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Advances of protected cultivation of vegetable crops in India as well as global scenario: A review

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Abstract
A new technology called protected cultivation is being used to grow perishable commodities like vegetables, flowers, and other high-value crops. Protected structures offered great potential for increased productivity and production in modern agriculture. Produce is also considerably more plentiful and of higher quality than produce from open fields. In this review, the production of numerous vegetable crops, flowers, and other high-value products was examined in terms of their economic impact on protected structures. Vegetable and flower production is higher in protected structures than in open fields, and productivity is also higher. In comparison to open settings, these structures had higher gross and net returns. The review of the paper is that the majority of farmers adopt open-field cultivation techniques, but these techniques ultimately result in decreasing land value, water availability, and farmer income since they do not supply the proper temperature, humidity, and other criteria. Therefore, protected structures-based farming (protected cultivation) technology is superior to open field cultivation/conditions in terms of improving agricultural yield, soil fertility, profitability, and sustainability, among other factors. The review's analysis revealed that the gross and net returns in protected structures (protective cultivation) were significantly higher than those in open conditions. It also revealed that the production of vegetables was profitable, along with its adoption status under polyhouses, as opposed to open fields.

Keywords: Perishable, protected structure, high-value products, economics, polyhouses

Introduction

India achieved the vegetable production of 175008 (‘000 MT) from 10290 (‘000 Ha) with productivity of 17.01 MT/Hectare (NHB, 2017) [35]. China accounts for 45% of the global value of vegetable production India comes second, accounting for 8% of global vegetable production, respectively (FAO, 2017) [13]. By the end of 2020, however, it is predicted that 135 million tonnes of vegetables will be needed annually (Ummyiah *et al*., 2017) [57].

According to Mishra et al. (2010) [39], protective farming practises are cropping methods that partially or completely regulate the microclimate around the plant body depending on the needs of the species of plants cultivated. Based on the current climatic conditions, many sorts of protective agricultural practises have been adopted. For year-round vegetable cultivation in temperate conditions, greenhouse/polyhouse is one of them (Mishra et al., 2010) [39]. Protected farming, sometimes referred to as controlled environment agriculture (CEA), is extremely productive, water and land efficient, and also protects the environment (Jensen, 2002) [29].

Protected farming, commonly referred to as controlled environment agriculture (CEA), is extremely productive, water and land efficient, and also protects the environment (Jensen 2002) [29]. Protected cultivation, which was previously thought of as a production method only for wealthy western nations with unfavourable environments, is now urgently needed in India in order to increase the productivity and quality of the vegetables in order to maintain competitiveness in the global markets (Kohli *et al*., 2007) [31].

The use of protected cultivation methods is spreading rapidly across Asia (Kang et al., 2013, Nair and Barche, 2014) [30]. A study in Bangladesh showed that training farmers to grow tomatoes in the hot-wet season using low-cost rain shelters, heat-resistant varieties and plant hormones to induce flowering increased farmers’ seasonal incomes by 48% (Schreinemachers et al., 2016) [49]

Protected agriculture is the best alternative and the least labor-intensive method for using land and other resources more efficiently in India, where there is a constant demand for vegetables and a sharp decline in land ownership (Sirohi and Bahera, 2000) [55]. For the off-season production of vegetables, their seed production, and the protection of the priceless germplasm,

controlled environmental conditions are used (Mangal and Singh, 1993) [36]. The most feasible way to achieve the goals of protected agriculture is in a greenhouse (Nagarajan *et al*., 2002) [41].
Tomato, Capsicum and cucumber are the most extensively grown vegetables under green houses and give higher returns. Growing of cucumber using cost effective plastic greenhouses provides an alternative for raising crop in the period of scarcity in Himachal Pradesh. This also ensures to meet year round supply of fresh produce with more efficient resource utilization (Sharma *et al*. 2009) [50].

Reason for protected cultivation at present scenario

i. 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.
ii. In the upper reaches of the Himalayas, cold desert conditions prevail where the wintertime lows (-5 to -30 °C and isolation from the rest of the nation from November to March due to heavy snowfall make growing vegetables a challenging task.
iii. Due to the abundance of vegetables available in the marketplaces during the growing season, vegetable growers do not receive excellent returns.
iv. Biotic pressures during the wet and post-rainy seasons in some regions of the country prevent successful vegetable production. As a result, the majority of vegetables suffer serious damage from pests, illnesses, and viruses, which lowers their quality.
v. Because of the strain from a growing population, fast urbanisation, and industrialization, cultivable land is becoming increasingly rare day by day.
vi. The growing demand for vegetables of superior grade.
vii. Growing nurseries early to get a crop early.

Protected structures types: protected structures types are
Net houses Walk-in-tunnels Plastic low tunnels/row covers
Plastic mulch Floating plastic covers Soil trenches
Hot beds

Greenhouses classifications

A. Based on Environmental Control

- Hi-Tech/Environmentally controlled Greenhouses, Low Tech Greenhouses

B. Based on Shape

- Lean to type Greenhouse, Even span Greenhouse, Uneven span type, Ridge and Furrow type, Saw tooth type Greenhouse, Quonset Greenhouse

C. Based on Covering material

- Glass Greenhouses, Plastic Film Greenhouses, Rigid Panel Greenhouses

Crop production systems and media for protected cultivation: There are several production systems currently being utilized worldwide by commercial greenhouse vegetable producers. All the greenhouse production systems require the use of similar environment control, shade structures, support wires and other general production practices. The irrigation and nutrient delivery systems and control would be the main variations. Various greenhouse production methods include:

Soil system/ Ground culture/ Geoponics: Under a greenhouse cover, it entails growing vegetables directly in the ground. It is the simplest approach to begin growing vegetables in a greenhouse. Double rows of plants are used, and proportioners, injection pumps, or sizable nutrient storage tanks with sump pumps are used to handle watering. At the base of each plant, drip or ring emitters are positioned to supply water and nutrients to the plants.

Soil-Less Culture: Growing of vegetables in the media other than soil is called soil-less culture. Containers of various shapes and sizes with drainage holes are required for soil-less culture and the system is called container system. There are many media produced by different organisations that are largely made of peat and include different combinations of peat with perlite, vermiculite, sawdust, rock wool, rice hulls, pine bark, peanut hulls, or other materials. For the plants' initial growth, the soilless mixture typically contains some fertiliser. Through a drip irrigation system, which uses a polyethylene line to convey water and fertilisers down the double row of containers and an emitter to irrigate each one, containers are watered and fertilised.

Hydroponics: The term "hydroponics" or "water culture" refers to the process of growing plants in nutrient solutions. Producing vegetables in sand, gravel, or synthetic soilless mixtures in bags, tubes, tanks, or troughs made to facilitate the circulation of nutrient media necessary for crop growth is what this method entails. Due to the system's limited ability to buffer nutrients and its flexibility to adapt quickly, hydroponics requires careful system monitoring (Singh and Singh, 2012) [52].

Nutrient Film Technique (NFT): The naked roots are continuously soaked in a flowing nutrient solution in this sort of water culture system. True NFT involves growing the plants in a shallow, plastic-lined trough that continuously receives oxygenated fertiliser solution. The nutrition solution can run through channels that are sloped so that it can be collected and returned to the sump tank. The sump tank's sump pump continuously pumps nutrient solution back into the channels. The vegetables tomato and cucumber are good for NFT systems.

Aeroponics: It entails growing plants in a trough or other container where the roots are suspended and nutrient mist is sprayed on them. The rooted plants are put in a specific kind of box with a humid environment that is computer controlled. It is a relatively new production system that is utilised exclusively for research.

The following list of crops can be grown commercially using soilless culture

Singh and Singh (2012) [52] stated flowing crops can be grown commercially for protected as well as soil less culture

The following list of crops can be grown commercially using soilless culture

Type of crops	Name of the crops
Cereals	Oryza sativa (Rice), Zea mays (Maize)
Fruits	Fragaria ananassa (Strawberry)
Vegetables	Lycopersicon esculentum (Tomato), Capsicum frutescens (Chilli), Solanum melongena (Brinjal), Phaseolus vulgaris (Green Bean), Beta vulgaris (Beetroot), Psophocarpus tetragonolobus (Winged Bean), Capsicum annum (Bell Pepper), Brassica oleracea var. capitata (Cabbage), Brassica olerace
Leafy vegetables	Lactuca sativa (Lettuce), Ipomoea aquatica (Kang Kong)
Condiments	Petroselinum crispum (Parsley), Mentha spicata (Mint), Ocimum basilicum (Sweet basil), Origanum vulgare (Oregano)
Flower / Ornamental crops	Tagetes patula (Marigold), Rosa berberifolia (Roses), Dianthus caryophyllus (Carnations), Chrysanthemum indicum (Chrysanthemum)
Medicinal crops	Aloe vera (Indian Aloe), Solenostemon scutellarioides (Coleus)
Fodder crops	Fodder maize, Sorghum bicolor (Sorghum), Medicago sativa (Alphalfa), Hordeum vulgare (Barley), Cynodon dactylon (Bermuda grass), Axonopus compressus (Carpet grass)

Technologies of vegetables crops and their varieties for greenhouse cultivation:-
Increased production and productivity per unit of land, water, energy, and labour, high-quality and clean products, high water and fertiliser use efficiency, subsidy provision for the establishment of high-cost infrastructure, and year-round employment for farmers were the major prospective aspects perceived by poly house farmers, according to the majority of these farmers (Ghanghas *et al*., 2018) [14].

Tomato in Greenhouse system: Tomato hybrids and cultivars grown in greenhouses have an erratic development pattern. Plants may therefore grow to a length of 30 to 40 feet after 10 to 11 months of cultivation. The following groups are typically used to classify greenhouse-grown tomatoes:

- **Beafsteak cultivars:** FA-574, FA-180 and FA-514.
- **Big-fruited varieties:** Naveen, Arka Vishal, Arka Vardan.
- **Hand type/ cluster type:** HA-646, FA-556, FA-521.
- **Cherry tomato:** NS Cherry-1, NS Cherry-2.

Tomato genotypes identified under protected cultivation and some advantages

S. No.	Genotypes/ advantages	Material used	Authors
1	Naveen (hybrid) a) No incidence of aphid, Aphis gossypii b) Enhanced fruiting span	Net house	Cheema *et al*., 2004 [7]
2	Mariachi (hybrid) a) Higher TSS and Lycopene	Green house	Min *et al*., 2004 [38]
3	Elegance (hybrid) a) High yield	Green house	Peet *et al*., 2004 [44]
4	Beril-7314 and Celeya (hybrids) a) Enhanced fruiting span	Green house (originally produced)	Tuxel *et al.*, 2004 [55]
5	Tomato- in general I) Use of mist system increased a) Leaf stomatal conductance b) Plant growth	Green house	Romero-Aranda *et al.*, 2002 [45]
6	Tomato- in general I) Increasing vapour pressure deficit reduces a) Fresh fruit weight and fruit water content	Greenhouse	Le Onardi *et al.*, 2000 [34]

Tomato is the most universally grown greenhouse vegetable crop found in varied agro-climatic regions all over the globe and is used as a salad, vegetable, fruit and in canning processes. Tomato varieties (cluster, heirloom, cherry etc) grown under greenhouse conditions are of indeterminate type as they continue to grow and set fruits almost for a yearlong plant life (Atherton and Harris 1986) [1].
Apart from the most recent and high-yielding hybrids, grafting technology is the most widely used method for growing tomatoes in greenhouses. It not only increases soil salinity tolerance and fruit production through increased plant vigour, but it also reduces susceptibility to root diseases. (http://www.hort.uconn.edu/ipm/ greenhs/htms/Tomgraft.htm). Tomato harvesting is a continual process which lasts throughout its growing season. Large sized fruits are harvested singly with their calyx attached, while some smaller varieties are harvested in bunches.

Sweet Pepper in Greenhouse system: Bharat, Mahabharata (both red), Golden Summer, Tanvi (both yellow), California Wonder, and more notable cultivars are available in our nation for greenhouse production. Although cultivating capsicums in greenhouses is more difficult than growing tomatoes, it is nevertheless a valuable sector in and of itself. Despite being a lucrative crop with promising futures, it grows slowly, requires a high temperature for development, fruit set happens over time, and fruits are harvested in flushes. (http://www.hortnet.co.nz/publications/hortfacts/hf359001.htm). Different coloured varieties of capsicum, viz. red, yellow, green and black are high in demand at fast food restaurants for variety of food preparations, extraction of natural colours and preparing oleoresins and oils (http://www.unlimitedprojects.com/a21.html). The coloured varieties rich in Vitamin and antioxidants along with processed products have very well added to the market value of capsicum and fetch a premium price in the international market. The major damage caused to capsicum is through thrips, mites and fungal diseases like Pythium/Rhizoctonia, Botrytis, powdery mildew, Fusarium wilt and Cercospora leaf spot. (Sabir and Singh, 2013).

Cucumber in Greenhouse system: In greenhouses, European cultivars of cucumber are typically produced. These set fruits parthenocarpically and are gynoecious. Satis, Alamir, Kian, and other significant parthenocarpic cultivars are available in India. In India, there are also several monoecious cultivars that can only be produced in greenhouses by managing pollination. These include Pusa Sanyog, Priya, and Japanese Long Green (Kumar, 2016) [37]. The production of three crops per year of parthenocarpic cucumbers in greenhouses can be profitable for vegetable growers. The cultivation of cucumbers in greenhouses using hydroponics (Brentlinger 2007) [4] and grafting technology (Uysal *et al*. 2012, Lee 1989, Wittwer and Honma 1979) [57, 33, 58] can significantly reduce pest and disease problems as well as promote the development of productive varieties. In comparison to traditional soil-based cultivation, soilless growing of greenhouse cucumber produces higher yields (Engindeniz and Gül 2009) [12]. Cucumber cultivation in greenhouses yields higher returns than in fields thanks to the soilless system's enhanced efficiency in using fertiliser and water that can be recycled (Cantliffe *et al.* 2008) [6]. By implementing IPM techniques, biotic stressors, in particular those brought on by soil-borne diseases and sucking pests of greenhouse cucumbers, can be effectively handled.

According to Singh et al., 2019 [53], Pant Parthenocarpic Cucumber -3 (V2) was discovered to be statistically superior to increase vine length (2.73 m), stem girth (0.80 cm), leaf area (412.34 cm2), internodal distance (8.38 cm), minimum days required to first flower bud initiation (42.14 DAS), days to first fruit harvest (55.42 DAS), number of fruits per vine (21.89), average weight of fruits (116).

Under Indian conditions successful cultivation of greenhouse cucumber through healthy production practices including GAP and IPM have given yields up to 50 q/1 000 m2 area in a span of four months and very high profitability for small growers (http:// www.iari.res.in /files/Success_Story-Parthenocarpic-Cucumber-11062012.pdf).Similarly,green-house capsicums yield about 8 tonnes/1 000 sq. feet area and fetch around ` 4- 5 lakh per acre (http:// www. tribuneindia.com/2011/20110304/punjab.htm#9; http://www.thaindian. com /newsportal/ indianews/tamil-nadu-capsicum-growing-farmers-reap-hugeprofits_ 1001757 26.html) while greenhouse tomatoes yield around 25 tonnes/quarter acre of land (http://www.thaindian.com/newsportal/india-news/coimbatorefarmer-gets-high-yield-of tomatoes-using-green-housetechnology_100277745.html).

Growing of cucumber using cost effective plastic greenhouses provides an alternative for raising crop in the period of scarcity in Himachal Pradesh. This also ensures to meet year round supply of fresh produce with more efficient resource utilization (Sharma et al. 2009) [50].

Lettuce in Greenhouse system: Lettuce is grown almost exclusively for the fresh market for salads, sandwiches and as a garnish. Its production in greenhouses has become popular and potentially a profitable venture (Sabir and Singh, 2013) [46]. Greenhouse lettuce is grown primarily in soilless media, using rookwool, perlite or a hydroponic nutrient film technique (NFT) (Elmhirst 2006, Morgan and Tan 1983) [11, 40]. Hydroponic lettuce is produced either through nutrient film technique (NFT) or the floating raft method, both as closed systems (http://www.uky.edu/Ag/NewCrops/introsheets/ hydrolettuce.pdf). The major advantages of hydroponic lettuce include a short production period (35-40 days), availability year round, and consistency of product attributes. Production of greenhouse lettuce requires strict control of temperature, light, carbon dioxide concentration and relative humidity (RH). The major diseases encountered in hydroponics are Pythium, Phytophthora, Botrytis gray mold, powdery mildew and downy mildew; while pests of particular concern are aphids, thrips, whiteflies, and mites (Sabir and Singh, 2013) [46].

Coriander: Isaac S.R. (2015) [26] revealed that coriander establishes and grow well with higher biomass production in naturally ventilated polyhouse.

Brinjal: with the development of parthenocarpic hybrids in brinjal, now it is possible to grow it under the protected conditions (Kumar and Singh, 2015) [32].

Other Vegetables

- Gherkin
- Bottle gourd
- Bitter gourd
- Melons
- Leafy vegetables like lettuce etc.
- Brinjal

Other vegetables –has success stories of growing tomato, capsicum, chillies, long gourd and seedless cucumber in Nabha, Punjab, India and gave yields of about ` 4-5 lakh per acre from capsicums (http://www.tribuneindia.com/2011/20110304/ punjab.htm#9) and 25 tonnes from one fourth of acre in Coimbatore as against similar yields from one acre. (http:// www.thaindian .com/newsportal/india-news/coimbatorefarmer-gets-high-yield-of-tomatoes-using-green-house technology_ 100277745.html and http://www.thaindian.com/newsportal/india news/tamil-nadu-capsicum-growingfarmers- reap-huge-profits_100175726.html).

Pollination under protected structure: Pollination of flowers is very essential and is needed for optimal fruit set and production of quality greenhouse vegetables. Depending on the crop, it can be done manually, mechanically (with electric vibrators and air blowers), or by using bumblebees in greenhouses. (Sabir & Singh 2013) [46]. It is assumed that electric vibrators or 'mechanical bee' are more effective, less time consuming and economical compared to air blowers and also produce greater marketable yield (Hanna 2004, Cuellar *et al*. 2001) [8]. But the mechanism of pollination with bumblebees is an effective alternative and has surpassed all other methods (Banda and Paxton 1991 [2], Dogterom *et al*. 1998) [10]. They are more effective pollinators of greenhouse crops like tomato, cucumber, capsicum etc. Different species used in greenhouses are *Bombus terrestris*, *B. impatience* and *B. occidentalis*. Stingless bees (*Scaptotrigona depilis* and *Nannotrigona testaceicornis*) can also be successfully used as pollinators of greenhouse cucumbers (Santos *et al.* 2008) [48]. The dipteran species *Eristalis tenax* possesses desirable attributes for the pollination of *Capsicum annuum* under greenhouse conditions (Jarlan *et al.* 1997) [27].

Constraints in greenhouse vegetable cultivation

i. The basic cost of construction and operational cost of the climate controlled greenhouse is very high.
ii. Uninterrupted and regular power supply is required for operating cooling and heating system of the greenhouse.
iii. Cladding material of required quality is not readily available.
iv. Non-availability of tools and implements for facilitating crop-production operations under greenhouse.
v. There is a lack of specific research programme on greenhouse vegetable production in the country.
vi. No specific breeding work has been initiated for development of suitable varieties/ hybrids for greenhouse cultivation. Exotic seeds are very costly and are out of reach of the Indian growers.

Future Needs: The nation's polyhouse vegetable production is still in its infancy, so it is urgently necessary to address the following problems with this technology in order for it to be quickly commercialized:

i. Standardising the appropriate design for polyhouse building, including the use of locally produced, affordable cladding and glazing.Developing cost effective agro-techniques for growing of different vegetable crops in the different types of polyhouses and lowering energy costs of the green house environment management.
ii. Major research activities on growing of vegetables under protected covers should be launched by ICAR and SAU's.
iii. Import of planting materials, structural designs and production technologies which are not relevant under Indian conditions should be stopped and in turn emphasis should be given to develop own F1 hybrid varieties so that seed are made available to the growers in time and at cheaper rates.

Suggestions for planning of policy makers

- Insurance cover may be given under crop insurance scheme and also especially for cladding material which is prone to hazards of wind storms and hail storms
- Agricultural electricity connection should be provided instead of commercial since running of foggers is costlier practice in poly house cultivation or solar panel system provision for poly houses instead of commercial connection
- Provision of enforcement laws for getting fulfillment of liabilities well in time by companies especially in case of cladding material and machinery or equipments provided by them.

Conclusions

Thus protected cultivation has great potential in the state to increase quality production per unit area per unit time. Thus, timely efforts by the state government under HTM, PDDKBSY and RKVY schemes can scaled-up protected cultivation and can prove to be a boon to small and marginal hill farmers. The State Departments of Agriculture and Horticulture, SAUs, CAUs, KVKs, stakeholders as well as some NGOs have to work together to make this enterprise a great success.

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