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REVIEW ARTICLE

Navigating Challenges and Prospects in Off-Season Vegetable Production

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Abstract

The demand for vegetables in India is substantial, driven by widespread vegetarian dietary preferences. However, the supply often falls short due to the inability to grow all types of vegetables throughout the year. This emphasizes the significance of off-season vegetable cultivation, offering a solution for year-round production, controlling price fluctuations during off-seasons, and ensuring accessibility for people across different economic classes. Off-season cultivation plays a pivotal role in addressing nutritional deficiencies and providing economic returns to farmers, especially during periods of market surplus and falling prices. Consequently, there has been a notable increase in off-season cultivation practices, where crops are grown outside the regular cropping calendar to counter supply shortages and capitalize on high market prices. Various methods are employed for cultivating off-season vegetables, including leveraging a country's agro-climatic diversity, using different varieties, cultivating in *diara* lands/riverbeds, and employing protected cultivation. However, this review specifically focuses on *diara*/riverbed and protected cultivation of vegetables for their off-season production. While these practices have shown promise, ensuring consistent technical support, training, and a reliable supply of inputs like seeds and fertilizers, along with market information, is crucial for sustaining the adoption of agricultural technologies. Long-term success depends on accessible extension services, and the combined impact of various technologies contributes to improved off-season agricultural practices. This underscores the importance of farmer-centric policies in guiding enduring technology adoption. Factors such as education, experience in vegetable production, access to extension services, and training significantly influence farmers' decisions regarding technology adoption.

Keywords: Year-round harvest, sustainable farming, river bed cultivation, protected cultivation.

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Introduction

The growing acknowledgment of the crucial role nutrition plays in our daily diet has heightened the importance of vegetables in our lives. Vegetables function as valuable sources of vital nutrients like vitamins and minerals. Globally recognized as "protective food," vegetables are esteemed for their abundant supply of vitamins, minerals, color pigments, antioxidants, and their essential role in guaranteeing food, nutrition, immunity enhancement and livelihood security (Krishna *et al.*, 2022). In India, the demand for vegetables is on a steady rise, fueled by heightened consumer awareness of health and the pressure of a burgeoning population. India stands as the second-largest vegetable-producing country globally, trailing only behind China. Despite a significant surge in total vegetable production from 58.5 million tonnes in 1991-92 to 212.91 million tonnes in 2022-23, cultivation practices remain restricted by seasonal and regional needs (Anonymous, 2023). This heightened awareness has led to an increased demand for vegetable production. However, conventional open-field cultivation methods are insufficient to meet the escalating global population's needs. Persistent reliance on traditional farming methods has led to low yields, reduced productivity, and inconsistent produce quality (Navnath *et al*., 2019). Consequently, there has been a surge in off-season cultivation practices, wherein crops are grown outside the regular cropping calendar to address supply shortages and capitalize on high market prices. Several methods exist for cultivating off-season vegetables, including leveraging a country's agro-climatic diversity, utilizing different varieties, growing in *diara* lands/riverbeds, and practicing protected cultivation. However, this review will specifically concentrate on *diara*/riverbed cultivation.

Leveraging Nature's Bounty for Off-season Production across Varied Landscapes

The three hill states of India—Jammu and Kashmir, Uttarakhand, and Himachal Pradesh—located in the North-Western Himalayan region, have earned the distinction of being the "Natural Glass House" of the country. This designation is attributed to their diverse climate, spanning from subtropical to dry temperate, making them ideal for off-season vegetable cultivation. The topographic features of these hills, including altitude, latitude, and slopes, create valleys conducive to raising off-season vegetables. Hill-grown vegetables from this region are highly regarded for their distinct flavor, freshness, crispness, sweetness, superior quality, and being free of pesticide residues. Winter-season vegetables, typically cultivated during the summer in the hills, find a ready market in the plains, providing farmers with lucrative returns during their lean periods. Several vegetables have gained prominence in off-season cultivation in the hills, including tomatoes, green peas, beans, cabbage, cauliflower, green capsicum, colored capsicum, summer squash, cucumber, broccoli, lettuce, Chinese cabbage, brussels sprouts, European carrots, and snow peas (Sharma *et al*., 2023).

Developing Varieties for Year-round Harvest

Due to the sincere efforts of breeders, several varieties have been developed in different vegetable crops, which can be grown out of their normal growing season; thereby, making the availability of particular vegetables around the year. The past few years have witnessed large-scale adoption of off-season varieties, especially, of radish, tomato, onion, cabbage and carrot amongst the growers which has resulted in ever-higher vegetable production. Tomato cvs. Pusa Sheetal and Pusa hybrid 1 have been identified for fruit set at low and high temperatures, respectively. Likewise, the development of cvs. like Pusa Chetki and Pusa Desi in radish has made it possible to grow it throughout year. Onion, which is a *rabi* season crop, traditionally, can now be grown in *kharif* as well with the advent of cvs. like N-53, Agrifound Dark Red, Arka Kalyan and Baswant 780. Furthermore, rescheduling the planting season has also extended the availability period of carrot. For instance, carrot cv. Pusa Vrishti and Pusa Meghali can be sown during July-August and made available during October-December. On the other hand, cv. Pusa Yamdagini can be sown during Dec.-Feb. To make roots available during March-May. Similarly, cv. like Pusa Nayanjyoti can be sown in March-April and roots are available for harvest in June-July (Aditika *et al*., 2017).

Diara Lands for Nurturing Off-season Vegetables for Sustainable Farming

Diara land, situated between natural levees in active flood plains, undergoes annual flooding, erosion, and sediment redeposition. The fresh silt and clay deposits received during the rainy season enhance soil fertility, making *diara* land well-suited for growing crops. This cyclic process contributes to the land's agricultural productivity, highlighting its value for cultivation in the region. *Diara* land or riverbed farming presents a viable avenue for off-season vegetable production, offering an easy-to-learn and cost-effective technology (Maharjan, 2017). This method allows landless households to utilize unused marginal lands. Particularly suitable for small and marginal farmers, riverbed farming enables them and their families to engage in cultivation, economically producing a variety of cucurbits and other vegetables (Wadhwani *et al*., 2007). Approximately 65% of the total cucurbit cropped area in the country is situated in riverbeds. *Diara* land, commonly known as a riverbed, refers to a basin or bank area between two or more streams of a river. It goes by several local names such as Khadar, Kachhar, Doab, Dariyari, Kochsr, Nad, Tali, and Nadiari. Interestingly, 68% of the cucurbit cultivation area is observed to be under riverbed cultivation (Choudhary *et al*., 2019). During the summer season, a significant portion (70-75%) of the total cucurbit production takes place in riverbeds or *diara* land areas (Kumar and Baraik, 2023). These vegetables become available in the market from February to June and October to January. Various riverbeds, such as those of Yamuna, Ganges, Gomati, Saryu, and their tributaries in Haryana, Uttar Pradesh, and Bihar, as well as other regions like Tonk district in Rajasthan, Madhya Pradesh, Maharashtra, Gujarat, Andhra Pradesh, and Kerala, are important areas for extensive cultivation of cucurbits (Choudhary *et al*., 2019). Cucumbers, bitter gourds, long melons, sponge gourds, ridge gourds, watermelons, muskmelons, bottle gourds, and pumpkins are among the cucurbits grown in these riverbeds (Panda, 1996). In regions like Kerala, cucurbits such as bitter gourds and snake gourds flourish in the riverbeds of Pamba and Manimala. The seeping subterranean moisture from adjacent rivers and streams enhances the upper layers of the land, making it conducive for early vegetable cultivation. This form of farming not only offers an additional income source for farmers but also helps meet the market demand for off-season vegetables. *Diara* lands are notably found in states like Uttar Pradesh, Bihar, Assam, and Orissa. The estimation of *diara* lands in Uttar Pradesh and Bihar is based on a width of 3 kilometers for every kilometer length of the river in the plains of various river systems. Consequently, Uttar Pradesh has flood-prone *diara* lands covering approximately 1.5 million hectares across various river systems. In Bihar, the reported area under *diara* lands is about 0.9 million hectares. In Assam, it is speculated that *diara* lands may exceed 2.3 million hectares, considering 30% of the state's geographical area is flood-prone. Orissa's *diara* land extent is not precisely available, but it's estimated around 1.0 million hectares, with flood-prone areas primarily in the Mahanadi delta. The prevalence of *diara* lands in these states highlights their significance for various agricultural activities and their vulnerability to flooding due to proximity to rivers and plains. (Panda, 1996).

Properties of Riverbed Soil

The soil in riverbeds predominantly consists of sand and moisture that has permeated from the adjacent river. Well-drained loamy soils are preferred for cucurbit cultivation in riverbeds. This texture provides an ideal substrate for the growth of these crops. Subterranean moisture from river streams and the alluvial substrate in sandy riverbeds contribute to the moisture content, supporting the growth of cucurbits. The soil should be well-drained to prevent waterlogging, especially during the rainy season. Cracking of the soil should be minimal to ensure optimal growing conditions (Singh *et al*., 2012). Adequate organic matter in the soil is essential for nutrient retention and the overall health of the crops. The optimum temperature range for proper growth and development of cucurbits in riverbeds is around 18 to 22°C. This temperature range supports their physiological processes. Cucurbits in riverbeds typically develop a long taproot system, which adapts well to the specific conditions of these soils. Most cucurbits thrive in a soil pH between 6 to 7. Maintaining this pH range is crucial for the availability of essential nutrients to plants. Understanding and managing these soil properties are vital for successful cucurbit cultivation in riverbeds, ensuring optimal conditions for growth and productivity (Kumari *et al*., 2018).

Diara lands can be classified based on their precise location from the mainstream as low land, medium land and upland *diara* (Pandey *et al*., 2023).

Main riverbed (low land) diara

These are the actual riverbeds with fine sand to coarse deposits on the surface. They become accessible during non-monsoon seasons, specifically from December to January until the onset of early rains in May to June. The riverbeds are typically low-lying areas exposed during dry seasons.

Main land (medium land) diara

Situated on the banks of the river, the width of these areas varies considerably. These areas are frequently inundated during the rainy season when floodwaters swell. The depth of the main *diara* region varies significantly at different locations along the river.

Upland diara

Continuous deposition has elevated these areas, resulting in them being less frequently flooded compared to the mainland *diara* areas. These areas experience relatively fewer floods than the low-lying *diara* regions. For operational purposes, these elevated *diara* lands are not significantly different from normal (non-*diara*) lands.

This classification provides insights into the distinct characteristics and seasonal variations of *diara* lands based on their proximity to the main river stream. Understanding these categories is essential for effective land management and agricultural planning in *diara* regions.

Optimizing Cropping Pattern for Ensuring a Bountiful Harvest

Mixed cropping is commonly practiced in riverbeds, where different crops are grown together for optimal utilization of space and resources. Specific examples of mixed cropping in riverbeds include the simultaneous cultivation of watermelon and muskmelon. Additionally, various other cucurbits are often grown together, depending on the region such as in North India, summer squash, bottle gourd, round melon, cucumber, sponge gourd, bitter gourd, and long melon; in Rajasthan, Madhya Pradesh, and Uttar Pradesh, ridge gourd and in Bihar, pointed gourd (Singh, 2012). It is recommended to harvest the crops when the fruits are tender and edible. Harvesting fruits at edible maturity should be done at 2 to 3 days intervals to maintain quality, as fruits tend to harden due to seed maturity if left unharvested. Regular harvesting intervals can be maintained from the end of June to the end of October. For off-season harvesting, fruits can be harvested as early as February-March, providing an early yield and higher returns. After harvesting, the crops are transported to local market centers for sale. This cropping pattern and harvesting strategy are designed to optimize the yield and quality of the crops grown in riverbeds, ensuring a continuous and profitable agricultural cycle (Kumari *et al*., 2018).

Like any other technology, *diara* land cultivation too have its own strengths and constraints (Table 1). Despite the listed constraints, many small and marginal farmers engage in riverbed cultivation, emphasizing the need for solutions to address these challenges and ensure a fair distribution of benefits (Choudhary *et al*., 2019). *Diara* land, the riverbed between two or more streams, becomes dry after the monsoon season, presenting opportunities for income generation and natural resource management. Properly managing these areas could contribute to income generation, natural resource utilization, and better disaster/risk management. Despite facing challenges, riverbed cultivation offers prospects for livelihoods, and further

Table 1: Prospects and challenges of river bed cultivation

Prospects	*Challenges*
• High net return per unit area: Riverbed cultivation offers a high net return, making it economically favorable for farmers. • Early and high yield: Riverbed crops often yield early, providing farmers with a quicker and higher return on their investment. • Ease in irrigation: Despite challenges, riverbeds generally have a high-water table, easing the process of irrigation for cultivated crops. • Low cost of cultivation: Riverbed cultivation is cost-effective, requiring fewer resources and inputs compared to other forms of cultivation. • Less mineral requirement due to high fertility: The naturally high fertility of riverbed soil reduces the need for additional mineral inputs, contributing to cost savings. • Limited weed growth: Riverbeds tend to have limited weed growth, reducing competition with cultivated crops. • Easy control of pest and disease by cultural means: Cultural practices can effectively control pests and diseases in riverbed cultivation, minimizing the need for chemical interventions. • Low-cost labor facilities: The nature of riverbed cultivation allows for the utilization of low-cost labor, contributing to overall cost-effectiveness. • No land ownership required: Riverbed cultivation does not demand land ownership, making it accessible to those without substantial property. • High economic returns: Despite challenges, riverbed farming can yield high economic returns, contributing to the financial well-being of farmers. • Income and food security for landless and marginal farmers: Riverbed cultivation plays a crucial role in ensuring income and food security for landless and marginal farmers who may not have access to conventional agricultural resources. • Local adaptation to climate change: The local adaptation of riverbed cultivation practices helps farmers cope with the impacts of climate change, making it a resilient option. • Utilization of underexploited resource: Riverbed farming utilizes an underexploited resource and enhances smallholders' skills on marginal soils. Riverbed farming provides small farmers with sustainable options for coping with environmental shocks like floods.	• Non-availability of quality seeds and land availability in *diara* land are the major constraints. The other constraints are; • Seed source: River-bed cultivation of melons relies on farmers' native ingenuity, and they often use seeds from fruits found sweet in season. • Cross-pollination Issues: Many of these fruits are produced through cross-pollination, leading to unreliable quality, especially in sweetness and flesh color. • Seed purity: Each farmer keeping their own seeds raises concerns about the purity of cultivars, with no guarantee of maintaining purity for more than one season. • Uncertainty: River-beds may remain underwater for extended periods, making land availability uncertain. • Ownership: Since vegetable growers do not own the land, securing it for cultivation is challenging. • River course changes: Changes in the course of the river pose problems, requiring growers to cultivate new areas. • Leaching issues: Heavy leaching of soils in riverbeds results in low fertility, necessitating additional efforts for manures and fertilizers. • Fertility status: Continuous leaching impacts the fertility status of the soil. • Irrigation challenges: *Diara* lands are rainfed and assured irrigation facility is not available. • High water table: Despite a high-water table, irrigation remains a challenge. • Water lifting: Small water lifting mechanisms or bamboo tube wells could help if provided on a subsidized basis. • Crop rotation challenges: River-bed cultivation does not align with conventional crop rotation practices, especially with cucurbits. • Profit distribution: The major share of benefits often goes to businessmen and middlemen who purchase cucurbits from farmers and sell them in the market. Small and marginal farmers, despite raising a good crop on riverbeds, are deprived of a significant share of profits. • Ecological constraints: During the monsoon season, the Ganges and Brahmaputra rivers cause catastrophic flooding in their plains, inundating large areas from June to September (Hofer, 1993). The lower course of the Ganga serves both as a creator and destroyer, depositing fertile alluvial soil and causing frequent floods.

exploration is warranted to enhance its relevance (Kumari *et al.*, 2018; Choudhary *et al.*, 2019; Kumar and Baraik, 2023). The advantages of riverbed cultivation highlight its potential as a sustainable and beneficial agricultural practice, particularly for small-scale and resource-limited farmers (Ghimire *et al.*, 2022).

Human Resource Development and Management vis-à-vis Diara Land Cultivation

Krishi Vigyan Kendra (KVKs) and extension agencies play a crucial role in disseminating vital information on soil, water, and crop management, along with promoting farm technology. This is done through demonstrations, fairs, and training. The goal is to empower farmers with improved skills. Extension agencies also support farmers' associations and provide training for a self-reliant workforce. Educating farmers on drainage impact, encouraging their involvement, and raising awareness about financial support contribute to economic sustainability. In challenging terrains, a holistic approach is crucial, addressing agriculture, environment, and ecology. Sustainable measures require scientific study and community participation in policy-making, ensuring success in agricultural practices (Choudhary *et al.*, 2019).

Balancing Challenges and Possibilities of Off-season Vegetable Farming through Protected Cultivation

In meeting the rising demand for off-season and high-quality vegetables, farmers are shifting from traditional cultivation to contemporary agri-business models (Chauhan *et al.*, 2016). The adoption of "protected cultivation," traditionally associated with affluent Western nations facing adverse environmental conditions, is gaining traction in

India. This approach aims to boost overall productivity and enhance vegetable quality, addressing issues encountered in open-field cultivation, particularly during the rainy season (Li *et al*., 2022). "Protected cultivation" focuses on controlling the microclimate around plant bodies, either partially or entirely, to meet the specific needs of different plant species during their growth stages. The adoption of structures like polyhouses, polytunnels, trench greenhouses, shade nets, net-houses, and walk-in tunnels has proven beneficial for cultivating off-season vegetables. Presently, forward-thinking farmers are embracing commercially protected cultivation of high-value vegetables (Maitra *et al*., 2020). Through the utilization of these structures and techniques, a variety of vegetables—such as tomatoes, brinjals, chilies, capsicums, broccoli, cabbages, cauliflowers, radishes, carrots, spinach, coriander, lettuce, cucumbers, bottle gourds, and bitter gourds—have captured the market by being available in different seasons. Regulation of climatic factors like temperature, light, humidity, and CO_2, coupled with the use of soilless media, has made year-round vegetable availability achievable. The production of vegetables involves geoponics, soil-less culture, hydroponics, and aeroponics techniques (Li *et al*., 2022). These innovative methods not only facilitate crop growth but also allow for the establishment of nurseries.

Off-Season farming of summer vegetables

The demand for summer vegetables, such as tomatoes, brinjals, okra, bitter gourds, bottle gourds, cucumbers, pumpkins, and summer squashes, has shifted towards cultivation in winter. Greenhouses play a crucial role in enabling this cultivation by providing controlled temperature conditions. Polyhouses, constructed with polyethylene, offer flexibility in size based on the producer's requirements. This development has become a specialized production technique to overcome abiotic challenges, ensuring year-round production of slow-season vegetables (Sahu *et al*., 2020). Besides crop growth, greenhouses also support the early development of seedlings for various summer-season vegetables, enhancing productivity.

Out-of-season farming for winter vegetables

Winter vegetables like cabbage, cauliflower, broccoli, carrots, radishes, and turnips face limited availability and high costs during the summer months. The use of shade nets, and enclosed structures permitting sunlight, moisture, and air, addresses this issue. Shade houses, composed of frames and cladding materials in various colors, extend the lifespan of vegetables by creating a conducive microenvironment. These structures are advantageous for raising seedlings and improving yields, particularly at higher altitudes.

Growing winter vegetables in rainy season

During the rainy season, vegetable prices soar due to low production caused by high soil moisture and heavy rainfall. This situation, exacerbated by increased infestation, can be mitigated using protected structures such as rain shelters and polytunnels. Rain shelters, roofed with plastic film or waterproof materials, shield crops from rain, reducing crop damage, promoting growth, and ensuring stable production. These structures are effective in heavy rain areas, cultivating crops like cabbage, cauliflower, French beans, radishes, spinach, and coriander (Sahu *et al*., 2020).

Yield and Quality of Greenhouse Produce

Various studies have demonstrated the success of off-season cultivation techniques. For instance, growing hybrid cucumber in naturally ventilated greenhouses during the off-season yields higher quantities and increased ascorbic acid content (Phookan and Barua, 2016). Cultivating under protective structures enhances the overall annual crop yield per unit area and elevates quality, while extending the production period (Nordey *et al*., 2017). Planting capsicum in polyhouses has a considerable impact on yield, as highlighted by Kumar *et al.* (2016). According to Bhatnagar *et al.* (1990), capsicum yield under greenhouse conditions in the winter in the mountainous region increased to 50 quintals per hectare compared to 24 quintals per hectare in open conditions. Greenhouse plantings demonstrated a 2.34-fold increase in capsicum production per square meter of land compared to open fields. Cheema *et al.* (2004) noted that the improved microclimate provided by a polyhouse is a key factor contributing to the enhanced output of various vegetable crops. Additionally, cauliflower cultivated in polyhouses exhibited a shorter period for curd development compared to field cultivation (Nagalakshmi *et al*., 2001). Protected technologies, such as polyhouses, have increased crop longevity compared to open field conditions. Polyhuts, in particular, demonstrated higher fruit weight and yield compared to open fields. The net return, with a better benefit-cost ratio (B:C), was highest in poly houses and lowest in open fields for various protected technologies (Singh *et al*., 2011). The B:C ratio for capsicum was notably high at 6.17, driven by elevated market prices resulting from low local supply during the off-season from conventional agriculture. Research by Dhaliwal *et al.* (2017) highlighted early and higher yields in polyhouse-grown bell peppers or capsicum. Similar observations were reported by Lal *et al.* (2016) for coriander leaf. Early cauliflower cultivated in polyhouses exhibited good quality and garnered decent demand in the market, proving to be a highly profitable crop for farmers. The choice of greenhouse cover materials, like films or screens, significantly influences the microclimate, affecting vegetable growth and quality. Yamaura *et al.* (2022) studied the impact of near-infrared reflective film on tomatoes in a high tunnel, finding decreased total dry matter but a lower fruit cracking rate. Wen *et al.* (2022) explored insect-proof screens' effects on Chinese flowering cabbages, noting improved microclimate, increased yields, and higher

Table 2: Prospects and challenges of protected cultivation

Prospects	*Challenges*
• Increased production: The use of low-cost protected structures can boost vegetable production by approximately four times, increasing productivity per unit of land.	• Availability of materials: Construction materials like gi pipes, polyethylene sheets, etc., Are not consistently found in local markets and often need to be imported at high costs, including freight and custom duties.
• High-quality crop: Protected cultivation ensures the production of high-quality and clean vegetables.	• Skilled labor: The installation, monitoring, and supervision of protected cultivation may require skilled workers, which are not readily available in village areas.
• Intensive crop production: Greenhouses enable multifold intensification of vegetable production compared to traditional open-field cultivation.	• Regional variation: The package of practices for year-round cultivation of different vegetable crops in protected environments has not been standardized. Recommendations for one region may not be universally applicable to others.
• Healthy seedling production: It supports the production of high-quality and healthy vegetable seedlings, resulting in strong and resistant crop stands.	• Lack of awareness: Limited awareness among farmers about the potential benefits of protected vegetable production hampers large-scale cultivation.
• High purity hybrid seed production: Greenhouse cultivation eliminates cross-pollination, ensuring high purity in hybrid seed production.	• Design: The current use of conventional screen net houses for off-season vegetable cultivation in north india's composite climate faces limitations such as poor structural design, high constructional costs, lack of a greenhouse effect in winter, and elevated plant temperatures in summer. Similarly, polyethylene sheet-covered greenhouses also encounter issues, including significantly higher constructional and operational costs and elevated indoor air temperatures during summers.
• Disease-free seed production: Protected cultivation facilitates disease-free seed production, ensuring the quality of seeds for future crops.	• R&d shortcomings: There is a scarcity of comprehensive research on protected vegetable farming for various commercial crops, limiting the availability of region-specific guidelines and best practices. Aicrp on peasem is inadequate for the diverse needs of the country in developing plasticulture technologies.
• Weather and pest protection: Protective structures shield high-value crops from unfavorable weather conditions and protect them from pests and diseases.	• Higher education programs are needed to support greenhouse-related research and development.
• Off-season horticultural production: Controlled microclimates in greenhouses allow year-round production, addressing off-season demand and enhancing profitability.	• Structural integrity and skills: Recurrent greenhouse structural failures due to winds highlight the need for climate-specific designs. Lack of operational skills is a serious constraint that requires addressing before providing subsidies.
• Expanding growing seasons: In regions like ladakh, greenhouses extend the growing season from 4-5 months to around 10 months.	• Skilled workforce: Ensuring greenhouse managers and workers receive adequate training is crucial for successful production.
• High-quality planting material: Favorable microclimates in greenhouses facilitate intensive preparation of high-quality planting material.	• Establishing state-level skill development centers for protected cultivation is recommended.
• Enhancing horticultural produce availability: Greenhouse technology can address gaps and enhance the availability of horticultural produce in india.	• Education-work ecosystem: Flexibility for students to learn and earn in greenhouses should be promoted.
• Conservation of input resources: Greenhouse technology improves resource utilization efficiency, conserving water, nutrients, and agro-chemicals.	• Biodegradable glazing materials: Efforts are needed to accelerate the availability of biodegradable materials for greenhouse glazing.
• Job creation: Greenhouses offer employment for about five persons per hectare, potentially generating direct and indirect employment opportunities for millions.	• Marketing infrastructure: Establishing a well-defined marketing infrastructure, including cold-chain and traceability, is essential as in its absence protected cultivation is still limited.
• Income enhancement for greenhouse farmers: Greenhouse cultivation significantly increases farmers' income, contributing to the country's gdp.	• Comprehensive insurance: Comprehensive and user-friendly insurance portfolios are crucial for reassuring greenhouse growers in emergencies, which is lacking currently.
• Meeting urban demand: Greenhouses play a vital role in meeting the fresh produce demands of the growing urban population.	
• Expanding food production in non-terrestrial spaces: Greenhouse activities can be expanded to unconventional spaces like underground, seas, ocean floors, and high mountains, addressing land limitations.	
• Bridging supply-demand gaps: Greenhouse cultivation helps overcome short-term shortages in open-field cultivation, ensuring a consistent supply of targeted commodities.	

irrigation water use efficiency. Likewise, the utilization of color shade nets has emerged as an effective method to shield crops from adverse environmental conditions, enhance vegetable quality, and prolong post-harvest freshness (Ilić *et al*., 2018). Ramasamy *et al.* (2021) noted the yield of white and red amaranths was consistently better (7.68–19.70 t/ha) under pink poly-net house in all the seasons, but the yield of water spinach was consistently better under white poly-net house (16.25–20.88 t/ha). Capsicum cultivation under shade nets during the off-season results in higher yields compared to open-field conditions (Ghosal and Das, 2012). The production of bitter gourd in the late *kharif* season, considered off-season cultivation, has been successful (Asati *et al*., 2018). Spinach cultivation in trench greenhouses has been practiced successfully (Angmo *et al*., 2017). Similarly, the cultivation of tomatoes under nethouses during the off-season increases yields while reducing the incidence of pests and diseases (Cheema *et al*., 2004). Growing cucumbers in a polyhouse incurs a higher cost per hectare compared to open-field cultivation. However, the production and net return per hectare in polyhouses are significantly higher, contributing to increased yields and income for growers (Kumar *et al*., 2017). The benefit-cost (B:C) ratio is also higher when cultivating cucumbers in a greenhouse (Malik *et al*., 2017). In Kerala, cucumbers are cultivated in cost-effective polyhouses with natural ventilation, achieving the highest B: C ratio (3.42) when nutrients are applied at a rate equal to 100% of the recommended dose (Chand *et al*., 2014). The cultivation in these protected environments typically involves three crop cycles: tomato-cucumber, capsicum-cucumber, and cucumber-cucumber-cucumber rotation.

Positive Outlook and Challenges in Greenhouse Cultivation

India's diverse agro-climatic conditions, long growing seasons, and varied soils provide a significant opportunity for cultivating a wide array of vegetables. Encouraging protected cultivation not only yields better benefits but also has the potential to attract young individuals, including women, to agriculture and instill pride in the profession. Currently, only 2,75,000 hectares in India are under protected cultivation, while China boasts more than 2 million hectares (Dixit *et al*., 2023). There is a pressing need for a multi-fold increase in the area under protected farming over the next 4 to 5 years. Protected cultivation offers advantages such as optimal water and nutrient utilization, enabling a 3 to 5 times increase in production compared to open-field planting. Various techniques, including plastic mulch, crop cover, low tunnels, walk-in-tunnels, naturally ventilated polyhouses, net houses, environmentally controlled greenhouses, and soilless farming (hydroponics, aeroponics), among others, can significantly enhance vegetable production. These interventions address specific needs such as early crop protection, off-season cultivation, and the production of healthy seedlings. Promoting and widely adopting these technical interventions is crucial for advancing the vegetable cultivation sector in India (Jayasurya *et al*., 2021; Chandra *et al*., 2023) (Table 2).

Despite the numerous benefits of specialized vegetable production techniques, challenges hinder their widespread adoption (Table 2). These challenges include a lack of specialized knowledge, insufficient funds for constructing protected structures, high production costs, limited skilled knowledge, elevated seed costs, and difficulties in market accessibility and cold storage units (Sethi *et al*., 2009; Jayasurya *et al*., 2021; Chandra, 2023; Dixit *et al*., 2023). Although protected cultivation technologies help address market demands for off-season vegetables, investment capacity remains a significant limitation. The heterogeneity of farms complicates upscaling protected cultivation technologies to smallholders. Targeting resource-endowed producers, promoting skills and knowledge, and addressing information gaps are crucial for successful adoption. China's vegetable basket plan in the late 1980s, emphasizing low-tech and cost-effective greenhouses, serves as an exemplary case of promoting protected cultivation through policy intervention. This initiative significantly increased greenhouse cultivation in China, making it the world's leading vegetable producer and the largest producer of plastic greenhouses globally (Nordey *et al*., 2017).

Conclusion

Cultivating fresh vegetables off-season provides farmers with higher income and employment opportunities, though it demands specialized techniques and regular supervision. Despite the risk of pests and diseases, the benefits outweigh the costs when modern production technologies are employed. Many, especially hill state, farmers are successfully growing off-season vegetables under polyhouse cover using organic cultivation, proving to be profitable and generating employment, especially for female family members. Prioritizing and promoting off-season vegetable cultivation under polyhouses is recommended (AERC, 2017). However, ensuring consistent technical support, training, and a reliable supply of inputs like seeds and fertilizers, along with market information, is crucial for the sustained adoption of agricultural technologies. The long-term success relies on accessible extension services, and the cumulative impact of various technologies contributes to improved off-season agricultural practices. This underscores the importance of farmer-centric policies in guiding enduring technology adoption. Factors such as education, experience in vegetable production, access to extension services, and training significantly influence farmers' technology adoption decisions. The conclusion highlights the impact of socioeconomic characteristics and institutional effectiveness on off-season vegetable production (Kunwar *et al*., 2018). Policies should leverage positive factors and address negative influences. Factors like farm size, gross return, access to extension, and credit significantly affect farmers' decisions to adopt off-seasonal vegetables. Engaging the village youth in marketing, promoting contract farming (Dhanta *et al*., 2022), implementing motivation, regular extension contracts, credit accessibility, training, and input support is recommended to enhance farmers' knowledge of off-seasonal vegetable production practices (Maruf *et al*., 2022).

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सारांश

भारत में सब्जियों की मांग व्यापक शाकाहारी आहार प्राथमिकताओं के कारण अधिक है। यद्यपि, पूरे वर्ष सभी प्रकार की सब्जियाँ उगाने में असमर्थता के कारण आपूर्ति प्राय: अपर्याप्त होती है। यह तथ्य बेमौसमी सब्जियों की खेती के महत्व देते हुये वर्ष-पर्यंत उत्पादन हेतु विकल्प, बेमौसम में सब्जियों के मूल्यों के उतार-चढ़ाव को नियंत्रित करने और विभिन्न आर्थिक वर्गों के लोगों के लिए सब्जियों की उपलब्धता सुनिश्चित करने पर बल देता है। बेमौसमी खेती पोषण संबंधी कमियों को दूर करने और किसानों को आर्थिक संबल प्रदान करने में महत्वपूर्ण भूमिका निभाती है, विशेषकर बाजार अधिशेष और मूल्य अवमूल्यन के दौरान। परिणामत:, बेमौसमी खेती के विधियों में उल्लेखनीय वृद्धि हुई है, जहां आपूर्ति की कमी के समाधान और उच्च बाजार मूल्यों का लाभ उठाने के लिए नियमित फसल कैलेंडर के इतर फसलें उगाई जाती हैं। बे-मौसमी सब्जियों की खेती के लिए विभिन्न विधियाँ अपनायी जाती हैं, जिनमें देश की कृषि-जलवायु विविधता का लाभ उठाना, विभिन्न किस्मों का उपयोग करना, दियारा भूमि/नदी के किनारों में खेती करना और संरक्षित खेती को नियोजित करना सम्मिलित है। परंतु, यह समीक्षा विशेष रूप से बेमौसम उत्पादन के लिए दियारा/नदी के किनारे और सब्जियों की संरक्षित खेती पर केंद्रित है। इन कृषि पद्धतियों ने आशाजनक परिणाम दिये हैं; तथापि, इनके अंगीकरण को बनाए रखने के लिए विपणन संबन्धित सूचनाओं के साथ-साथ लगातार तकनीकी सहायता, प्रशिक्षण और बीज और उर्वरक जैसे निविष्टियों की विश्वसनीय आपूर्ति सुनिश्चित करना महत्वपूर्ण है। इन तकनीकों की दीर्घकालिक सफलता सुलभ विस्तार सेवाओं पर निर्भर करती है, और विभिन्न तकनीकों का संयुक्त प्रभाव बे-मौसमी कृषि पद्धतियों को बेहतर बनाने में योगदान देगा। यह तकनीक-अंगीकरण के मार्गदर्शन में किसान-केंद्रित नीतियों के महत्व को रेखांकित करता है। शिक्षा, सब्जी उत्पादन में अनुभव, कृषि-विस्तार सेवाओं तक पहुंच और प्रशिक्षण जैसे कारक उत्पादन-तकनीकों के अंगीकरण के संबंध में किसानों के निर्णयों को महत्वपूर्ण रूप से प्रभावित करते हैं।