Growing under Glass: Polyhouse & Greenhouse Innovations for Agrifarming as Environmental Sustainability

Suman Gupta

Assistant Professor, Department Of Botany, Rajkiya Mahavidyalaya Bairia Ballia-277208, Uttar Pradesh
Email: Iamguptasuman@Gmail.Com

Abstract : Greenhouse technology has emerged as a powerful tool for streamlining crop production, offering numerous benefits such as extended growing seasons, protection from adverse weather conditions, and reduced pest and disease pressure. The integration of advanced technologies, including hydroponics, aeroponics, and aquaponics, robotics, artificial intelligence has further enhanced the efficiency and sustainability of greenhouse cultivation. Precision agriculture techniques, such as sensor-based monitoring, automation, and data analytics, have enabled growers to optimize resource use, improve crop performance, and make data-driven decisions. Heat-pump technology, semi-transparent photovoltaic (PV), lighting technology, and control systems are examples of recent energy-saving technologies in greenhouses. Additionally, energy-saving lighting can be provided by retrofitting greenhouses with Light Emittance Diodes (LEDs), which can cost up to 75% less annually than traditional artificial lights.

Keywords : Greenhouse, Yield, Light, Agriculture

Introduction

Agricultural sustainability is much more required for the future agriculture to ensure food and nutritional security for the future (Maitra *et al*., 2023). Protected cultivation refers to the agricultural practice of growing crops within controlled environments, such as greenhouses, polyhouses, and shade nets. These structures provide a regulated climate that protects crops from adverse weather conditions, pests, and diseases, thus enabling year-round production and enhanced yield quality. The controlled environment typically involves the use of technologies to regulate temperature, humidity, light, and CO_2 levels, creating optimal growth conditions for various crops (Maitra *et al*., 2024). Another name for protected cultivation is controlled environment agriculture. Growing populations, tiny land holdings, declining crop productivity and biodiversity, and rapid urbanization all contributed to the development of protected agriculture, which offered an innovative means of producing more crops on a smaller plot of land. To put it another way, protected cultivation practices can also be described as cropping methods in which the microclimate surrounding the plant body is either completely or partially controlled during the growth phase in accordance with the needs of the crops planted. Another name for it is Controlled Environment Agriculture. Protected cultivation offered a new dimension to produce more crops in a limited area of land as rapid urbanization, small land holdings, declining crop production and biodiversity, increasing population, demand for food especially vegetables are some constraints in agricultural production. It involves the cultivation of vegetables to attain maximum production in a controlled environment where temperature, humidity, light, soil, water, fertilizers etc. are manipulated even during off season. There are various types of protected cultivation practices. It involves growing vegetables to their highest potential in a regulated setting where factors like light, soil, water, fertilizer, humidity, and temperature are adjusted even during off-season and facilitates year round crop cultivation (Kumar *et al*., 2017). There are various forms of protected cultivation techniques. Forced ventilation greenhouses, naturally ventilated polyhouses, insect-proof net houses, and shade nets are a few of the often employed techniques house, raised beds, drip irrigation, mulching, and a plastic tunnel. These techniques can be applied separately or in combination to create a favorable environment that protects plants from adverse weather conditions and increases the length of cultivation or off-season agricultural production.

In addition to eliminating weeds, drip irrigation on mulch-covered raised beds prolongs soil moisture retention by lowering evaporation losses.

Reason for Glass house/Polyhouse cultivation at present scenario

- The actual problem of low production and productivity has been attributed to the extremes of temperatures ranging from 0-48 °C during the year which does not allow year round outdoor vegetable cultivation.
- Growing vegetables is difficult in the upper parts of the Himalayas because of the cold desert climate, which includes wintertime lows of -5 to -30 °C and isolation from the rest of the country from November to March due to severe snowfall.
- Vegetable growers don't get great profits because there are so many vegetables on the market during the growing season.
- In certain parts of the nation, biotic stresses during the wet and post-rainy seasons hinder the successful production of vegetables. Because of this, most vegetables are severely harmed by pests, diseases, and viruses, which reduces their quality.
- The growing demand for vegetables of superior grade.
- Growing nurseries early to get a crop early.

Concept of greenhouse

A greenhouse is a framed or inflatable structure coated in translucent or transparent material that allows crops to be grown in environments that are either totally or partially regulated. The greenhouse effect is the fundamental idea underlying a greenhouse: solar energy enters through the glass cover, is absorbed by the soil and plants, and is then held inside, raising the temperature. The purpose of greenhouses is to prolong the growing season producing fruits, flowers, and vegetables that are not in season. propagation of nursery plants and seedlings. programs for breeding and research. It is possible to cultivate crops that are climate resilient. A greenhouse system consists of the following components viz., structural framework made of galvanized iron (GI), aluminum, or bamboo. Covering materials made up of glass, polyethylene, polycarbonate sheets, or acrylic films. Ventilation system includes natural or forced ventilation with exhaust fans. Cooling system like evaporative cooling pads, foggers, or shading systems. Heating system includes electric heaters, hot water pipes, or biomass heating. Irrigation and fertigation include drip irrigation, hydroponics, or aeroponics etc. Vegetable crops that can be grown in greenhouses include tomatoes, capsicums, cucumbers, french beans, cabbage, chillies, and more. When crops cannot be produced outdoors, vegetables are grown in greenhouses. Vegetables that are in season, such as lettuce, tomatoes, cucumbers, and peppers, command a higher market price. The climate and topography of a region influence the design of greenhouses. Glass houses, or carefully regulated greenhouses, are utilized in temperate climates. In temperate climates, vegetables are cultivated in carefully controlled greenhouses, sometimes referred to as "glass houses," because it is challenging to grow crops outside due to the frigid weather. It lowers crop environmental risks and promotes the growth of a variety of crops.

Type of various Polyhouse/greenhouse

Hi-Tech poly house : It is the costly structure among all the protected structures because it is based on the latest technology and all operations i.e. fertigation, irrigation, up and downs of plastic walls, temperature control, etc. operated through computers. It is also known as a fan & pad poly house. High valued crops are grown in these structures. Due to higher costs, the adoption of these structures is very less but the production under these structures is higher as compared to other protected structures. The automated production process should be carefully analyzed. Generic technology principles should be developed to make a feasible R and D business case and also for the smaller market size of crops.

Low-cost poly house : For marginal and small farmers who cannot afford the exorbitant cost of the high-tech poly home, the low-cost poly house was cost-effective. It was used to raise nurseries; in the winter, crops are raised in similar structures. An attempt was made to create low-tech, climate-adaptable protected farming methods that smallholder farmers could afford. Natural Ventilated Poly home The essential materials for the natural ventilated poly home are tabular, wooden, and bamboo. The cost of a tabular poly home is in the middle; it is more expensive than other structures but less expensive than high-tech ones.

Innovative Greenhouse Structure

Naturally ventilated poly house : The primary materials for a naturally ventilated Polyhouse are bamboo, wood, and tabular. The price of a tabular Polyhouseis in the middle; it is more expensive than other options but less expensive than high-tech. In a tubular poly house, the structure is made up of stainless steel with a plastic wall and roof. Polythene sheet (150 nm thick) used in its construction which prevents the entry of ultraviolet light, conserves CO_2, and enhances plant growth and development. Temperature and moisture under the poly house are higher than outdoor condition, which improves photosynthesis and uniform plant growth. Bamboo or wooden poly house is similar to a tubular structure but it is made up of bamboo or wooden and life of this structure is small as compared to the tubular structure. In this no specific control device used for regulating the internal environment in the poly house. Natural ventilation poly house is the most essential. tool that growers can use to maintain the greenhouse/poly house microclimate (temperature, humidity, and CO_2) within the best range for the crop.

Walk-in tunnel : Walk-in tunnel structure covered with Ultra Violet film, it is suitable for all types of crops, vegetables & flowers, and its lower initial cost structure motivates small farmers to adopt it. This structure temperature (high) is not controlled but the internal climate has differed from the outside. It helped sustain air and severe summer temperatures while shielding plants from soil moisture. Vegetable farmers in temperate regions can boost their revenue by growing early harvests in protected structures (Sanwal *et al*., 2004).

Shade Net House : Shade net houses are structures covered with specially designed shade nets made of synthetic materials. These nets provide partial shade to crops, reducing heat stress and protecting them from direct sunlight. Shade net houses are particularly beneficial in regions with high temperatures and intense sunlight, allowing for better control of temperature and humidity levels inside the structure (Lamichhane *et al*., 2023).

Recent Innovations in Polyhouse Technology

Polyhouse using IoT

By incorporating Internet of Things (IoT) technology into its operations, an IoT-based polyhouse turns conventional greenhouse buildings into intelligent, networked systems. In order to collect real-time data on a variety of environmental parameters, including temperature, humidity, soil moisture, light intensity, and ventilation, this innovation entails integrating sensors, actuators, and monitoring devices into the polyhouse architecture (Arbind Agrahari Baniya *et al*., 2023). These sensors gather data, which is subsequently sent to a central IoT platform for analysis. Farmers can use laptops or smartphones to remotely monitor and manage the polyhouse environment by utilizing IoT. Based on predetermined parameters or data-driven insights, automated systems can modify nutrient distribution, watering schedules, and climatic controls. For instance, if sensors detect a deviation in temperature or moisture levels, the IoT system can trigger actions like adjusting ventilation or initiating irrigation to maintain optimal conditions for crop growth. Additionally, IoT-based polyhouses facilitate data-driven decision-making by providing valuable insights into crop health, resource usage, and environmental conditions. This technology enables predictive analytics, allowing farmers to anticipate potential issues and optimize crop production more efficiently. Overall, this integration of IoT into polyhouse operations enhances efficiency, precision, and yield while reducing resource wastage and manual labor (Dhanaraju *et al*., 2022).
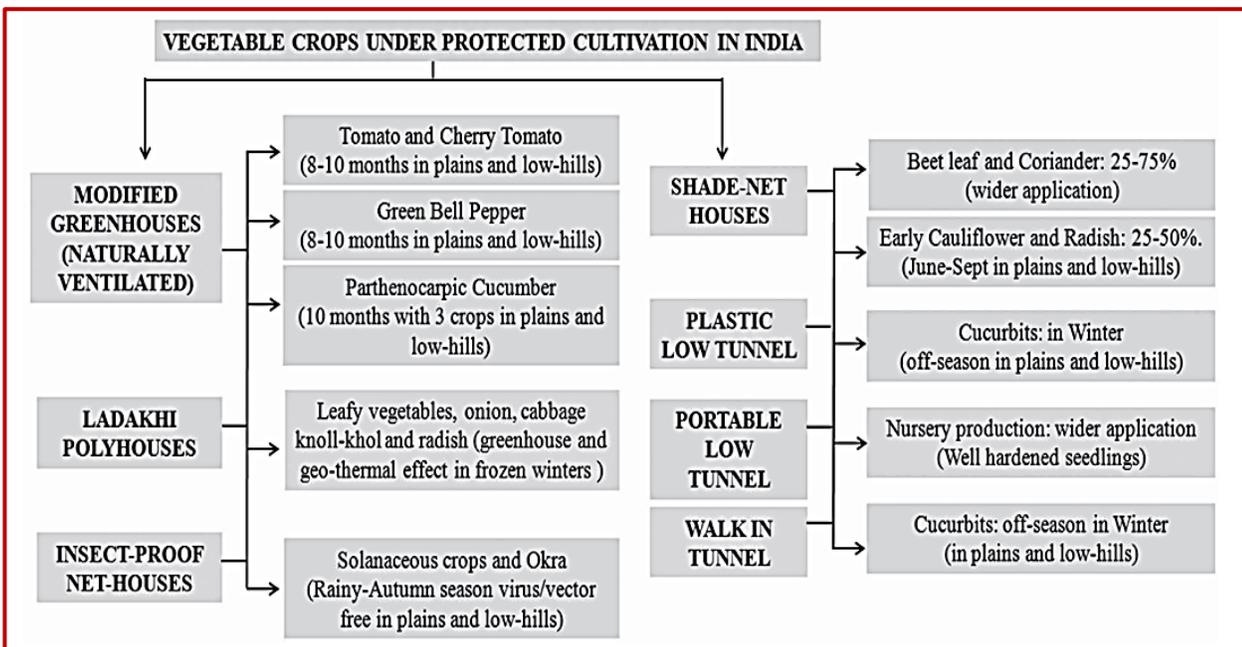
One of the primary AI technologies used in smart greenhouses is Computer Vision. AI-powered cameras and sensors monitor crop health, detecting issues like pests, diseases, and nutrient deficiencies. This enables farmers to take prompt action, reducing crop loss and improving yields. Machine Learning (ML) is another crucial AI technology used in smart greenhouses. ML algorithms analyze data from sensors, weather forecasts, and other sources to predict crop yields, optimize climate control, and detect anomalies. This enables farmers to make data-driven decisions, reducing resource consumption and improving crop quality. The Internet of Things (IoT) is also playing a vital role in smart greenhouses. IoT sensors and devices connect the greenhouse, enabling real-time monitoring and control of temperature, humidity, light, and other factors. This enables farmers to adjust the climate and optimize crop growth, reducing energy consumption and improving yields. The applications of AI in smart greenhouses are numerous. Precision farming is one of the key applications, where AI optimizes crop growth by adjusting temperature, humidity, and light levels. Predictive maintenance is another application, where AI predicts equipment failures, reducing downtime and maintenance costs. Crop monitoring is also a critical application, where AI detects issues early, enabling prompt action to prevent crop loss. The benefits of AI in smart

greenhouses are significant. AI-optimized greenhouses can increase crop yields by up to 30%. AI can also reduce water consumption by up to 50% and energy consumption by up to 40%. Additionally, AI detects issues early, ensuring healthier crops and reduced pesticide use. However, there are also challenges associated with AI in smart greenhouses. Data management is a significant challenge, as managing large amounts of data from sensors and cameras can be complex. System integration is another challenge, as integrating AI technologies with existing greenhouse systems can be difficult. Cost is also a challenge, as implementing AI technologies can be expensive, especially for small-scale farmers.

Benefits of Polyhouse/Greenhouse Technology

Economic Benefits to Farmers : For farmers, protected cultivation offers substantial financial benefits. Regardless of the outside weather, farmers may grow high-value crops all year round by establishing a controlled atmosphere. This results in higher agricultural yields, better produce quality, and fewer crop losses from bad weather or pest infestations. Additionally, cropping patterns may diversify as a result of protected cultivation, enabling farmers to investigate new and more profitable markets (Banjare *et al*., 2024).

Impact on Employment and Income Levels : In rural areas, protected cultivation has a good effect on employment and income levels. The construction and upkeep of greenhouses, polyhouses, and shade nets necessitate labor, which gives rural residents employment options. In addition to lowering rural-urban migration, this boosts the local economy by creating new revenue streams. Additionally, because protected farming is more profitable and productive, farmers may hire more workers, which raises employment rates overall (Ravindra and Kumar, 2022). Long-term economic growth in rural regions is facilitated by the skills and knowledge acquired from working in protected cultivation.

Cost-Benefit Analysis : The long-term economic sustainability of protected cultivation is revealed by a thorough cost-benefit analysis. Even so, the initial outlay for structures such as The benefits of greenhouses and polyhouses in terms of higher production, quality, and market pricing frequently exceed the expenses. Over time, lower operating costs result from the decreased need for fertilizers and pesticides as well as the effective use of energy and water resources. Government financial aid and subsidies can also lessen farmers' initial investment costs, increasing the accessibility of protected farming.

Environmental Sustainability : Protected cultivation plays a crucial role in promoting environmental sustainability through various mechanisms that enhance resource efficiency, reduce chemical inputs, mitigate climate change impacts, and contribute to biodiversity conservation.

Resource Efficiency : Resource efficiency is one of protected cultivation's major environmental advantages. Greenhouses and polyhouses are examples of controlled habitats that maximize the use of resources including soil, water, and energy. By supplying water directly to plant roots, cutting waste, and increasing water efficiency, technologies like drip irrigation and automatic climate control systems reduce water usage. By using renewable energy sources, like solar electricity, to run lighting, heating, and ventilation systems, energy efficiency is attained, lowering greenhouse gas emissions and reliance on fossil fuels.

Reduction of Pesticide and Fertilizer Use : Compared to traditional open-field farming, protected agriculture drastically lowers the need for chemical fertilizers and pesticides. Greenhouses and polyhouses reduce the need for chemical pest control methods by creating physical barriers that restrict pest access. In order to efficiently manage pests and diseases without using hazardous chemical inputs, integrated pest management (IPM) strategies are frequently used. These strategies combine biological controls, crop rotation, and monitoring systems (Sharma *et al*., 2023). In a similar vein, nutrient management strategies like hydroponics and precision fertilization minimize fertilizer consumption and nutrient runoff into water bodies by ensuring that plants receive the required nutrients in ideal amounts (Selvan *et al*., 2023).

Conclusion

In recent years, the agricultural sector has undergone a revolutionary transformation driven by technological advancements and advanced knowledge. By enabling year-round crop production, maximizing resource usage, and improving crop yields and quality, greenhouse technology has completely transformed modern agriculture. This thorough analysis examines the various ways that greenhouse technology might simplify agricultural production procedures. It explores the fundamentals of greenhouse design, going over key elements such covering materials, structural materials, and environmental control systems. The benefits of greenhouse farming are covered in the article, including longer growing seasons, shelter from bad weather, and less pressure from pests and diseases. It looks at how cutting-edge technologies like hydroponics, aeroponics, and aquaponics can be used in greenhouse systems to maximize resource efficiency and minimize environmental impact.

References

Baniya, A. A., Eklund, P. W., & Aryal, S. (2023). Current state, data requirements and generative ai solution for learning-based computer vision in horticulture.

Banjare, C., Mahanta, D., Sahu, P., & Choudhary, R. (2024). A comprehensive review on protected cultivation: Importance, scope and status. *Int. J. Environ. Clim. Change*, *14*(7), 46-55.

Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., & Kaliaperumal, R. (2022). Smart farming: Internet of Things (IoT)-based sustainable agriculture. *Agriculture*, *12*(10), 1745.

Kumar, P., & Chauhan, R. S. (2017). An economic analysis of cucumber (Cucumis sativus L.) cultivation in eastern zone of Haryana (India) under polyhouse and open field condition. *Journal of applied and Natural Science*, *9*(1), 402.

Lamichhane, P., Adhikari, J., & Poudel, A. (2023). Protected cultivation of horticultural crops in Nepal: Current practices and future needs. *Archives of Agriculture and Environmental Science*, *8*(2), 268-273.

Maitra, S., Sahoo, U., Sairam, M., Gitari, H. I., Rezaei-Chiyaneh, E., Battaglia, M. L., & Hossain, A. (2023). Cultivating sustainability: A comprehensive review on intercropping in a changing climate. *Research on Crops*, *24*(4), 702-715.

Maitra, S., Sairam, M., & Santosh, D. T. (2024). Evaluation of the growth, flower quality, yield and vase life of gerbera (Gerbera jamesonii L.) cultivars under open ventilated saw-tooth type polyhouse. *Research on Crops*, *25*(1).

Ravindra, K. and Kumar, N. 2022. Sustainable Agriculture Practices: The Role of Protected Cultivation. J. Sustain. Dev., 11(4): 180-196.

Sanwal, S. K., Patel, K. K., & Yadav, D. S. (2004). Vegetable production under protected conditions in NEH region: Problems and prospects. *ENVIS Bulletin: Himalayan Ecology*, *12*(2), 7.

Selvan, T., Panmei, L., Murasing, K. K., Guleria, V., Ramesh, K. R., Bhardwaj, D. R., ... & Deshmukh, H. K. (2023). Circular economy in agriculture: Unleashing the potential of integrated organic farming for food security and sustainable development. *Frontiers in Sustainable Food Systems*, *7*, 1170380.

Sharma, S., Parmar, G., Shukla, R., & Leua, A. (2023). Factors affecting marketing among small and marginal vegetable farmers of South Gujarat. *Indian Research Journal of Extension Education*, *11*(2), 99-104.