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Protected cultivation of vegetable crops under temperate conditions

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Abstract
India has a wide range of diverse agro-climatic conditions, but vegetable cultivation has generally been restricted to regional and seasonal needs. Although the production has increased to a level of 113.5 million tonnes from an area of 7.2 million hectares, still the technology used and practices followed are predominantly traditional, resulting in low productivity and inconsistent quality and quantity of produce. In the upper reaches of Himalayas, cold desert conditions prevail where the temperature is extremely low (-5 to -30^{0}C) during winter season and most of the regions remain cut off from the rest of the country from November to March due to heavy snowfall. Due to this reason, people in these areas experience acute shortage of vegetables in winters. Sometimes in winter, vegetables are transported by air in Srinagar and Ladakh and the cost of these vegetables is beyond the reach of common man. Therefore self-sustenance is a need for these regions. To overcome these problems, Protected Cultivation offers a great potential. Protected cultivation enables us to grow vegetables in the off-season and also to extend the vegetable growing seasons for a much longer period than is possible under open field conditions. Vegetables are available earlier than usual and some can be grown well even during frosts. Though certain breakthroughs in vegetable cultivation in adverse climates using protected devices have been registered, more extensive research and generation of awareness are required to tap potential of Protected Cultivation of vegetable crops and also increase the area under protected devices.

Keywords: cultivation, vegetable crops, temperate conditions, microclimate

Introduction
Protected cultivation is a technique wherein the microclimate in the surrounding area of the plant is controlled partially or fully or modified to protect the crop from weather especially very low or high temperatures, hail storms and heavy rains. This technology is also useful for protecting the plants from birds, insects etc. and conserving the soil moisture simultaneously.
Protected cultivation of vegetables offers distinct advantages of quality, productivity and favorable market price to the growers. Vegetable growers can substantially increase their income by protected cultivation in off-season as the vegetables produced during their normal season generally do not fetch good returns due to their large availability in the markets. Off-season cultivation of cucurbits under low plastic tunnels is one of the most profitable technologies under northern plains of India. Walk-in tunnels are also suitable and effective to raise off-season nursery due to their low initial cost. Insect proof net houses can be used for virus free cultivation of tomato, chilli, sweet pepper and other vegetables mainly during the rainy season. These low cost structures are also suitable for growing pesticide free green vegetables. Polytrenches have proved extremely useful for growing vegetables under cold desert conditions in upper reaches of Himalayas in the country.

Need for Protected Cultivation
- Indian Horticulture achieved a significant increase in vegetable production with a total of more than 113.5 million tons and stands second next only to China. However, annual requirement of vegetables is estimated to be about 135 million tons by the end of 2020. The actual problem of low production and productivity has been attributed to the extremes of temperatures ranging from 0-48 ^{0}C during the year which does not allow year round outdoor vegetable cultivation.
- In the upper reaches of Himalayas, cold desert conditions prevail where the temperature is extremely low (-5 to -30 ^{0}C) during winter season and the regions remain cut off from the rest of the country from November to March due to heavy snowfall which makes vegetable growing a difficult exercise.
- Vegetable growers do not fetch good returns due to large availability of vegetables in the markets during the on season.

- In several parts of the country biotic stresses during rainy and post rainy season do not allow successful vegetable production. As a result, most of the vegetables are damaged by severe incidence of diseases, pests and viruses, thus affecting the quality of vegetables.
- Day by day cultivable area is becoming scarce due to the pressure of increasing population, rapid urbanization and industrialization.
- Increasing demand of high quality vegetables.
- Early nursery raising to get an early crop.

Protected Structures

The different types of protected structures used in this industry are:

Net houses: These are of two types, namely shade nets and insect-proof nets. Shade nets are used to cut down the solar radiations and protect the crops from wilting/scorching. These are available in three colours, i.e. black, green and white and in different shading intensities ranging from 25 to 75%. Insect proof nets are available in different intensities from 25 to 60 mesh. Nets of 40 and higher mesh are effective means of controlling most of the flying insects. These are also used for controlled pollination in breeding programmes.

Walk-in-tunnels: These are simple structures which are generally arc shaped of about 2 to 2.5 m height at the centre and a width of about 4m. These accommodate almost 2 to 3 beds of vegetables and are suitable for crops of low canopy like capsicum, lettuce, bush type beans etc. they are suitable for nursery raising.

Plastic low tunnels/row covers: These structures are laid in open fields to cover rows of plants with transparent plastic film stretched over steel hoops of about 50cm height and about 1m width. Polyethene film of 30-50 micron thickness is used. These are also called miniature greenhouses. They conserve warmth, thus protect crops from frost injury. They hasten growth for early markets, especially in cucurbits.

Plastic mulch: Mulching is a practice of covering the surface around the plant to make conditions more conducive for plant growth through moisture conservation, weed control, better CO_2 exchange for the root system and soil structure maintenance. It permits cleaner crop cultivation as the fruits don't come in contact with the soil. Silver and yellow coloured films are successfully used to repel insects like aphids and white flies. Black polyethene mulches are more popular due to their opacity.

Floating plastic covers: Transparent plastic sheet is used to cover large open fields to protect vegetables from frost/ snow and low temperature.

Soil trenches: Trench is a simple and cheap structure for growing vegetables in extreme winters. They are also called Underground solar green houses. Generally they have a width of 5 to 6m and a depth of 2 to 3m. Trench cultivation harnesses soil and sun heat for vegetable growing. They are very popular in the cold desert areas especially Ladakh.

Hot beds: The traditional hot beds work on the principle that the heat generated from the decomposition of dung can be utilized in growing vegetables even in sub-zero temperature conditions. These are made over the ground by alternating layers of straw and half rotten dung. These are suitable for off-season nursery raising. **Greenhouses:**

A greenhouse is a framed or an inflated structure covered with a transparent or a translucent material in which crops could be grown under the conditions of at least partially controlled environment and which is large enough to permit persons to work within it to carry out cultural operations. It is a technique of providing favorable environmental or growth conditions to the plants. In greenhouses, the growing environment is altered to suit the specific requirements of the plants. Of all the structures greenhouse is the basic and important structure for harnessing the full potential of this technology. Greenhouse technology is the most effective way to achieve the goal of protected cultivation since it provides favorable and controlled environment for the crop to grow and give high productivity round the year.

Principle of Greenhouse

It works on the principle of greenhouse effect which states that "depending on the transmittance of the cladding material, most of the solar radiations are absorbed by the plants or crops and other materials inside the polyhouse. These materials inside the greenhouse in turn emit long wave thermal radiations in the infrared region for which the cladding material has got lower transparency. As a result heat starts accumulating inside the greenhouse which raises the temperature". This rise in temperature (10-12^{0}C) up to certain extent is useful for growing crops in the cold arid desert regions or high hills where winters are very severe.

Attributes of Greenhouse: A greenhouse has four important attributes:

- It has a framed or inflated structure.
- It is covered by a transparent or translucent material to maintain optimum light levels.
- Crop micro-climate can be at least partially controlled.
- It is large enough to permit a person to work inside.

Advantages of Greenhouse

- Throughout the year four to five crops can be grown in a greenhouse.
- The productivity and financial return per unit area of the crop is increased considerably.
- Superior quality produce can be obtained.
- High quality seed production attributes can be undertaken.
- Effective control of pests and diseases is possible.
- Percentage of germination of seeds is high in greenhouses.
- The acclimatization of plantlets of tissue culture technique can be carried out in a greenhouse.
- Agricultural and horticultural crop production schedules can be planned to take advantage of the market needs.
- Greenhouses are ideally suited for farmers having small holdings.
- It is labour intensive and helps in generation of rural employment.

Disadvantages of a Greenhouse

The main disadvantage in the development of greenhouse technology is the high initial cost. Since most of the Indian farmers are poor, they are unable to establish high cost greenhouse structures for vegetable growing. Moreover lack of awareness about this technology and illiteracy of the farmers are the major impediments.

Suggestions

- Use local materials like bamboo/wood instead of expensive steel pipes to reduce the initial cost of greenhouse installation.
- To regulate the temperature and humidity in such cheap greenhouses, open the polyethylene sheet on one side manually when the temperature increases inside and irrigate or sprinkle the beds to increase the humidity and reduce the temperature.
- The rate of subsidy already given to the farmers should be increased to popularize greenhouses.
- Farmers can set up their own co-operative societies to make best use of greenhouse in arranging materials jointly at cheap rates for their installation and further taking the produce to the market to get good returns.
- Regular training programmes should be organized to transfer the appropriate technology to the farmers.

Classification of Greenhouses

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

Planning of Greenhouse Facility

There are five essential components of greenhouse technology to harvest its full potential in growing the vegetables. These are:

- Selection of crops to be grown in the greenhouse.
- Proper design and construction of greenhouse.
- Optimum environmental control.
- Developing and standardizing suitable technology and agro-techniques.
- Marketing of the greenhouse produce.

India has different agro-climatic zones, thus the selection of proper greenhouse design and construction depends upon the topography and the available climate of the area.

Site selection

The specific selection of a greenhouse location must take into account a variety of factors (Castilla, 2007). The site considerations are as follows:

- Site should be as leveled as possible to reduce the cost of leveling and grading.
- Site should be well aerated and should receive good solar radiation.
- Provision of drainage system is advisable.
- It is advisable to select a site with a natural wind break on the north and north-west sides.
- Site should have a continuous supply of electricity.
- Access to good roads and proximity to expected markets should also be considered.

Orientation

The transparent covering should be at right angles to the sun's rays for maximum transmission of solar radiation into the greenhouse. Since the sun's position is not fixed, the relationship between direct solar radiation and the structure varies throughout the year. The North-South orientation has good radiation distribution. The East-West greenhouses caste fewer shadows than those oriented North-South. The E-W orientation is preferable during winter above 40-45^0 latitude and at other times of the year and closer to the equator, N-S arrangement is better.

Structural design

It is important to develop greenhouses with maximum intensity of natural light inside. The structural parts that can cast shadows inside should be minimized. So the covering material should have the largest possible unsupported area, and should offer the highest possible light transmittance. At the same time greenhouse structures should be strong enough to resist different kinds of loads.

Design load: The design of a greenhouse structure is mainly governed by the dead load, live load and snow load.

- Dead load is the weight of all materials used in the construction of greenhouse such as floor, roof, framing and covering.
- Live load is the weight superimposed by use (like baskets, shelves, ropes etc.) but not the wind, snow and dead load. The minimum value of it is taken as 50kg/m^2.
- Snow load is vertical load applied to the horizontal projection of the roof.
- Wind load is caused by blowing wind in any horizontal direction i.e. load due to wind velocity. Its minimum value is taken as 100kg/m^2.

Plant Response to Greenhouse Environment

The components of a crop micro-climate are light, temperature, air compositions and the nature of the root medium. The crop productivity is influenced not only by its heredity but also by the micro-climate around it.

Light: The visible light of the solar radiation is a source of energy for plants. A narrow range of electromagnetic radiation falls within the range of 400 to 700 nm wavelength which is referred to as the spectrum of visible light. The radiation in the 400 to 700 nm waveband is also known as Photo synthetically Active Radiation (PAR). Plants are relatively inefficient at using light and are only able to use about a maximum of 22% of it. The greenhouse intercepts a percent of light falling on it allowing a maximum of 80% of it to reach the crop at around noon with an overall average of 68% over the day. It is important that the crop be oriented in such a way that the light transmitted through the structure is optimized for its efficient distribution to the canopy. The major greenhouse vegetable crops are arranged in either single or double rows which ensure effective compromise between the accessibility to work and light interception by the crop.

Temperature: All vegetables have a temperature range in which they can grow well. Below this range, the plant life processes stop due to ice formation within the tissues which finally get punctured. Moreover at the upper extremes the enzymes become inactive causing the processes essential for life to cease. As a general rule, greenhouse vegetables are grown at a day temperature which is 3 to 6 ^{0}C higher than the night temperature on cloudy days and 8 ^{0}C higher on clear days. The night temperature of greenhouse vegetables is generally in the range of 7 to 21 ^{0}C.

Relative Humidity: As the greenhouse is a closed space, the relative humidity of the inside air will be more when compared to the ambient air due to the moisture added by the evapotranspiration process. In order to maintain desirable relative humidity levels in greenhouses, processes like humidification and dehumidification are carried out. For most vegetable crops, the optimum range of relative humidity is between 50 to 80%.

Carbon dioxide: Carbon dioxide (CO_2) is one of the inputs of photosynthesis and as such plays an important role in increasing the crop productivity. Under normal conditions, CO_2 exists as a gas in the atmosphere slightly above 0.03% or 345 ppm. Optimal CO_2 concentration for the greenhouse atmosphere falls in the range of 700 to 900 ppm.

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 major differences would be in the irrigation and nutrient delivery methods and control. Different greenhouse production systems are:

Soil system/ Ground culture/ Geoponics: It involves growing of vegetables directly in the natural soil under the greenhouse cover. It is the easiest way to start greenhouse vegetable production. Plants re oriented in double rows and irrigation is handled through the use of proportioners, injection pumps, or large nutrient storage tanks with sump pumps. Drip or ring emitters are placed at the base of each plant to provide 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. Many media manufactured by various agencies are available, which are mostly peat based and include various blends of peat with perlite, vermiculite, sawdust, rock wool, rice hulls, pine bark, peanut hulls, or other mixtures. The soil-less mix usually contains some fertilizer to start the plants. Containers are irrigated and fertilized through a drip irrigation system in which a polyethylene pipe delivers water and fertilizers down the double row of containers and each container is irrigated from an emitter.

Hydroponics: The system of growing plant in nutrient solution is known as hydroponics or water culture. It involves the production of vegetables in sand, gravel, or artificial soil-less mixes in bags, tubes, tanks, or troughs designed to allow the circulation of nutrient media needed for crop growth. In hydroponics, because of limited nutrient-buffering capacity of the system and the ability to make rapid changes, careful monitoring of the system in necessary (Singh and Singh, 2012).

Nutrient Film Technique (NFT) is a type of water culture system in which the bare roots are continuously bathed in a flowing nutrient solution. True NFT consists of growing the plants in a shallow plastic-lined trough in which oxygenated nutrient solution is flowed continuously. Channels are on a slope to allow the nutrient solution to flow from one end to the other and collected for return to the sump tank. Nutrient solution is pumped continuously from the sump tank back to the channels. Vegetables suited for NFT system are tomato and cucumber.

Aeroponics: It involves growing of plants in a trough or container in which the roots are suspended and sprayed with a nutrient mist. The rooted plants are placed in a special type of box with computer controlled humid atmosphere. It is relatively a new production system used especially for research purposes.

Raising Healthy Nursery

Healthy nursery raising is very important for successful growing of crops under protected cultivation since it sets foundation for harvesting full potential of greenhouse technology by providing strong and disease free planting material for commercial plantings and ultimately contributes to the higher earnings at the growers' level. Popular plant protection structures used in growing of healthy planting materials are:

1. **Plastic low tunnels:** These structures are commonly used in the hilly and cold desert regions of the country for growing nurseries of crops during winter months so that the crops can be transplanted immediately after fields are free from snow resulting in considerable saving of growing periods. During the bright sunny days, the plastic cover is removed and again spread over during night.
2. **Insect cages:** These are also popular among the growers as the insect cage restricts the entry of insects which generally lay eggs on the young seedlings and also provide some shade especially in summers. The insect proof nets of 60 meshes are considered excellent for this purpose.
3. **Glass house or Mist Chambers:** Such structures are being used by the commercial nursery growers in the form of big plant production factories throughout the world to provide the quality planting material to mass propagate the genetically modified crops. These also provide an additional advantage of total/ partial environment control and many layers of plants/ young seedlings area accommodated to utilize full canopy area.

Common vegetables and their varieties for Greenhouse Cultivation

Tomato: Greenhouse tomato cultivars/ hybrids are of indeterminate growth habit. As a result plants may reach a length of 30 to 40 feet in 10 to 11 months duration of cultivation. Tomatoes grown in greenhouses are generally put nto the following categories:

- **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.

Sweet Pepper: The important varieties available in our country for greenhouse cultivation are: Bharat, Mahabharat (both red), Golden Summer, Tanvi (both yellow), California Wonder etc.

Cucumber: The cucumber varieties grown in greenhouses are usually European types. These are gynoecious and set fruits parthenocarpically. The important parthenocarpic varieties available in India are Satis, Alamir, Kian etc. some monoecious varieties are also available in India which can be grown in greenhouses only through pollination management. These are Japanese Long Green, Pusa Sanyog, Priya etc.

Other Vegetables

- Bottle gourd
- Bitter gourd
- Melons
- Leafy vegetables etc.

Growth, yield attributing characters and yield of different tomato cultivars in polyhouse

Cultivars	Plant height (cm)	No. of Branches	Flowers/ inflorescence	Fruit set (%)	Retention of matured fruits (%)	Marketable Yield/ plant(kg)	yield/ 100 m^2(q)
NS-7531	91 .53	7.93	7.24	68. 66	89.59	0.84	3.10
NS,1945	89.07	8.53	6.60	71 .52	86.16	0.77	2.84
NS-2145	92. 80	9.20	7.27	77 .77	89.78	0.88	3.26
DRD-8014	125. 47	10.53	7.78	70 .02	86.87	0.98	3.63
Karna	91. 73	9.27	6.93	64. 09	87.18	0.72	2.66
Hyb SC 3	97. 90	8.00	7.52	72 .68	87 80	1.09	4.02
Hyb-621	115 .40	9.33	7.20	68 .95	85 41	0.99	3.65
NTH-2004	120.00	10.33	6.80	7 4.51	89.24	1.15	4.27
Yash	152. 40	14.07	8.00	83. 96	90.29	1.76	6.52
CTH-230	143. 53	7.53	7.20	69 .95	84.54	0.57	2.11
Pusa Ruby	135 .07	9.20	6.60	74. 25	89.64	1.01	3.73
Pusa Hybrid1-	109. 80	8.80	7.53	78. 09	87.23	1.08	4.00
Avinash-2	101 .67	6.47	7.38	76 .11	83.83	1.16	430
VC4B-1	109. 13	6.53	6.87	74.89	89.20	1.21	4.48
Bilahi-2	105.93	9.00	6.53	75.79	87.78	1.00	3.71
Arka Shreshta	111.27	7.80	6.30	70.78	85.87	0.89	3.31
Arka Abhilit	116.27	7.87	5.87	77 .17	82.25	0.87	3.21
Arka Vlkas	109.73	9.33	5.55	77.83	87.84	1.00	3.69
Arka Saurabh	104.73	10.07	6.33	72.80	87.92	1.16	4.31
Arka Abhijit	103.67	11.53	6.60	80.54	92.89	1.31	4.85
Arka Ashish	78.47	12.67	7.27	77.87	87.31	1.29	4.77
Arka Alok	99.80	10.80	6.60	73.37	89.53	1.05	3.88

Hazarika and Phookan, 2005

Tomato genotypes identified under protected cultivation and some advantages

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

Advantages of Protected Cultivation

- Early nursery raising, easy management, protection from biotic and abiotic stresses and production of healthy vegetable seedlings.
- Vegetable crops can be grown under adverse weather conditions round the year and in the off-season.
- Vegetables with higher productivity and uniform quality than open field cultivation are produced and can be exported to WTO markets for higher returns.
- Management of insect-pests, diseases and weeds is easier.
- There is efficient and less use of resources especially land, labour, irrigation water, fertilizers, and insecticides

and fungicides.
- It is suitable for farmers having small land holdings.
- Organic farming of vegetables is easier in greenhouses and these structures are ideally suited for production of genetically engineered and micro-propagated vegetable varieties and hybrids.

Constraints in Greenhouse Vegetable Cultivation
- The basic cost of construction and operational cost of the climate controlled greenhouse is very high.
- Uninterrupted and regular power supply is required for operating cooling and heating system of the greenhouse.
- Cladding material of required quality is not readily available.
- Non-availability of tools and implements for facilitating crop-production operations under greenhouse.
- There is a lack of specific research programme on greenhouse vegetable production in the country.
- 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 Strategies
- Standardizing proper design of construction of polyhouses including cost effective cladding and glazing material.
- Developing cost effective agro-techniques for growing different vegetables and lowering energy costs of the greenhouse environment management.
- Developing professional and skilled polyhouse manufacturers.
- Awareness among farmers pertaining to the potential of protected vegetable production should be created.
- Major research activities on growing of vegetables under protection should be launched by ICAR and SAU's.

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