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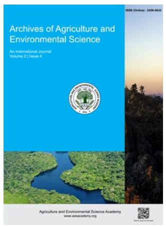

REVIEW ARTICLE

Protected cultivation of horticultural crops in Nepal: Current practices and future needs

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ABSTRACT

Protected cultivation infers the cultivation under guarded conditions or we can say simply, cultivation under a modified atmosphere or man-made micro-climatic conditions such as alteration in the CO_2 concentration also use of different temperature levels on specific protected structures such as hoop houses, cold houses, shade houses, hot frames or hotbeds, hot-bed manures as well as high tunnels which are less costly as well and can be easily afforded by Nepalese farmers. Horticultural crops rely heavily on specific environmental conditions i.e., temperature, soil moisture, sunlight, and soil fertility. However, with climate change, weather patterns worldwide are shifting, significantly impacting horticultural crops directly and indirectly in the mid-hills as well as high-hills of Nepal. The people of the mountainous region are getting malnutrition due to the scarcity of food. By adapting the different climate-smart practices we can increase the productivity of the seasonal crop as well as the availability of off-season crops throughout the year which not only improves the malnutrition status of Nepalese people but also helps the country to lower the vulnerability towards climate change. This review highlights the common protected practices used in Nepal and their need in the future.

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INTRODUCTION

Protected cultivation is the practice of raising crops (seasonal as well as unseasonal) under a man-made environment (Pachiyappan *et al.*, 2022) which aims to improve farmer`s socio-economic status (Mehta *et al.*, 2020). Precision agriculture is designed to enhance agricultural production by applying crop information systems, cutting-edge technology on production, and better crop management practices (Atreya *et al.*, 2020). Therefore, precision and safeguarded horticulture will be the tools of modern farming, and more incisively, protected horticulture comes under precision horticulture (Atreya *et al.*, 2019a). Protected cultivation is a type of precision agriculture that uses various structures to provide an environment suitable for crop growth. It is a growing trend in the horticultural industry as it allows for year-round production of high-quality crops protected from environmental stressors such as extreme temperatures, pests, and diseases. Out of the expected 1000 ha of protected farming, 70% and 30% of areas fall under vegetable, fruit, and flower production in Nepal (Atreya *et al.*, 2019b). Growing plants in an open field have limitations when it comes to environmental factors like sunlight, air quality, and temperature, which can affect plant growth and productivity. This means that certain types of crops, particularly those that require specific environmental conditions, such as cold-temperature vegetables, flowers, and other horticultural crops, cannot be grown in the field during the summer season. Similarly, warm-season crops may not thrive during winter, and growers must transport them from other regions. This is where protected cultivation comes in as a solution, which involves growing plants in a controlled environment to optimize their growth and yield. Protected cultivation offers a way to overcome the limitations of open-field practices by providing controlled environmental conditions for optimal plant growth, regardless of the season (Sengar *et al.*, 2008).

METHODOLOGY

The paper highlights the collision of changed climate on controlled environment practices, particularly on the yield, productivity, physiology, and quality of protected horticultural crops. To do so, we conducted a methodical literature review, reviewing the published articles. The literature search used the following academic databases: Web of Science Core Collection (WoSC) platform from Clarivate Analytics, Scopus and Science Direct from Elsevier, ResearchGate from Berlin, and Google Scholar from Google.

Protected cultivation and it's need

The climate is the most responsible factor for the successful production of agricultural crops. Climate change has been a major problem in production for the least developing countries like Nepal. Many researchers have found that the amenability of climate change will be more in higher altitudes as compared to lower altitudes (Karki and Gurung, 2012). As most of the agricultural land is located on mid-hills and high hills of Nepal so we must have to adopt alternative methods to reduce the vulnerability towards climate change and protected agriculture is one of the alternative methods that aim to increase yield as well as productivity through using modern cultivation and management practices (Atreya *et al.*, 2018). In Nepal to date maximum no of agriculture farmers are still devolved on climate-sensitive agricultural practices which have no control over climates if the same pattern goes on, the effects of climate change will also rise rapidly such as an increase in temperature, change in rainfall patterns, heavy drought, floods that not only affects the land but also the whole agricultural sector as well as the livelihood of farmers adversely. So, the adoption of climate-smart practices is the most necessary for the Nepalese agriculture system (Karki and Gurung, 2012).

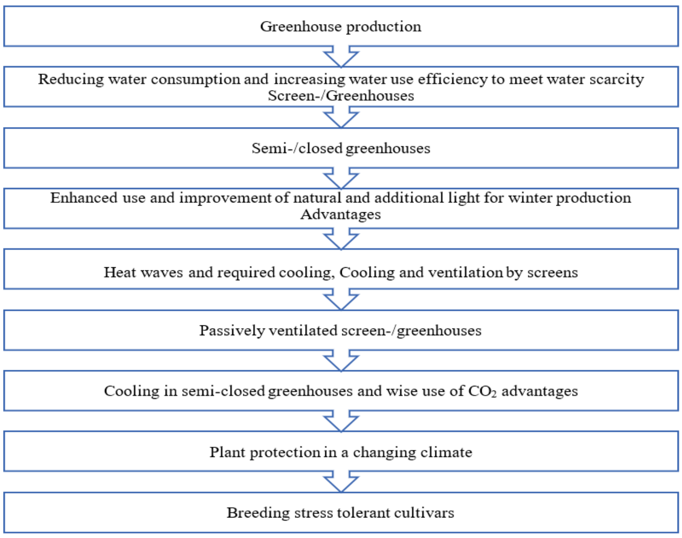

Figure 1. *Adaptive strategy to meet the challenges of the impact of climate change on protected cultivation.*

Controlled Environment Agriculture helps in a healthier and larger production as it propounds the feasibility to minimize and optimize farm-to-door supply chains by making food available even in the off-season and thereby can go a long way to the betterment of the country's Gross Domestic Product (GDP) and lessens imports dependency. As a result, most of Nepal's small and medium farmers have started cultivating flowers and vegetables under modular protected structures depending upon their investment capacity and market availability (Talukdar *et al.*, 2003) reported the following major factors in protected cultivation:

- Productivity in the greenhouse is increased manifold in comparison to the open field (Figure 1).
- Better-quality produce – protection from pests and diseases.
- Early maturity (Figure 2).
- Round-the-year cultivation.
- Cultivation is possible in hostile climates.
- Create microclimate for optimum plant performance – controlled temperature, humidity, and light as per plant requirement.
- Cultivation of crops during the off-season when growing in open fields is impossible.
- Tropical vegetables like cucurbits, capsicum, brinjal, and okra are rare in hilly regions, but these crops can be grown in the greenhouse.
- The greenhouse provides an excellent opportunity to produce quality crops for export.
- Raising nurseries earlier and advancing their availability is also possible through a greenhouse.
- Conservation of valuable planting materials and their cultivation is also possible under the greenhouse.
- The greenhouse can also be used to grow flower plants, strawberries, and grapes and to propagate quality fruit plants.
- Pest and weed management are more manageable in the greenhouse than in the open field.
- The greenhouse conserves moisture. Hence, the frequency of watering plants is reduced.
- Adopting suitable crop sequences can increase productivity per unit area and time.

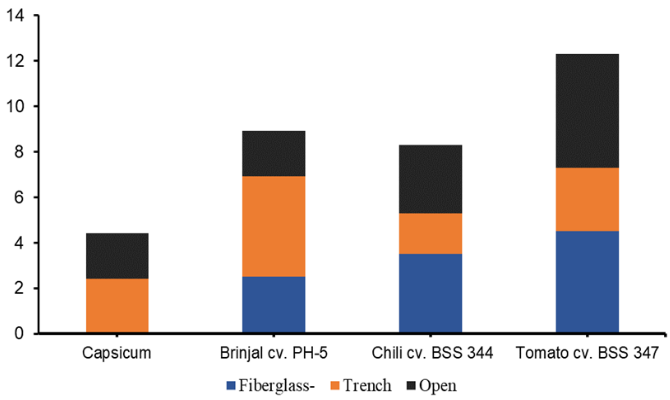

Figure 2. *Comparative performance of Solanaceous vegetable crops in the greenhouse (Source: Talukdar et al., 2003).*

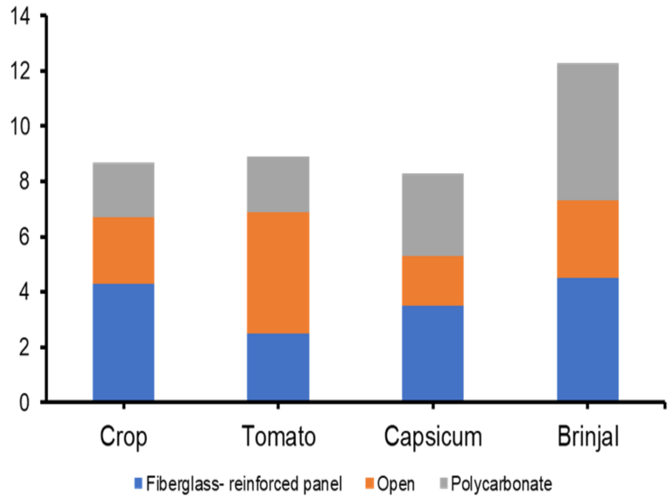

Figure 3. *Effect of greenhouse in achieving earliness in selected Solanaceous crops (Source: Talukdar et al., 2003).*

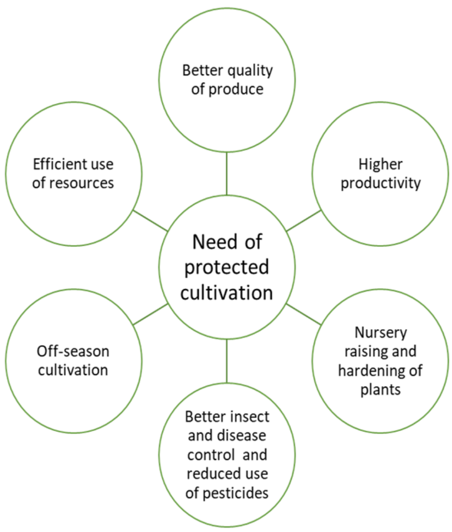

Figure 4. *Need for protected cultivation.*

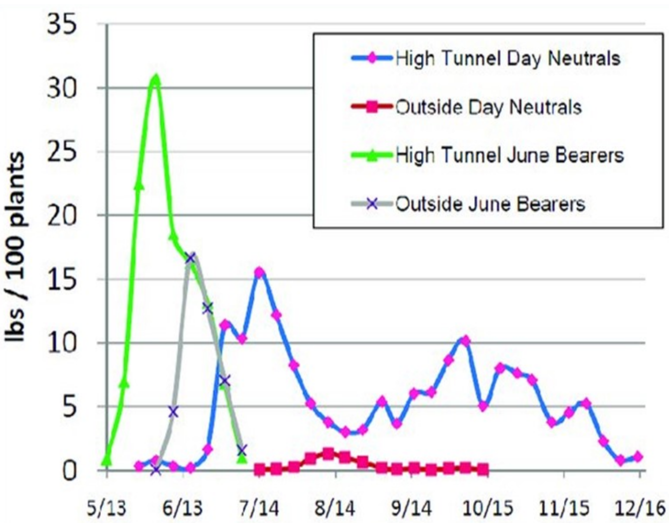

Figure 5. *Yield trends of strawberries in Utah high tunnels. It shows that under tunnels, day-neutral strawberry produces fruit from May to December compared to outside, where the yield is obtained from July to October. Likewise, under tunnels, June's bearer strawberry produces fruit from May to July compared to outside, where the yield is obtained from June to July showing that early-season and late-season fruit can be obtained from these tunnels.*

Several man-made structures used in Horticulture

The components of a control system determine which environmental factors need to be monitored, and the cost of controlling them with the value of the crop being produced. The purpose is to design a controlled environment framework that enables the control of the microclimate that directly affects product quality and productivity. Commonly controlled environments that are practiced in Nepal are Hoop Houses, Cold Frames, Hot Beds, Shade Houses, Greenhouses, coolers, growth chambers, etc.

Hoop houses

Hoop houses also known as polyethylene ("poly") tunnels are easily adaptable, low-cost propagating environments. The semicircular structures of the metal pipeline are covered through a level of polyethylene where water-resistant plywood is used to construct the end walls. Generally, early days at the beginning of spring, a transparent plastic address is employed during seed germination. As the times become warmer, the material i.e., the plastic address may be removed to offer ventilation. Following the threat of frost, the plastic address is replaced and removed with shade fabric. Often, several color cloths, each with a reduced shade, are used to reveal plants to the sun that is full slowly. The shade fabric is eliminated during solidifying to expose the plants to an ambient environment. Whenever covered with white synthetic sheeting, hoop houses may be used for overwintering.

Shade houses

Shade houses are the most enduring semi-controlled propagation surroundings and suffice countless uses, mainly used for hardening plants and also suffice even as over-wintering frameworks (Jacobs *et al.*, 2009). Shade houses (sometimes called Saran Houses) are protected structures made with a fabric manufactured of polypropylene, cotton, plastic, or other material that omit light partially. Some aluminized shading materials are used so that light reverberates opposite to the structure. Generally, shade houses do not have warming or chilling systems rather it frequently produces foliage plants, cut flowers, and nursery stock mostly used in sub-tropical and tropical regions.

Hot frames or hotbeds

Structurally hot frames are much like cool frames. Mainly useful for overwintering non-seedlings, which are robust newly grounded cuttings. Cold structures can also be converted into hotbeds quickly. Start by removing the soil up to 8 or 9 in (20 cm). Lay thermostatically controlled cables that tend to be heated in loops with 2 in (5 cm) of sand. Ensure that the cable loops are evenly spaced and don't cross each other. Protect the cable with 2 in (5 cm) of sand and protect the sand by having a bit of cable mesh (hardware fabric). Trays of cuttings or seedlings can right be placed on the top-of-the-line mesh.

Hotbed manure

Another very different age-old way of heating the earth is to apply manure using a hotbed. Microbial fermentation temperature creates heat by piling up fresh straw-rich waste and covering it

Table 1. Strawberry varieties tested for Utah high tunnels.

Day-neutral	Berry size	Uniformity	Heat tolerance	Cold tolerance	Grey mold resistance	Flavor
Albion	Good	Excellent	Excellent	Poor	Excellent	Excellent
Evie 2	Excellent	Good	Excellent	Poor	Poor	Moderate
Seascape	Good	Good	Moderate	Good	Good	Good
Tribute	Poor	Moderate	Good	Moderate	Poor	Poor
Chandler	Good	Good	NA	NA	Good	Good

The table shows strawberry cultivars tested for Utah are suitable for growing in high tunnels Source: (Rowley *et al.*, 2010).

Table 2. Effect of changing environmental parameters on yield and product quality.

Changing factor	Impact on yield	Impact on product quality	Impact on agricultural practice	References
Increasing atmospheric CO_2	**Advantages** Yields increase with more CO_2, primarily in screen houses, and lessen input cost	**Advantages** Increased antioxidants, sugar, and calcium in vegetables **Disadvantages** Decreased protein, nitrate, zinc, and iron	A considerable amount of N_2 ion uptake by the plant needs extensive fertilizer application and ultimately changes into fertilizer demand	Tanny *et al.*, 2003 Dong *et al.*, 2018
Changing precipitation patterns	**Disadvantages** Yield loss as well as crop failure resulting from water scarcity in summer. 1% of light reduction leads to 0.5 to 1% yield loss in vegetables and ornamentals	**Disadvantages** Low light intensity adversely affects crop performance and quality. High humidity causes *Botrytis*, mildew, and grey mold, reducing output production quality.	**Disadvantages** Higher transpiration rate at warmer temperatures **Advantages** Irrigation requirements decrease in a protected environment	Gruda, 2009 Gruda *et al.*, 2014 Saadi *et al.*, 2015
High summer temperatures	**Disadvantages** Heat causes massive yield reduction and increased wastage	**Disadvantages** Uneven and delayed ripening, soft fruit, blossom end-rot on vegetable fruits. e.g., tomato	**Disadvantages** Difficulties in predicting cultivation sequence, particularly of that crop that requires a continual supply	Adams *et al.*, 2002 Gruda, 2005 Collier *et al.*, 2008
Elevated temperatures on pests and diseases	**Disadvantages** Diseases and pests cause erratic yield loss. E.g. Up to 100% by *Tuta absoluta*	**Disadvantages** Altering mycotoxins content in fruits, molds occur more in cooler regions and less in warm regions	**Disadvantages** Stronger and earlier infestations with new species	Teitel *et al.*, 2005 Krechemer *et al.*, 2015 Zanin *et al.*, 2015
Climate Simulations for greenhouse horticulture	The yield of winter tomatoes will increase by 28% in 2050 compared to 1995 due to an increase in co2 concentration and temperature	Not stimulated	**Advantages** A decreasing demand for greenhouse heating was observed through simulations.	Zanin *et al.*, 2019

with the soil level. Therefore, the warmth of the top surface soil increases, encouraging root development and crop development. Furthermore, CO_2 is released, which stimulates photosynthesis. Adding straw enriched with nitrogenous fertilizer and wetting it can speed up fermentation. Straw-in bales can also be used. They should be covered with 15- 20 cm greenhouse soil after ensuring the straw has been thoroughly wetted and soaked with a nitrogenous fertilizer. The temperature can rise to 30°C or more, depending on the amount used per meter.

High tunnels

These passive solar structures depend primarily on the sun's energy, designed to extend the growing season and strengthen production. High tunnels also lessen hazards and enhance crop quality by safeguarding crops from potentially unfavorable microclimatic conditions such as frost, temperature fluctuations, precipitation, wind, or excess moisture that slow down cultivation. High tunnels are easily affordable too. The improved microclimate inside the structure gives an output of higher quality yields than normal field-grown crops. In addition, crops are less affected by disease and insect pressure inside the high tunnel and are also less costly to manufacture, therefore high tunnels are grouped as temporary agricultural structures for purposes of property. Crops can also be grown hydroponically or in flats or pots on benches under a greenhouse, whereas crops are consistently grown in the ground under high tunnels. High tunnels can be designed in different shapes and sizes, including Quonset or Gothic and narrow or wide, respectively, which can be semi-persistent, temporary, or movable structures (Dumroese *et al.*, 2009). A greenhouse is used for planting and cultivating flowers (carnation, rose, gerbera, chrysanthemum, orchids); fruits (strawberry); vegetables (tomato, cucumber, bell pepper, cabbage) in many developed countries (Figures 1 and 2).

Collision of changed climate on Farming in the protected environment

Nepal ranks 4th vulnerable country to climate change with a Global hunger index (GHI) of 21.2% (Rijal and Rijal, 2019). The FAO proposes a way forward for food security in changing climate to improve food security, assist communities in adapting to climate change, and contribute to climate change mitigation by adopting appropriate practices, policies, and financing. The proposal focuses on three innovative practices: water-smart practices, soil-smart practices, and crop-smart practices. These practices aim to increase water accessibility through water harvesting, improve soil health by using safe farm inputs, and assist in multiple cropping and crop rotation using climate-tolerant varieties. This proposal also promotes communication technology and crop and livestock insurance (Subedi *et al.*, 2019). A study conducted at Chormara outlined that local farmers have started the adoption of climate-smart technologies for vegetable production in contemplation of mitigation of the negative impact of climate change which ultimately has raised the efficacy and the productivity of vegetables at Chormara of Nawalparasi District (Gaire and Dahal, 2021). Applying climate-smart agriculture could reduce greenhouse gas emissions by approximately 7-23%, increase yield by 0.7-0.9 t/ha with an R/C ratio >2, and be more eco-friendly and economically feasible (Ariani *et al.*, 2018).

Nepal is a developing country ranked 147th out of 177 on the Human Development Index (Transformation 2020). The practice of protected horticulture in Nepal was started in 1996 A.D. by Lumle and Kaski, and it was found that the productivity in the greenhouse can increase by 3-5 folds compared to open fields (Atreya *et al.*, 2019a). However, because of the inadequacy of arable land and changeable climate, people of rural areas in the mid-hills and mountainous regions of Nepal rapidly endure incurable and active undernutrition. Still, if the growing season is extended, i.e., by using a greenhouse, the problem may be somewhat overcome (Fuller *et al.*, 2009). (Peck, 2009) describes protected structures in high-latitude areas such as Solukhumbu, peoples benefit from multiple planting of fast-growing and cold-resistant crops such as Chinese cabbage in February-November; other additional crops include spinach, cucumber, zucchini, squash, pumpkins, chilies, and tomatoes, which are also growing in, Mid-April-May benefiting via moggy monsoon season. Vegetables, being daily diet to humankind, require more in quantity for consumption than other crops so their offseason production is very important and can be done by altering different climatic zones, times, and structures i.e., protected cultivation which can draw on dramatic income improvement and encourages farmers towards more commercial production (Kunwar *et al.*, 2015).

Conclusion

Protected cultivation is profitable and beneficial for producing quality fruit for export. It offers advantages such as organic production, pest control, and prevention of frost injury. Breeding of specific varieties suited for protected cultivation is necessary, and production technology should be standardized. Using different climate-smart practices has positive and negative effects on crop productivity. Increasing atmospheric carbon dioxide concentration in greenhouse crops have a direct impact on higher yield, and increase antioxidant, sugar, and iron content but if used in higher amount for longer period it can cause a decrease in protein, zinc, and iron content in horticultural crops. Inappropriate use of elevated temperature can cause favorable conditions for the survival of disease-causing pathogens and insect-pest infestation that will hamper crop health, ultimately lowering crop yield. So, we must be aware of such practices' direct and indirect effects before adopting them. Greenhouse structures (closed, semi-closed, partially closed), Heat waves, and wise use of carbon dioxide under greenhouse structures might be effective strategies to fight climate change.

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