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Cost-effective and high-impact sustainable vegetable farming utilizing low tunnel technology: a review

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Abstract

The practice of low tunnel vegetable cultivation has emerged as a promising solution to address market fluctuations and enhance farmers' income by enabling off-season vegetable production. This method involves the use of miniature structures that mimic greenhouse conditions, providing protection and creating a favorable microclimate for vegetable crops. Low tunnels are constructed using locally available materials such as bamboo, wood, or metal bars covered with thin plastic sheets or nylon screens. These structures help conserve warmth, stimulate germination, and protect plants from adverse weather conditions, ultimately improving crop quality and yield. Plastic low tunnel technology, in particular, has proven to be a cost-effective method for cultivating various vegetable crops, including cucurbits, melons, and cole crops, in winter season. By advancing the cropping season by 30-60 days and facilitating early market entry of the produce, low tunnels offer significant advantages to farmers, enabling them to capitalize on off-season demand and command higher prices for their produce. Additionally, low tunnel cultivation minimizes pest incidences and reduces pesticide consumption, making it an environmentally sustainable option for vegetable production. Studies have demonstrated the versatility of low tunnel construction techniques and materials, with various covering materials and support structures tailored to specific crop requirements and environmental conditions. The economic viability of low tunnel vegetable cultivation is further supported by high net returns and favorable benefit: cost ratios recorded in comparative evaluations. Overall, low tunnel vegetable cultivation represents a promising technology for enhancing agricultural productivity, optimizing resource utilization, and improving farmer livelihoods, particularly in regions with extreme temperature regimes and fluctuating market conditions.

KEY WORDS: Off season, Farmers'-friendly, Mulching, Microclimate, Irrigation, Low tunnels, Vegetable pest incidences

Quite often, market witnesses glut of vegetables in the season, which leads to poor return to the growers (Pagaria and Swami, 2023). On the other hand, consumers are willing to pay high prices for vegetables in off-season. Vegetables can be cultivated in off-season, with the introduction of greenhouses technologies (Dodiya *et al.,* 2021), wherein temperature and humidity are modulated for desirable growth of vegetables (Singh *et al*., 2007; Singh *et al*., 2021). The production of vegetables round the year facilitates the growers to make the maximum use the resources and augment income from vegetable growing as compared to other agricultural crops (Singh and Kumarnag, 2023). One such cost-effective, farmers-friendly technology is 'low tunnel'.

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Low tunnels are miniature structures producing greenhouse like effect. This type of structures cover rows of plants; therefore, they are also known as 'row cover' (Jayasurya *et al*., 2021). Low tunnels are constructed with locally available material such as bamboo (Bhatt *et al*., 2016) and wood or with GI wires, plastic or metal bars to form semi-circular frames, which are covered with thin plastic sheet (PE or PVC 30-50 μ) or with nylon screen (Kang *et al*., 2013). The sides are secured down by placing them in soil or by side-to-side crisscrossing nylon rope anchored to the base of each pole; however, in the growing season, the sides are opened by lifting them up for improving ventilation or plastic is slit as the temperature increase within the tunnels (Jayasurya *et al*., 2021).

Such structures are erected to provide temporary protection to crops and usually no higher than 1 m in height. In general, the height of the tunnel is kept at 45-60 cm with 45-60 cm width. Low tunnels are used to conserve warmth to stimulate germination and early growth of seedlings in winters, to protect the plants from frost injury, to improve the quality of the crops (Singh *et al*., 2007), to provide protection from wind and rain damage in melon cultivation and in winter production (forcing production) of vegetables (Kang *et al*., 2013). Further, low tunnel

production of vegetables offers other advantages such as enhanced nutrients uptake and increased photosynthetic activities of plants owing to favourable micro-climate inside tunnel, crop diversification and making cultivation of vegetables possible in areas where it can't be grown in open field conditions (like high altitudes) (Yadav *et al.*, 2017). Low tunnels are extensively used for off-season production of muskmelon, summer squash, bottle gourd and bitter gourd for advancing cropping season by 30-60 days ahead to their normal season of cultivation.

These tunnels enable the entrapment of carbon dioxide; thereby, improving the photosynthetic activity of the plants, which ultimately leads to yield enhancement (Lodhi *et al.*, 2015). Apart from being inexpensive, they are easy to assemble, dismantle and reassembled for their use in subsequent seasons. This technology enables the growers to capture the market in the early season for getting good return from the sold produce. This technology is quite promising and profitable for the farmers of northern plains of India (Jayasurya *et al.*, 2021)

Material in low tunnels

Plastic low tunnel technology proves to be a straightforward and lucrative method for cultivating cucurbits during the winter season in the northern plains of our country. This technique enables the growth of crops such as summer squash as a complete off-season crop, while other cucurbits like muskmelon, round melon, bottle gourd, cucumber, bitter gourd, and watermelon can be advanced by 30-40 days compared to their normal growing season. Plastic low tunnels consist of flexible transparent coverings that are installed over single or multiple rows of vegetables. They serve to enhance plant growth by warming the air around the plants in open fields during the winter season when temperatures drop below 8°C. Supported by hoops made of GI wire, these low tunnels are covered with clear or transparent plastic measuring 20-30 microns, which is stretched over the hoops and secured at the sides by burying them in the soil.

During the growing season, the plastic is vented or slit open to regulate the temperature within the tunnels as it increases. Farmers can take advantage of this technology to cultivate various varieties of summer squash (both round and long-fruited types), which are emerging crops, alongside the cultivation of netted muskmelon varieties in place of traditional ones. Bitter gourd and round melon are two other crops with increasing demand that usually fetch high prices during the off-season, and they can be successfully grown using plastic low tunnel technology. This approach is highly suitable and profitable for farmers residing in the northern plains of India.

For making plastic low tunnel for bottle gourd cultivation, 60 cm width, 50 cm high and 50-micron transparent plastic were used by Kumar *et al.* (2018). Earlier, Bhatt *et al.* (2016) also employed bamboo sticks for constructing the low tunnels for summer squash production. Saleem *et al.* (2014) used locally and abundantly available willow sticks of 1.5 to 2 cm diameter for making the supporting structure of low tunnel under Kargil conditions. The tunnel was covered with ordinary transparent polythene (2.4 m wide). The low tunnels were constructed by applying the covering material over metal hoops. Clear perforated polythene (0.051 mm) was used to cover the melons, while spun-bound polyster was used on the pepper and tomatoes (Waterer, 2003). Verma *et al.* (2019) used two types of covering material i.e. biodegradable plastic sheet (25 micron) and non-woven cloth (25 gsm) for low tunnel production of long melon; however, polythene covering was found better in terms of yield and fruiting duration. Kapanen *et al.* (2008) assessed the performance of biodegradable starch-based low tunnel films, which had the lifetime of 6 months.

The radiometric properties of the biodegradable films influenced positively the microclimate: air temperature under the biodegradable low tunnel films was 2 ^{0}C higher than under the low-density polyethylene films, resulting in an up to 20% higher yield. The use of a low tunnel covered with organza fabric allowed greater commercial yield of the Kale cv. Hi-crop. Although it is not an agricultural material, the organza fabric resulted in higher productivity with greater production of total and commercial leaves during the rainy season (da Silva Ponce *et al.*, 2021). These studies demonstrate the versatility and adaptability of low tunnel construction techniques and materials, each tailored to specific crop requirements and environmental conditions, aiming to optimize yield and productivity.

Production technologies for low tunnel vegetable cultivation

Low tunnel vegetable cultivation is an effective method for extending the growing season, protecting crops from adverse weather conditions, and improving yield and quality. Indeed, mulching and low tunnels have proven to be one of the highly effective techniques in promoting early production, particularly in warm-season vegetable crops that are susceptible to low temperatures. By creating a microclimate that is warmer and more conducive to plant growth, both mulching and low tunnels provide protection from cold weather, thereby extending the growing season and accelerating plant development. These techniques not only enhance the yield and quality of crops but also contribute to more sustainable agricultural

practices by reducing the need for chemical inputs and conserving water. Overall, the utilization of mulching and low tunnels represents valuable strategies for maximizing productivity and resilience in vegetable cultivation, especially in regions where temperature fluctuations pose challenges to crop production. Adamović *et al.* (2021) conducted a study focusing on the impact of mulching and low tunnels on the yield, yield components, and dry matter content of watermelon hybrids: 'New Fantasy F1', 'Celine F1', and 'Top Gun F1'.

Their findings revealed that the use of black PE mulch led to significantly higher yields across all three hybrids, with an average increase of 34.6% compared to the control treatment of bare soil. Moreover, the combination of mulching and low tunnels resulted in the highest average number of fruits per plant (4.7), which was notably greater than mulching alone (3.7) and the control without mulching (3.0). Interestingly, the control treatment without mulching exhibited the highest fruit weight, surpassing both mulching and low tunnel methods. Regarding dry matter content, the hybrid 'Top Gun F1' with mulching demonstrated the highest content at 11.5%, while the hybrid 'Celine F1' with mulching in a low tunnel displayed the lowest dry matter content at 9.6%. These results underscore the effectiveness of both mulching and low tunnels, particularly in enhancing early production and yield of warm-season vegetables like watermelon.

Niaz *et al.* (2009) cultivated three vegetables (tomato, cucumber, and bell pepper) in plastic tunnels as off-season crops to assess their comparative water use efficiency. Irrigation was administered using both drip and furrow irrigation systems. All three crops exhibited lower water consumption under drip irrigation compared to the furrow irrigation system. Drip irrigation yielded the highest water use efficiency for tomato (2.37), followed by cucumber (1.85) and bell pepper (1.22), contrasting with the performance under furrow irrigation. Additionally, apart from achieving high water use efficiency, the drip irrigation system also resulted in greater production compared to the furrow system across all vegetable crops. These findings suggest that vegetable crops require less irrigation water when utilizing the drip system compared to the furrow system, while also achieving higher water use efficiency and crop yields.

Therefore, the drip irrigation method emerges as the most economical choice for vegetable production in rainfed areas. In their study, Lodhi *et al.* (2024) explored the effects of low tunnel heights and various irrigation regimes on the growth parameters of Capsicum. They found that across the crop season, plant height, leaf area index, and dry matter accumulation were consistently highest in the 75 cm tunnel height treatment, followed by 90 cm and 60 cm tunnel heights. Regarding irrigation treatments, drip irrigation with a 0.90 Irrigation Water to Crop Pan Evaporation (IW/CPE) ratio resulted in the greatest plant height and leaf area index compared to other irrigation methods. Conversely, drip irrigation with a 0.75 IW/CPE ratio yielded the highest dry matter accumulation compared to alternative irrigation regimes.

Hastening of harvest season and net return

Plastic low tunnel force early flowering in off season (Kumar *et al.*, 2009). Under low tunnel cultivation, different cucurbits can be transplanted from first week of December to first week of February and can be advanced 30-60 days over their normal season of cultivation. Generally, cucurbits are harvested from 15 February onward (Kumar *et al.*, 2018). This is economical for growing off season vegetables in peri-urban area of the northern plains of the country. City dwellers are willing to purchase these high-priced vegetables; therefore, this technology is promising for improving the socio-economic status of farmers (Kumar *et al.*, 2009).

Among different dates of sowing, the maximum yield of 4.25 quintal per hectare was recorded when bottle gourd was sown on 30th December under low tunnel condition (Kumar *et al.*, 2018). Likewise, for bitter gourd as well 30th December was found to be the best date of sowing for raising crops under low tunnels (Kumar *et al.*, 2017). However, for muskmelon, the highest return per hectare was observed in low poly tunnel when crop was sown on 15th December under Bihar conditions. The prevalent time of sowing at farmer's field was 15th February (Ranjan *et al.*, 2019). Thereby, low tunnel cultivation advanced the growing of crop by around two months.

The success of low tunnel technology is not limited to the cultivation of off-season cucurbits in northern plains. Its potential has been realized for fetching early crops in regions with extremes of temperature regimes such as temperate and arid conditions. Saleem *et al.* (2014) reported that the low tunnel technology hastened the production of marketable seedling of cabbage as well as attainment of marketable heads from 53 to 45.6 days and 85.3 to 75.3 days, respectively under temperate conditions (Kargil, J&K). Higher net returns per unit area were realized under low tunnel cultivation of cabbage than open cultivation due to early maturity, early market entry of produce and evading market glut. Likewise, Verma *et al.* (2019) recorded an advancement of 24-50 days in long melons harvest, when sown on 20th December, as compared to normal season under western Rajasthan conditions. In similar study conducted by Ibarra *et al.* (2001), they observed that muskmelon crop

grown under plastic cover flowered 24 days earlier than uncovered plants. The early growth of the crops under low tunnel could be attributed to microclimate created by low tunnels. Ogden and van Iersel (2009) have indicated that low tunnels modify climatic conditions, promoting earlier flowering and fruit ripening as well as fruit precocity production. Temperature within the structure can be regulated for optimum growth of plants. Similarly, higher relative humidity built inside reduces evaporation loss from plants, which lead to optimum utilization of nutrients. It also maintains turgidity of cells, which is useful in enzyme activity leading to a higher yield. Singh *et al.* (2009) investigated the off-season cultivation of five summer squash cultivars (Australian Green, Pusa Alankar, Goldy, C-135, and Adlika) under low plastic tunnels. Australian Green exhibited the shortest time to first harvesting (58.0 days) and the highest average fruit yield (5.80 kg per plant or 696.0 quintal/ha).

Later, Khan and Khan (2020) studied eighty-four farmers engaged in cultivating off-season vegetables using tunnel farming, as well as seasonal vegetables without the use of tunnels. A comparison was made between their respective productivities. The results indicated that the yield per acre was significantly greater when utilizing tunnels compared to traditional methods. Among the three vegetables examined—tomato, cucumber, and bottle gourd—all demonstrated increased revenue, with tomato yielding the highest returns. However, it's important to note that employing tunnel farming entails higher expenses due to the installation of structures and input costs.

Net income and cost benefit ratio is significantly influenced by off season flowering and fruiting induced by low tunnel technology. Kumar *et al.* (2018) noted the highest net income and cost benefit ratio when sowing was done on 30th December under tunnel, which was ascribed to high market value in off-season. Off-season muskmelon cultivation was found economically feasible due to additions of yield (17%), gross income (122%), profit (161%) and market price (90%) in comparison to normal season crop (Latif *et al.* 2018). Rani *et al.* (2022) examined the economics of off-season vegetable cultivation under low tunnel technology and the study findings indicate that the primary cost was attributed to human labor, closely trailed by expenses related to transportation and seed procurement.

Notably, cultivating high-quality produce during the off-season proves advantageous for farmers, enabling them to command better prices in the market. Furthermore, the Benefit-to-Cost (B:C) ratio for the selected cucurbit crops ranged from 1:2.05 to 1:3.35, underscoring the economic viability and profitability of employing low tunnel technology in cultivation. The performance of cole crops in low tunnels has emerged as a successful technological intervention in the Ladakh region, proving to be a boon for farmers of all kinds (Spaldon *et al.,* 2021). This innovation offers a cost-effective, portable, and straightforward installation method. Notably, the yields recorded in cabbage (780 quintals per hectare) and cauliflower (720 quintals per hectare) are significantly higher within low tunnels compared to open-field conditions, where cabbage yields reach only 266.6 quintals per hectare and cauliflower yields are at 500 quintals per hectare.

Moreover, these increased yields translate to higher net returns for farmers, highlighting the efficacy and profitability of adopting low tunnel technology in cole crop cultivation (Spaldon *et al.,* 2021). Subsequently, Spaldon *et al.* (2022) documented the yields of two broccoli hybrids. They observed that the Lucky hybrid exhibited a yield of 400 quintals per hectare (q/ha), whereas the Fiesta hybrid yielded 350 qtl/ha. Notably, the Lucky hybrid demonstrated a high economic return of INR 1,086,200 per hectare, accompanied by an impressive benefit-cost ratio of 1:9. Following closely, the Fiesta hybrid also showed a favorable benefit-cost ratio of 1:75. The comparative evaluation conducted by Kumari *et al.* (2021) between low poly tunnel technology and traditional growing methods of bottle gourd revealed compelling results.

The average yield of bottle gourd demonstrations using low tunnels was significantly higher at 298 quintals per hectare (q/ha), compared to 245 q/ha for the local crop grown conventionally. Moreover, the economic indicators demonstrated the superiority of bottle gourd cultivation under low tunnels. Gross returns were recorded at Rs. 238,400 per hectare, while net returns stood at Rs. 138,200 per hectare, both of which were the highest among all methods evaluated. Additionally, the Benefit-to-Cost Ratio (BCR) was notably higher at 2.38 for bottle gourd grown under low tunnels compared to the local check. One of the key advantages observed was the early market availability of the produce grown under low tunnels, which helped prevent market glut and ensured higher total yields and net profits per unit area. These findings underscore the effectiveness and profitability of adopting low poly tunnel technology for bottle gourd cultivation, offering valuable insights for farmers seeking improved yield and economic returns.

Minimization of pest incidences and reduced pesticide consumption

Low tunnels, when covered with spun-bonded fabric (row covers), serve as a valuable tool for extending the growing season of vegetable crops while also acting as a physical barrier against airborne insects and other

non-soil pests. In a study by Acharya *et al.* (2020), it was observed that low tunnels significantly reduced insect infestation and leaf injury due to chewing herbivory in Brussels sprouts. Compared to open fields without protection, plants under low tunnels experienced reduced infestations of lepidopteran insects and the harlequin bug, *Murgantia histrionica* (Hemiptera: Pentatomidae). However, it's worth noting that aphid infestations were observed under low tunnels during the fall season. Interestingly, the study found no significant effect of mulch colour (white or black) on insect infestation or chewing injury, and there was no interaction observed between tunnel covering and mulch colour. The findings suggest that low tunnels can serve as an effective management tool for sustainable vegetable production by reducing insect infestations and feeding injury. Despite some challenges such as aphid infestations, the overall benefits of using low tunnels as a protective measure against pests outweigh the drawbacks, contributing to more resilient and sustainable farming practices. Likewise, Nordey *et al.* (2020) suggested using low tunnels as a suitable alternative for reducing pesticide use. da Silva Ponce *et al.* (2021) showed that the use of nonwoven shade mesh reduced the damage from *Plutella xylostella* and *Diabrotica speciosa* on kale plants grown in low tunnel during the rainy season and reduced *Myzus persicae* during the dry season. However, cultivation under the protection of the organza fabric provided more effective protection against *P. xylostella* and *D. speciosa*, resulting in greater production of kale leaves. Kale cultivation in the open field showed lower commercial production, more damaged leaves and greater damage by *Hellula undalis*.

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