouse crops. Besides in hilly areas, tropical vegetables can be grown in greenhouses.

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 (Slathia et al., 2018). 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 (Baylis, 2017), and the integration of Internet of Things (IoT) solutions for data collection and analysis (Alansari, 2018). Expanding role of protected cultivation in meeting global food demands: Protected cultivation plays a crucial role in meeting global food demands (Shiferaw, 2013). It allows for the production of high-uality 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 (Subin, 2021). However, advancements in technology and increasing awareness about sustainable farming practices present opportunities for overcoming these challenges and expanding the use of protected cultivation.

Globally, farming generally and GH farming in particular evolved from the traditional farming system to exploring the application of Internet of Thing (IoT) in the agricultural sectors - smart agriculture. The use of artificial intelligence (AI) in GH, is called intelligence greenhouse for food production. Thus, the current trends of research in smart farming/GH includes the use of drones, robotic agriculture/farming, application of GIS and farm/GH site mapping for sustainable food production. The application of IoT, robots, AI, GIS and site mapping to GH agriculture/farming and hydroponics (soilless farming) are the new trends in GH farming with a robust chances of improving and increasing crops yields and eliminating human interference and drudgery for sustainable food production and security (Chen et al., 2020; Fedotova et al., 2020; Katzin et al., 2020). Future greenhouses will likely place more emphasis on the carbon footprint, especially by decreasing the use of fossil fuels and increasing the use of renewable energy sources. As consumers become increasingly conscious about food safety, greenhouse production technologies that

completely avoid pesticides and use nonchemical methods (e.g., ultraviolet sterilization) to control insects and diseases will likely be developed in the future.

8. Conclusion

The increasing demand for vegetables, floriculture and ornamental horticulture presents a significant opportunity for the commercial greenhouse market. As urbanization and disposable incomes rise across the globe, there is a growing interest in enhancing living and working spaces with aesthetically pleasing plants, flowers and vegetables. Commercial greenhouses provide an ideal environment for cultivating a wide variety of vegetables, flowers, plants, and ornamental foliage with precision and control. Demand for food, particularly vegetables, has increased significantly as a result of these factors. The review also opened vista of researchable areas in GH farming technology to include, but not limited to robotic farming, application of artificial intelligence (AI) in GH farming, use of drone in GH farming, application of GIS and farm/GH site mapping, all aimed towards sustainable food production and security. Institute of Horticulture Technology (IHT) provides trainings to the farmers, filed functionaries and other interested bio entrepreneurs in the protected cultivation of horticultural crops, greenhouse construction and commercial hydroponic cultivation. Precision farming is another area of capacity building undertaken by IHT. Institute have world class facilities for production and training programme in its main campus at Greater Noida, Uttar Pradesh, NE Centre in Mandira, Kamrup District. Crop specific and customized training courses are made available and offered to stake holders to keep our programme demand driven.

9. References

1. Abegunde V.O., Sibanda M., Obi A. (2019). The dynamics of climate change adaptation in Sub-Saharan Africa: A review of climate smart agriculture among small-scale farmers. Climate, 7(11), 132.
2. Agricdemy (2020). https://agricdemy.com/post/greenhouse-farmingnigeria. Greenhouse Farming. Assessed online 14 November 2020.
3. Alansari Z., Anuar N.B., Kamsin A., Soomro S., Belgaum M.R., Miraz M.H., (2018). Challenges of internet of things and big data integration. In Emerging Technologies in Computing: First International Conference, iCETiC 2018, London, UK, August 23–24, 2018, Proceedings 1.Springer International Publishing, 47-55.
4. Ameta K.D., Kaushik R.A., Dubey R.B., Rajawat K.S. (2019). Protected cultivation-An Entrepreneurship for modern agriculture. Biotech Today: An International Journal of Biological Sciences, 9(1), 35-40.
5. Asati B.S. and Yadav D.S. (2004). Diversity of horticultural crops in north eastern region. ENVIS Bulletin: Himalayan Ecology, 12(2), 1-10.
6. Baylis A. (2017). Advances in precision farming technologies for crop protection. Outlooks on Pest Management. 28(4), 158- 161.
7. Benghanem M., Mellit A., Khushaim M. (2023). Environmental monitoring of a smart greenhouse powered by a photovoltaic cooling system. Journal of Taibah University for Science, 17(1), 2207775. https://doi.org/10.1080/16583655. 2023.2207775.
8. BIS (Bureau of Indian Standards), IS 14462 (1997): Recommendations for layout, design and construction of greenhouse structures [FAD 22: Agricultural Systems and Management]
9. Castilla, N. & Baeza, E. (2013). Greenhouse site selection. In Baudoin,W., Nono-Womdim, R., Lutaladio, N., HoddeGood, A., Castilla, N., Leonardi, C., De Pascale, S. and Qaryouti, M. (eds).

Agricultural Practices for Greenhouse Vegetable Crops: Principles for Mediterranean Climate Areas. FAO Plant Production and Protection Paper 217, pp. 21–34.

10. Chandana J.L., Supriya N.V. S., Karakambadi V., Anusha S. (2023). Advances in Protected Cultivation of Vegetables. Research Gate.
11. Chen, M., Zhou, J. and Li, P. (2020). Data communication mechanism for greenhouse environment monitoring and control: An agent-based IoT system. Information Processing in Agriculture, 7, 444 – 456.
12. CGMR - Commercial Greenhouse Market Report (2023). www.marketsandmarkets.com, Report Code: AGI 4088.
13. Fedotova, G. V., Gorlov, I. F., Glushchenko, A. V., Slozhenkina, M. I. and Natyrov, A. K. (2020). Trends of Scientific and Technical Development of Agriculture in Russia. In Popkova, E. G. and Sergi, B. S. (eds). Digital Economy: Complexity and Variety Versus Rationality. Lecture notes in Networks and Systems 87. Springer Nature Switzerland AG, pp. 193–200.
14. Fernández J.A., Orsini F., Baeza E., Oztekin G.B., Muñoz P., Contreras J., Montero J.I. (2018). Current trends in protected cultivation in Mediterranean climates. Eur. J. Hortic. Sci., 83(5), 294-305.
15. Gorjian S., Calise F., Kant K., Ahamed M.S., Copertaro B., Najafi G. (2021). A review on opportunities for implementation of solar energy technologies in agricultural greenhouses. Journal of Cleaner Production, 285, 124807.
16. Gruda N., Bisbis M., Tanny J. (2019). Impacts of protected vegetable cultivation on climate change and adaptation strategies for cleaner production—A Review. J. Clean. Prod., 22, 324–339.)
17. Kang, Yunyan; Chang, Yao-Chien Alex; Choi, Hyun- Sug; Gu, Mengmeng (2013). Current and future status of protected cultivation techniques in Asia, Acta horticulturae, ISSN, 0567-7572.
18. Katzin, D., Van Mourik, S., Kempkes, F. and Van Henten, E. J. (2020). Green Light - An open source model for greenhouses with supplemental lighting: Evaluation of heat requirements under LED and HPS lamps. Biosystems Engineering, 194, 61–81.
19. Kumar D. & Singh B. (2020). Vegetables cultivation under protected conditions. Progressive Agriculture, 20 (1and2), 148-152.
20. Kumar S., Meena R.S., Jakhar S.R., Jangir .CK., Gupta A., Meena B.L. (2019). Adaptation strategies for enhancing agricultural and environmental sustainability under current climate. Sustainable agriculture. Scientific Publisher, Jodhpur, 226-274.
21. Marın-Garcia E., Torres-Marın J.N., Chaverra-Lasso A. (2023). Smart Greenhouse and Agriculture 4.0. Revista cientıfica., 46, 37–50.
22. Mizik T. (2023). How can precision farming work on a small scale? A systematic literature review. Precision Agriculture, 24(1), 384–406. https://doi.org/10.1007/s 11119-022-09934-y.
23. Mukherjee, A., Rakshit, S., Nag, A., Ray, M., Kharbikar, H. L., Shubha, K., & Burman, R. R. (2016). Climate change risk perception, adaptation and mitigation strategy: An extension outlook in mountain Himalaya. In Conservation Agriculture (pp. 257-292), Springer, Singapore.
24. Pachiyappan P., Kumar P., Reddy K.V., Kumar K.N.R., Konduru S., Paramesh V. (2022). Protected cultivation of horticultural crops as a livelihood opportunity in western India: An economic assessment. Sustainability, 14(12), 7430.
25. Pallas Jr J.E., Michel B.E., Harris D.G. (1967). Photosynthesis, transpiration, leaf temperature, and stomatal activity of cotton plants under varying water potentials. Plant Physiology, 42(1), 76-88.

26. Paradiso R. & Proietti S. (2022). Light-quality manipulation to control plant growth and photomorphogenesis in greenhouse horticulture: The state of the art and the opportunities of modern LED systems. Journal of Plant Growth Regulation, 41(2), 742-780.
27. Paramveer Singh, Ajay Bhardwaj & Randhir Kumar (2020). Protected Horticulture in India: An Overview: Book Sustainable Agriculture, Edition1st Edition, eBook ISBN9780429325830
28. Patil S., Munshi M.M., Prashantha C. (2023). Greenhouses (Protected) cultivation: importance, scope, and status. International Journal of Innovative Research in Technology, 9(8), 276-278.
29. Patowary, K. (2013). The greenhouses of Almeria 11 July 2021. https://www.amusingplanet.com/2013/08/the-greenhouses-of-almeria.html/
30. Raina R.S., Joseph K., Haribabu E. & Kumar R. (2009). Agricultural innovation systems and the coevolution of exclusion in India. Systems of Innovation for Inclusive Development Project.
31. Raj E.F.I., Appadurai M., Athiappan K. (2022). Precision farming in modern agriculture. In: Smart Agriculture Automation Using Advanced Technologies: Data Analytics and Machine Learning, Cloud Architecture, Automation and IoT. Springer, 61–87.
32. Rajender, G., Sushanth, K., Mithun, K. Devender, B., Raju, D. and Anoosha, K. (2017). Design and development of low cost greenhouse to raise different cultivars. International Journal of Agricultural Science and Research, 7(3), 29-36.
33. Sabir N. & Singh B. (2013). Protected cultivation of vegetables in global arena: A review. Indian Journal of Agricultural Sciences, 83(2), 123-135.
34. Samapika, D., Barsha, T., Smaranika, M., Basabadatta, S. & Jnana, B. P. (2020). Green-houses: Types and Structural Components. In Maitra, S., Gaikwad, D.J. and Tanmoy Shankar, T. (eds). Protected Cultivation and Smart Agriculture. New Delhi Publishers, New Delhi, pp. 9-17.
35. Sengar R.S. & Rani V. (2020) Opportunities and prospective of integrated development of horticulture: A review. Annals of Horticulture, 13(1), 1-8.
36. Shiferaw B., Smale M., Braun H.J., Duveiller E., Reynolds M., Muricho G. (2013) Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. Food Security, 5, 291-317.
37. Sindhu V. & Ranjit Chatterjee (2020). Off-Season Vegetable Cultivation under Protected Structures: A Promising Technology for Doubling Farmers Income. Int. Arch. App. Sci. Tech. (IAAST), 11(3), 208-214.
38. Slathia D., Nisa M.U., Reshi M., Dolkar T., Hussain S. (2018) Protected cultivation of ornamentals. Global Journal of Bio- Science and Biotechnology, 7(2), 302-311.
39. Subin M.C., Chowdhury S., Karthikeyan R. (2021) A review of up gradation of energy-efficient sustainable commercial greenhouses in Middle East climatic conditions. Open Agriculture, 6(1), 308-328.
40. Tiwari G. N. (2003). A Text book of Greenhouse Technology for Controlled Environment. Alpha Science Publisher.
41. Ullah I., Fayaz M., Aman M., Kim D. (2022). An optimization scheme for IoT based smart greenhouse climate control with efficient energy consumption. Computing, 104(2), 433–457. https://doi.org/10.1007/ s00607-021-00963-5.
42. Waaijenberg D. (2006). Design, construction and maintenance of greenhouse structures. Acta Hortic., 710, 31-42. DOI: 10.17660/ActaHortic.2006.710.1.