Chapter 11
Protected Cultivation of High-Value Vegetable Crops Under Changing Climate

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Abstract Vegetables provide all the nutrients ingredients *viz.*, vitamins, minerals, protein and nutraceutical properties that are essential for balanced diet, which makes vegetables protective food. In order to enhance the quality production and productivity per unit area of vegetable crops, protected cultivation technologies may be opted. Protected cultivation is a cropping technique wherein microclimate surrounding the plants modified partially or fully to suite them for better production. It offers several advantages to produce vegetables of high quality and yields, thus using the land and other resources more efficiently. There are various protected structures/methods *viz.*, plastic mulching, plastic low tunnel, walk-in-tunnel, high roof tunnel with or without ventilation, insect proof nethouse, shade nethouse, naturally ventilated polyhouse, hi-tech or climate controlled greenhouse, retractable top greenhouse, rain shelters, etc. for large scale vegetable production. In hi-tech or climate controlled greenhouse, most of the parameters *viz.*, temperature, light, humidity, fertilizer, irrigation is sensed and corrected as per programme through auto control systems. Soilless cultivation technology is system of plants growing in which solid rooting growing media are used instead of soil. The solid materials of soilless growing media in alone or mixtures may provide superior environment for plants in comparison to agricultural soil. Hydroponics and aeroponics technologies are also the predominant growing systems used under protected structures. These technologies offer numerous advantages such as saves water, increases crop production, environment friendly, food can be grown round the year, and provides jobs for residents. Parthenocarpic cucumber, tomato, capsicums (coloured), and lettuce are well known for protected cultivation.

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11.1 Introduction

India is the second largest producer of vegetables after China in the world with a production of 184.40 million tonnes from 10.26 million hectares area (DAC&FW 2018). Vegetables provide all the nutrients ingredients *viz.*, vitamins, minerals, protein and nutraceutical properties that are essential for balanced diet, which makes vegetables protective food. According to the study of the Indian Council of Medical Research (ICMR), New Delhi and the National Institute of Nutrition (NIN), Hyderabad, changing food habit, limited availability of vegetables and high prices of pulses are considered responsible for malnutrition in India. Generally, vegetables are eating for nutrition, health maintenance and prevention of diseases**.** In developing countries vegetables are the main source of livelihood for most of communities because vegetables are loaded with several vitamins, carbohydrate, salts and proteins (Solankey et al., 2021). To ensure good health it is recommended that a person should consume at least 300 g of vegetable as a part of balanced diet, comprising 125 g leafy vegetables, 75 g other vegetables and 100 g root vegetables every day. The per capita land resources are shrinking due to the tremendous pressure of the population growth; therefore, it is very imperative to ensure the higher production and productivity per unit area. Vegetable crops are more productive than other crops, which have potential of providing more food per unit time and land area (Tomar et al. 2019). Thus, in order to enhance the quality production and productivity per unit area of vegetable crops, protected cultivation technologies may be opted. Protected cultivation offers several advantages to produce vegetables of high quality (Fig. 11.1) and yields, thus using the land and other resources more efficiently. Protected cultivation is more sustainable as the effect of climate is minimized (Pachiyappan et al. 2022). Protected cultivation of high-value crops offers higher productivity which in turn increases the profitability of the farm (Prakash et al. 2022). Therefore, growers would also be interested in this technology. However,

Fig. 11.1 Cherry tomato: A quality produce of protected cultivation

protected cultivation of vegetables has need of comparatively good management practices (Kashyap et al. 2019). In addition to nutritional security, vegetables production enhances the economy because it is an excellent source of income and employment as well. The share of vegetables is maximum (59–61%) in horticulture crop productions over the last five years in India (DAC&FW 2018).

11.1.1 Protected Cultivation

It is a cropping technique wherein microclimate surrounding the plants modified partially or fully to suite them for better production. In this technology land and water requirement is minimized for plants to yield better. Protected cultivation technologies cover climate control or hi-tech greenhouses, use of sensors, naturally-ventilated green/ polyhouses, hydroponics, aeroponics, plasticulture, drip irrigation, fertigation, mulching, integrated greenhouse pest and nutrient management, low cost protected structures like insect-proof and shade nethouses, soilless cultivation and vertical farms with good agricultural practices (Singh 2018; Singh 2019). It is system of controlled environmental agriculture in which all characteristics of the real environment are altered for highest economic return (Kashyap et al. 2019).

11.1.2 Scenario of Protected Cultivation in India and World

In India, protected cultivation is become popular because of its potentiality and profitability. This hi-tech protected farming of vegetables and high-value horticultural crops came through the Indo-Israel project, initiated at Indian Agricultural Research Institute (IARI), New Delhi in 1998. By the end of the twentieth century area under the protected cultivation was about 110 ha in India and the world over 275,000 hectares. Presently, total space coated under protected cultivation in India is approx. 30,000 ha (Pattnaik and Mohanty 2021). In the last decade, India has greatly accepted this new technique, and today this farming method done by almost every Indian state.

Greenhouse crop production is currently a growing reality throughout the planet with associate calculable 405,000 hectares of greenhouses contact all the continents (Pattnaik and Mohanty 2021). China is the largest users of greenhouses. The development of greenhouse technology in China has been faster than in any other country in the world. In China, alongside an unpretentious inception in late seventies, the area under greenhouses was expanded extensively (Kacira 2011).

11.1.3 Need to Go for Protected Cultivation

There is currently a high demand from consumers for a year-round supply of quality vegetables. The challenge of supplying high quality vegetables all year round can be met by adopting one of two basic strategies such as (i) growing in high-tech greenhouses, avoiding strong dependence on the outdoor climate or (ii) growing in two or more locations with complementary harvesting periods, enabling a regular and synchronized year-round supply to markets (Castilla and Hernandez, 2007).

The United Nations (UN) population branch has estimated that the world population could reach 9.15 billion by 2050, thus the expected rate of increase in world population will be 2.25 percent over the next forty years. 80 million peoples are added to the planet's population per annum. Food security has become a major concern at present and agriculture sector is going down because of climate changes along with food borne diseases are increasing, water distribution to agriculture farming is becoming scares in many areas. To feed countless mouth we will need to generate enough food with the restricted land, water and nutrient sources and this is accomplished through protected cultivation (Jat et al. 2019).

11.2 Major Advantages of Protected Cultivation System

According to Singh 2018 and Singh 2019, the Major advantages of Protected cultivation system are as follows:

1. Larger increase in productivity, quality and income.
2. The productivity of water is high.
3. Remarkable reduction in pesticide use.
4. Higher price because of off-season production.
5. Affordable economical greenhouses/polyhouse/poly tunnel/nethouses are fabricated locally, by small-scale entrepreneurs, which generate employment.
6. Expensive greenhouse cultivation methods such as hydroponics, vertical farming, aeroponics and hi-tech plant nursery production are pre-urban and unban farming of tomorrow.
7. It balanced light, temperature and humidity inside the structure.
8. Production cycle is longer.
9. Suitable for off-season and high value crops.
10. Generates employment.

11.3 Components of the Protected Cultivation System

Singh 2019 has proposed two main constituents in protected cultivation technology.

11.3.1 Agriculture Engineering

It deals with structures and engineering inputs.

11.3.2 Crop Production Technology

It involves development of hybrids and high-yielding varieties suitable for protected cultivation, their package of practices to manage pests, harvest preferably following good agriculture practices.

11.4 Protected Structures for Vegetable Cultivation

There are various protected structures/methods *viz.*, plastic mulching, plastic low tunnel, walk-in-tunnel, high roof tunnel with or without ventilation, insect proof nethouse, shade nethouse, naturally ventilated polyhouse, hi-tech or climate controlled greenhouse, retractable top greenhouse, rain shelters, etc. for large scale vegetable production. A brief discussion of some of these is mentioned below:

11.4.1 Plastic Mulching

The plastic sheet/film of 10–15 micron thickness is used as mulching which reduces the evaporation and acts as a barrier for emergence of weeds (Fig. 11.2). It is convenient for large-scale cultivation of vegetables (Singh and Choudhary 2019). There are different colours plastic films used as mulches such as silver-black, black, yellow, red, etc. It enhances uptake of micronutrients, sustain soil moisture and increases quality (Singh 2018; Singh 2019).

Fig. 11.2 Plastic mulching

11.4.2 Plastic Low Tunnel

Plastic low tunnel is miniature structure and facilitates entrapment of carbon di oxide thereby enhancing the photosynthetic activity. It safeguards plants from severe climatic conditions such as rain, wind, hail, snow, etc. It is mainly used for raising nursery for early germination of seeds and production of healthy saplings. Plastic low tunnels are also helpful in round the year cultivation of certain crops. This low cost technology is helpful in raising early cucurbits in north India by protecting them from low temperature and frost and has expended in a remarkable way in India and abroad (Fig. 11.3). The cost of low tunnels is affordable by most of the farmers. Non-woven fabrics in place of low tunnel cladding-plastic are gradually becoming popular (Singh 2018; Singh 2019). Presently, the area under plastic low tunnel technology is estimated to be around 30–40 thousand hectares (Singh and Choudhary 2019).

11.4.3 Walk–In-Tunnel

This is a low-price and temporary structure assembled on half-inch GI pipes covered with transparent plastic (UV grade film) with 200 micron thickness. Generally, tunnel height is 2 or 3 meters with around 4 meters width. It is suitable for raising plant nursery and off-season cultivation of vegetables particularly cucurbitaceous crops (Fig. 11.4). However, it is also suitable for production of tomato, brinjal, capsicum, leafy vegetables and early production of certain vegetables. It should be prepared to hold out against wind up to 120 km/h and trellising burden up to 25 kg/m^2 (Singh 2018; Singh 2019; Singh and Choudhary 2019).

Fig. 11.3 Plastic low tunnels

Fig. 11.4 Cucurbitaceous crop under walk-in-tunnel

Fig. 11.5 Insect proof nethouse

11.4.4 Insect Proof Nethouse

It is a closed crop production system and structure covered with insect proof nylon net (UV stabilized) of 40 mesh (Fig. 11.5). UV stabilized insect nets have a longer life. Such type of structure is preferred for several vegetables like seedless cucumber, tomato, capsicum, brinjal, etc. Double layer nethouses are also available which lowers the temperature in summer months (Singh 2018; Singh 2019). The availability of the nets is in distinct strength of holes (25 to 60 mesh). It is also acceptable for hybrid seed production of high value vegetable crops (Jat et al. 2015; Jat et al. 2016).

11.4.5 Shade Nethouse

This structure is covered with shade net of different shading intensity (20–75%) and used to grow the crops which are affected adversely by high temperature and high radiation (Singh and Choudhary 2019). This technology is very useful in improvement of healthy grafts/seedlings as well as hardening for seedlings/saplings (Fig. 11.6). Shade nethouses are made keeping in view the requirements of kind of crop to be raised generally with 6–8 feet height (Singh 2018; Singh 2019). Leafy

Fig. 11.6 Shade nethouses

Fig. 11.7 Naturally ventilated polyhouses

vegetables are mainly recommended to be grown under shade nethouses (Sirohi 2003). In arid and semi-arid regions, this technology is advised for cultivation of different vegetable crops on large scale during severe summer months (Singh and Choudhary 2019).

11.4.6 Naturally Ventilated Green/Polyhouse

There are two types of naturally ventilated green/polyhouses *viz.*, single and multi-span. Both structures are erected on GI pipes covered with UV stabilized transparent plastic/film (Fig. 11.7) and are found suitable for round the year production of crops depending on the geographical area. Single span is made with central height of 5 meters, side ventilation of 3 meters along with roll-able poly-cover with or without roof ventilation and double door entry. Generally, multi-span naturally ventilated polyhouse with a central height of 6.5 meters, gutter height of 4.25 meters and side ventilation of 1.5 meters is considered more suitable and economical for raising vegetable crops. Naturally ventilated polyhouses have been found suitable for cultivation of large number of vegetables besides raising their nurseries (Singh 2018; Singh 2019). It should be equipped with foggers for reduce the temperature during peak summer months. These structures are also fit for seed production (hybrid) with seed productivity of two-three times more in comparison to open field condition (Singh and Tomar 2015).

11.4.7 Polyhouse with Pad and Fan System

This polyhouse unlike naturally ventilated polyhouse has exhaust fan and cellulose cooling pad system to regulate temperature and humidity (Fig. 11.8). They have generally 4.5 meters height with common side and top ventilation. The pads of 150 mm thickness are allied at the height of 1.8 m in the structures. The establishment, operation and maintenance charges are high. This house is required to be equipped with overhead sprinklers for cooling in peak summer (Singh 2018; Singh 2019). It is suitable for raising vegetable seedlings and off-season cultivation of vegetable crops.

11.4.8 Hi-Tech or Climate Controlled Greenhouse

Hi-tech greenhouse is a climate controlled structure and have a variety of applications such as off-season growing of vegetables, foliage and flower plants, planting material multiplication and acclimatization, plant breeding and new varieties and hybrids development. This is available in different sizes ranging from as small as 100m^2 to 10,000m^2 and more and constructed as per requirement. In this house, most of the parameters *viz.*, temperature, light, humidity, fertilizer, irrigation is sensed and corrected as per programme through auto control systems. The climatic requirements of vegetable crops under protected cultivation have been presented in Table 11.1. Hi-tech greenhouse can be fully or partially automated and mechanized. This is considered, based on experience, very good and essential structure for nursery multiplication of vegetable crops in plugs with soilless medium (Singh 2018;

Fig. 11.8 Polyhouse with pad and fan system

Table 11.1 Climatic necessity of different crops under protected cultivation

Crop	Temperature (°C)		Humidity (%)	Light intensity (lux)
	Day	Night		
Solanum lycopersicum L.	22 to 27	15 to 19	50 to 65	50,000 to 60,000
Cucumis sativus L.	24 to 27	18 to 19	60 to 65	50,000 to 60,000
Capsicum annuum L.	21 to 24	18 to 20	50 to 65	50,000 to 60,000
Seedling (nursery)	22 to 27	16 to 19	50 to 65	50,000 to 60,000

Singh 2019). Hybrid seed of different vegetable crops may be produced under semi-climate controlled greenhouses with three-four times more productivity in comparison to open filed conditions (Jat et al. 2017).

Solar radiation, air temperature and air relative humidity are important alterable of the greenhouse climate that can be controlled (Kittas et al. 2013). The quality of greenhouse produce enhance with the help of improved controlled climate (Castilla and Montero 2008).

Modified from Singh et al. (2015).

11.4.9 Retractable Roof Greenhouse

This structure protects leaf and root of the plants from extreme environmental conditions *i.e.* imprudent or deficient heat, cold, wind, rain, and disorders related to inadequate transpiration. The arrangement of roof, walls and curtain systems with automation in structure of the retractable roof greenhouse can create an outdoor greenhouse and modified greenhouse conditions for the plants (Singh 2018; Singh 2019).

11.4.10 Rain Shelter

This structure is also known as a low cost naturally ventilated polyhouse. It is found ideal for off-season vegetable cultivation in high rainfall areas (Fig. 11.9). Off-season cultivation of vegetables by utilizing low cost protected structures like rain shelter can be considered as a profitable enterprise besides protecting crop nurseries from high rain during monsoon months. Such structures are boon for vegetable production in rainy season (Singh 2018; Singh 2019).

Fig. 11.9 Rain shelters

11.5 Classification of Green/Polyhouse Based on Cost

Based on cost, the different types of green/ polyhouse are as follows (Singh et al., 2015):

11.5.1 Low-Cost Green/Polyhouse

This structure is made with bamboos, ropes and nails and covered with 200-micron (800 gauge) transparent polythene sheet. The temperature within structure increases by 6–10^0 C more than outer. The polythene sheet is reduced 30–40% solar radiation. Generally, this structure is used for safeguard the crop from heavy rainfall.

11.5.2 Medium Cost Green/Polyhouse

The structure is built up with 15 mm diameter of GI pipes and covered with UV-stabilized polythene (200-micron thickness) in single layer. Naturally ventilated with exhaust fans and naturally ventilated with fan-pad system are examples of this type of green/polyhouse. The fan-pad system lowers the temperature in polyhouse.

11.5.3 High-Cost Green/ Polyhouse

This structure is constructed with GI pipes having cone or dome shaped design. Light, humidity and temperature are controlled automatically with the help of sensors as per requirement of the crop. The cost of structure is approximately five to six times more. It desires genuine maintenance, appropriate care and trained operator.

Generally, depending on the covering material (glass or flexible plastic) of greenhouse structure, different terminologies are being used. A greenhouse with glass as the covering material is called as greenhouse whereas polyethylene as the covering material is known as polyhouse (Sirohi 2003).

11.6 Protected Cultivation Technologies

11.6.1 Low Tunnel Technology

Growing off-season crops in controlled atmosphere inside polythene tunnels is known as tunnel technology. During the period of December to February, it is not feasible to cultivate summer vegetables in open field conditions because of high frost and low temperature. However, inside polythene tunnels these vegetables can grow with their maximum growth and yield by providing genuine atmosphere to the plants (Tomar et al. 2019). Low tunnel technology is most acceptable as well as beneficial in northern plains of India (Singh and Solanki 2015).

11.6.1.1 Off-Season Cucurbits Production with Low Tunnel Technology

Low tunnels or row covers are pliable transparent plastic (23–30 micron) and creates microenvironment under the tunnel. Low tunnels effectively increase air and soil temperature thus enhancing the vegetative growth, improve water and nutrient use efficiency and increases yield. The cucurbits can be advanced by 30-40 days in comparison to the normal sowing time. Therefore, this technology can improve productivity and land use efficiency. This technology is most acceptable for off-season cultivation of cucurbits (Tomar et al. 2019).

11.6.1.2 Seedlings Raising of Cucurbits Under Low Tunnels for Off-Season

During the month of December or January, the cucurbits seedlings are raised in plastic pro-trays of 1.5″ cell size in soilless media with low tunnel technology. In northern parts of the India, at four leaves stage (28–32 days old) seedlings are transplanted under low tunnel in the open field when the night temperature is very low (from mid-January to mid-February). Even though, for complete off-season production the summer squash may transplant in December month and crop will ready to harvest in the first week of February. This crop will realize exceptionally good price in the market (Tomar et al. 2019).

11.6.1.3 Seedling Transplanting of Cucurbits Under Low Tunnel

The flexible galvanized iron hoops with a height of 40-60 cm are fixed on beds at a distance of 1.5–2.5 m before seedling transplanting. The distance between two ends of hoop is maintained 40-60 cm. Thereafter, the seedlings of cucurbits are transplanted at a spacing of 1.5–1.6 × 0.50 m in single row on each bed and cover the rows or beds with transparent plastic (30 micron) in the afternoon. Low tunnels keep higher temperature inside the structure than outside field. During peak day time of growing season when temperature increases inside the tunnels, 3–4 cm size vents are made in plastic at a distance of 2.5–3.0 m on eastern side just below the top. Further, the size of vents may enlarge with the increase in the temperature. Finally, in the month of February and March entirely plastic will take out from the plants depending on crop growth and current night temperature (Tomar et al. 2019).

11.6.1.4 Seedlings Raising of Tomato, Chilli and Brinjal under Low Tunnel

In Northern India nursery of tomato, chilli and brinjal is raised under low tunnel in the month of December-January for early transplanting of the seedlings. The seeds are sown in the nursery bed and nursery bed is covered with fabricated tunnel (size: 3.0 m long and 1.5 m wide along with 1.0 m central height). The semi-circular structure is clad with UV polythene sheet (20 Micron) with 75% transmittance. Low tunnel is also used for raising seedlings of cole crops during rainy season with side ventilation.

11.6.1.5 Fertigation in Low Tunnels

The water may be applied @ 4.0 m^3/1000 m^2 at six-seven days interval during the period of first month with fertilizer solution of N:P:K (5:3:5) @ 50-100 ppm per cubic meter of water. Thereafter, water @ 4.0 m^3 along with fertilizer solution @ 120-150 ppm/m^3 of water may apply at 4 days interval in second month to until beginning of flowering. The quantity of fertigation is expanded up to 300 ppm at the peak of fruiting period (Tomar et al. 2019)

11.6.1.6 Pollination under Low Tunnels

Majority of the cucurbits being monoecious need pollination. The main pollinating agent is honeybees (*Apis melifera*). At the time of complete flowering, one beehive/acre area is required for effective pollination and bees will work in tunnels easily through the vents. For effective working of bees, the beehive box should keep on the north-west side of the field.

11.6.1.7 Harvesting and Crop Advancement under Low Tunnel

In northern plains of the India, low technology is fully cost effective for growing off-season vegetable crops in peri-urban areas. Different cucurbit crops may advance 30–60 days by transplanting them from December (first week) to February (first week) over their usual season of cultivation (Table 11.2).

Table 11.2 Crop advancement and transplanting time in cucurbits under low tunnel

S. No.	Name of the crop	Time of transplanting	Time of harvesting	Crop advancement (days)	Anticipated yield (q/ha)	Expected cost benefit ratio
1.	Cucumber	January (IIIrd week) – February (Ist week)	March (Ist week)	25–30	125–150	1:2.0–1:2.5
2.	Muskmelon	January (IIIrd week) – February (Ist week)	April (IInd week) – April (last week)	30–40	200–250	1:2.5–1:3.0
3.	Summer squash	December (Ist week)	February (Ist week)	40–60	400–500	1:3.0–1:3.5
4.	Bottle gourd	January (IIIrd week) – February (Ist week)	April (IInd week) – April (last week)	30–40	250–300	1:2.0–1:2.5
5.	Bitter gourd	January (IIIrd week) – February (Ist week)	April (IInd week) – April (last week)	25–30	100–150	1:2.0–1:2.5
6.	Water melon	January (IIIrd week) – February (Ist week)	April (IInd week) – April (last week)	25–30	200–250	1:2.0–1:2.5

Modified from Tomar et al. (2019)

11.6.2 Hydroponics Technology

Hydroponics is the predominant growing system used under protected structures. In this system, soil is replaced with growing medium like cocopeat, perlite, rockwool, gravel etc. Here, the plant roots are submerged in the solution of nutrients (Fig. 11.10). This technology can reduce the various soil associated issues *viz.*, bacteria, fungus, and insects which develop in soil. It requires relatively low maintenance. It is a cleaner process, which excludes use of animal excreta and provides an easier way to control nutrient levels and pH balance. In this technology, the best combination of nutrients is applied hence, yielded more with consistent produce. With the NFT system, a thin film of nutrient solution flows through plastic channels, which contain the plant roots with no solid planting media (Singh 2018; Singh 2019).

11.6.3 Aeroponics Technology

National Aeronautical and Space Administration (NASA) coined the term aeroponics in the 1990's. The aeroponics may be defined as growing plants in an air or mist environment with no soil and very little water. In aeroponics system, the plant boxes are stacked in such a manner that the bottom and top of the plants are hanged in air allowing the crown to grow upward and the roots down ward freely. The plants are fed through a fine mist containing nutrient rich and water mix solution with the help of sensors, which can be fully recycled as the system is an enclosed one. High density planting can be carried out in aeroponics making harvesting easier and providing higher yield (Jat et al. 2019). It is commonly used for growing leafy vegetables particularly lettuce and herbs in vertical system of farming. For plant factories, this is an appropriate technology.

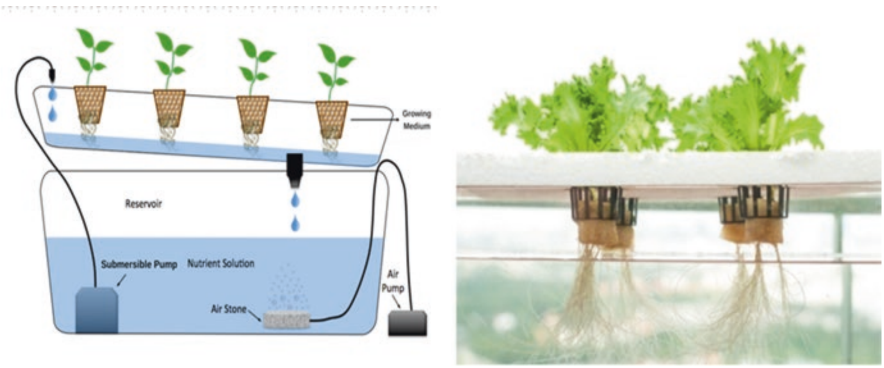

Fig. 11.10 Hydroponics technology

Advantages of Hydroponics and Aeroponics Technology

These technologies are important for protected cultivation in following ways (Jat et al. 2019):

- Increase crop production
- Continuous crop production
- Crops are grown indoors therefore, no crop failures due weather related problems.
- Organic crop production is feasible
- Conservation and recycling of natural resources
- Hydroponic system uses 70% less water
- Mechanical equipment is not required hence, reduces the use of fossil fuel
- Environment friendly
- Sustainable ecology as the urban sewage is purified, solar panels and wind turbines as a source of energy making the system entirely sustainable
- Food can be grown round the year
- Provide jobs for residents

11.6.4 Microgreens: A Smart Food

Microgreens are young edible seedlings of vegetables, herbs and plants rich in flavour and nutrition. Microgreens are the infant version of plants (Fig. 11.11). They are more healthier (4–40 times) than their full-grown stages. Usually, they are harvested at a height of 2.5–7.6 cm (within 14 days of the seed germination) and consumed because of the highest amount of anti-oxidants as well as nutritional benefits at this stages (Table 11.3). They are grown under protected structures (Singh 2018; Singh 2019).

Seedling colour, flavour, texture and market demand are base for selection of the crop for microgreens. However, the most potential microgreens are found in vegetable crops belonging to the family amaranthaceae, chenopodiaceae, cruciferae and apiaceae. The crop for microgreens should have high nutritive values with very fast

Fig. 11.11 Vegetable microgreens

Table 11.3 Antioxidant potential of microgreens

S. No.	Microgreen	Days to harvesting	Antioxidant activity (μmol TE/g)
1.	Bottle gourd	11	8.35
2.	Cucumber	9	4.65
3.	Pumpkin	10	8.92
4.	Amaranthus red	9	4.60
5.	Amaranthus green	19	2.15
6.	Amaranthus Katwa	12	4.58
7.	Basella	12	3.90
8.	Water spinach	9	20.23
9.	Radish	9	17.77
10.	Palak	11	6.71
11.	Carrot	15	26.81
12.	Fennel	14	16.88

Fig. 11.12 Plug tray seedlings raising under protected conditions

germination and easy to grow as well. Generally, sterilized soilless media (coco peat, vermiculite and perlite in a ratio of 2:1:1) is recommended for best growth of microgreens. Around 6–8 seeds and 10–12 seeds per square inch are sown for larger and smaller seed, respectively. Microgreens are extremely perishable due to their more respiration rate. Hence, its shelf life is very short *i.e.,* 3–5 days at ambient temperature (Anonymous 2016).

Modified from Anonymous (2016).

11.6.5 Plug Tray Seedlings Raising Technology

Under this technology seedlings are raised in plastic multicell plug tray in artificial soilless media in principally designed protected structure (Fig. 11.12). By this technology, the healthy and off-season seedlings can produce and it will help in generate the additional employment in horticulture sector. This is the major and first key step for increasing yield, quality and profitability in vegetable crops through protected cultivation technology. A nursery greenhouse area of 1000 m^2 is able to develop about 15–20 lakhs of vegetable seedlings and can generate the net return of Rs. 2.5–3.0 lakhs. Therefore, it is capable to create employment for 4–5 youths throughout the year (Singh et al. 2005; Singh and Solanki 2015).

11.6.6 Soilless Cultivation Technology

It is systems of plants growing in which solid rooting growing media are used instead of soil. The solid materials of soilless growing media in alone or mixtures may provide superior environment for plants in comparison to agricultural soil. Therefore, these growing media may helpful in healthy vegetable production with higher yield (Gruda et al. 2013). Usually, the containers and sometimes prepared cubes, bags, slabs, mats, troughs, etc. are used for soilless cultivation (Fig. 11.13). The containers are filling up with required sterile mix and put down under controlled environment (Sehrawat and Malik 2015).

Soilless culture offers numerous advantages such as virtual absence of nematodes and pathogens, gives fine aeration and drainage, economizes the fertilizer use due to nutrient control, adequate oxygen exchange, anchorage or support to plant, light weight and standardization in comparison to natural soil culture and land-less growers are also able to grow vegetables. The plant growing media in soil-less cultivation technology are cocopeat, rockwool, vermiculite, perlite, bark chips, sawdust, sand, gravel, pumice, polyurethane mats, sand, rice hulls, bagasse, water, air, etc. It has become a desirable practice in to have vegetable and other crop nurseries in plug trays multiplied in soilless medium under protected conditions. Production of vegetables like leafy vegetables mainly lettuce, tomato, capsicum, cucumber is becoming popular to grow with soilless cultivation technology (Singh 2018; Singh 2019).

11.7 Vegetable Crops and their Varieties/Hybrids

In protected cultivation, the selection of varieties may remarkably affect the economic return (La Malfa and Leonardi 2001). The varieties for protected cultivation are vary from open-field vegetable productions. Parthenocarpic cucumber, tomato, capsicums (coloured), and lettuce are well known for protected cultivation (Table 11.4).

The details of major varieties/ hybrids of the high value vegetable crops suitable for protected cultivation and developed by public and private sectors are described below:

Fig. 11.13 Crops in soilless growing media

Table 11.4 Vegetables varieties suitable for protected cultivation

Sl. No.	Crops	Variety/ hybrids
1.	Tomato	ID-32, ID-37, Rakshita, Himsona, Himsikhar, Snehlata, Naveen, GS-600
2.	Coloured capsicum	Natasha, Swarna, Indra, Bombi, Orobelle, bachata, inspiration
3.	Parthenocarpic cucumber	Isatis, Kian, Hilton, sun star, multistar, Fadia, mini angel
4.	Summer squash	Pusa Alankar, Pusa Pasand, Australian green, Seoul green, Kora, yellow zucchini, Himanshu
5.	Bitter gourd	Pusa Rasdar
6.	Musk melon	Pusa Sarda

Adapted from Solankey et al. (2021)

*11.7.1 Tomato (*Solanum lycopersicum L.*)*

The major varieties/hybrids are as under:

1. Pant Polyhouse Tomato-2: Average fruit weight 100-105 g, pericarp thickness 0.9-1.0cm (better storage quality) and 5-6 fruits per cluster.
2. Pant Polyhouse Hybrid Tomato-1: Large fruit weight (130-140 g), pericarp thickness 1.0-1.25cm (better storage quality) and 7-8 fruits per cluster.
3. Arka Rakshak: This hybrid is resistant to triple disease (ToLCV+BW+EB) with the yield potential of 75-80 t/ha in 140 days. Fruits are medium (90-100 g) with superior storage quality (15-20 days).
4. Heemsohna: Fruit are medium in size (90–100 g) with outstanding serviceable life. Long duration, high productivity, and plants are tall vigorous with profuse branching.
5. Heemshikhar: Fruits are medium in size (80–90 g) and uniform with outstanding serviceable life. Long duration, high productivity, and plants are tall vigorous with profuse branching.
6. Pusa Hybrid-4: Fruits are medium sized (70–80 g), round, attractive, smooth with thick pericarp and uniform ripening. Plants are compact, determinate with dark green leaves and field resistance to root knot nematode. Average yield is 54.8 t/ha.
7. Pusa Hybrid-8: Fruits are medium (75–80 g), round with uniform ripening. Plants are compact, determinate and massive fruit bearer. Average yield is 43–45 t/ha.
8. Punjab Sartaj: Plants are indeterminate. Fruits are round, medium (average fruit weight 85 g) and firm. Average yield 90 t/acre under polyhouse (Dhaliwal et al. 2016).
9. Punjab Gaurav: Plants are indeterminate. Fruits are oval, medium (average fruit weight 90 g), very firm with pointed tip and excellent shelf life. Average yield 93.5 t/acre under polyhouse (Dhaliwal et al. 2016).

Some of the indigenous and multinational seed companies' varieties/hybrids are Rakshita, NS-4266 (Fig. 11.14), Snehlata, Avinash-2, GS-600, Shreshtha, Avtar, Indam Hybrid, All Rounder, Arka Samrat, Arka Meghali, Arka Surabhi, Tropic, Tolstoi, Dombello and Tuckcross-520 (Singh 2018; Singh 2019; Singh et al. 2015; Anonymous 2021).

11.7.2 Cherry Tomato (Solanum lycopersicum var. cerasiforme)

The major released and/or popular varieties are as under (Fig. 11.15):

1. Pusa Cherry Tomato 1: Fruits are deep red, uniform ripening, round with average fruit weight of 13 g. Average fruit weight is 22 kg/plant with yield potential of 4–5 tonnes/1000 m^2. Vine length is 9–12 m and crop duration is about 9–10 months (https://ztmbpd.iari.res.in/technologies/varietieshybrids/vegetables/cherry-tomato).
2. Punjab Red Cherry: Red fruited variety, fruit weight 8–14 g, plant having the capacity to yield 4–4.5 kg of fruit, tolerant to leaf curl virus, total soluble sugars (TSS) 8–9 per cent, 18–20 fruits per cluster and yields 110 t/ha.
3. Punjab Sona: Fruits are yellow with 7.5% TSS and 13 mg carotene/100 g fruits. Bears 20–25 fruits per cluster and yields 105 t/ha.

Fig. 11.14 Regular tomato under protected condition

Fig. 11.15 Cherry tomato under protected condition

4. Punjab Kesar: Fruits are orange with 7.6% TSS and 13 mg carotene/100 g fruits. Bears 1–23 fruits per cluster and yields 100 t/ha (Malik et al. 2017).
5. Nagmoti: Early maturing, vigorous plant with good foliage, fruits are small, round, shining deep red (ripe), firm and uniform in shape and very good flavour and sweetness.

Some of the other varieties/hybrids available in the market are BR-124 (Holland), Olle, Sairan, NS Cherry-1, Pant Cherry tomato, Pairesco, Rosa (Singh 2018), Roma and Super Sweet-100.

11.7.3 Capsicum (Capsicum annuum var. grossum L.)

The major released and/or popular varieties are as under (Fig. 11.16):

11.7.3.1 Yellow Fruited

1. Orobelle: Almost square fruits (10x9 cm) with a medium-thick wall, turning from green to yellow at maturity and average fruit weight are 150 g.
2. Yellow Wonder: Light green to golden-yellow fruit colour at maturity, upright plants that set continuously, plants are vigorous and high-yielding, ready to harvest in 62–73 days from transplanting and can be sown directly from seed in February when the night temperature is 20-300C.
3. Golden Summer: Sweet and mild flavour, fruits are lime green ripening to golden yellow and is 4-lobed, plant provides good foliage cover for the sweet bell peppers that are excellent stuffed or added to salads and pinch off early flowers to encourage plant growth.
4. Swarna: Blocky to long fruits with appealing dark green colour and thick and firm wall. Plants are vigorous and strong. Fruit weight is 200–250 g.

Fig. 11.16 Coloured and green capsicum under protected conditions

11.7.3.2 Red Fruited

1. NS 280: Fruits are firm, blocky (3–4 lobed) and good size (10x8 cm) with average fruit weight of 220–230 g. Plants are tall vigorous and strong with broad leaves.
2. Bomby: Fruit are glossy and dark green with average weight of 130–150 g. Plants are tall, strong, early branching with dense foliage and requires staking.
3. Tanvi: Plant medium tall and medium spreading, fruit weight is 150-180 g, turn yellow after maturity, high yielding and excellent keeping quality.

11.7.3.3 Green Fruited

1. California wonder: Open pollinated variety, large bell shaped fruits, ideal for gardens and large containers, relative days to maturity is 70, fruit weight is 180-200 g and fruit shape is blocky 3–4 lobed.
2. Indra: Fruits are glossy, thick-walled, dark green, 10–12 cm length, 10 cm girth and having 3–4 lobes with average weight of 170 g. Plants are bushy, medium tall and having vigorous growth with dark green leaves and dense foliage.

Pusa Deepti (green), Green Gold (green), Bharat (green), Mahabharat (green), Natasha (red), DARL-71 (yellow), Super Gold (yellow), NS-285 (yellow), Torkel (red) and Tarquino (green) are also some of the popular varieties/hybrids of the capsicum (Singh et al. 2015; Singh 2018).

11.7.4 Cucumber (Cucumis sativus *L.*)

Generally, parthenocarpic cucumber is preferred under protected conditions (Fig. 11.17). The following hybrids/varieties can be successfully grown under protected cultivation.

Fig. 11.17 Cucumber under protected condition

1. Pusa Seedless Cucumber- 6: It is parthenocarpic gynoecious cucumber and extra early (40–45 days for first fruit harvest). Fruits are uniform, glossy, dark green, appealing, cylindrical, straight and non-hairy with 14.24 cm average length, 3.45 cm average width and 105 g average weight. Average fruit productivity is 1260 q/ha (1260 kg/100 m^2) in the time of winter season.
2. Pant Parthenocarpic Cucumber- 2: Bears only female flowers (gynoecious) and fruits are ready to first harvest at 30 DAS. Average fruit weight is 400-450 g and plant produces seed less fruits.
3. Pant Parthenocarpic Cucumber- 3: Bears only female flowers (gynoecious) and fruits are ready to first harvest at 32 DAS. Single fruit weight is about 350-400 g and plant produces seed less fruits.
4. Hilton: Vigour and strong plant, uniform green lustrous fruits and high fruit setting ability with earliness and maturity days (first harvest after sowing) 38–40.
5. Isatis: Good plant vigour, good adaptability, fruit length 18–20 cm, good fruit setting, high yielding and crispy and bitter free with uniform fruits.
6. Kian: Cylindrical, glossy, medium green colour fruits, semi-multi fruited on main stem and bears 2–3 fruits per node.
7. Multistar: Fruit are about 16–18 cm length with dark green, uniform, cylindrical in shape and shiny. This is perfect for slicing and salads.
8. Deltastar: Vigorous growth, suitable for autumn, early spring and summer cultivation and fruit length is 16-18 cm with dark green colour and good flavour as well as storage life.
9. Hasan: Tender long attractive fruit with shiny whitish colour, ready to first picking in 40–45 days after sowing, average fruit length 22–25 cm, fruit weight 125-130 g, high yielder, excellent taste and keeping quality.
10. Sunstar: Small leaves and multi fruit bearing with relatively open plant type. Fruits are 17–19 cm long slightly ribbed along with dark green shiny and cylindrical in shape. Mostly used for slicing and salads.
11. Kingstar: Strong plant with less side shoots, 1–2 fruits per node, average fruit length 16–18 cm and suitable for late autumn and early winter.

Some of the popular parthenocarpic varieties from multinational seed companies are Kalunga, Bellissma, Millagon, Discover, Marianna, Fitness, Aramon, Fidelio, 90–0048, Futurea, E-1828, B-1157, Country Fair, Bush Crop, Space Master, Patio Pick, Bush Whopper, Bush Champion, Bush Pickler, Euro-American, Adrian, AI Rashid F1, Mustang, Brucona, Fanspot, and Toska-70 (Hochmuth 2012; Singh 2019; Anonymous 2021).

11.8 Crop Management and Operations

11.8.1 Nursery Raising

Seedlings of the vegetable crops are raised in multi-cell protray in soil-less growing media such as a mixture of vermicompost + sand + sterilized cocopeat (1:1:1) or cocopeat + vermiculite + perlite (2:1:1) under protected structure. The seeds are treated with carbendazim @ 2.5 g/kg seed before sowing and single seed is sown in each cell. After germination, the seedlings should be drenched with solution of copper oxy chloride (@ 3 g/litre of water). At the stage of 13–15 days old seedlings, the nutrition is applied through the drenching/foliar application of 0.2% solution of 19:19:19 (N:P:K) along with micronutrients. The seedlings can protect form insect infestation with spray of imidacloprid (0.03 ml/litre) or acephate (0.75 g/litre). The seedlings get ready for transplanting after 21–35 days of sowing (about 20-25 cm height) depending upon crop. The hardening of the seedlings is required for better establishment and it can be done by gradually reduction in frequency of irrigation and exposing them to sunlight. For better establishment and prevent from damping off in main field, the seedlings should be drenched with carbendazim (0.1%) or ridomil (0.1%) before planting.

11.8.2 Preparation and Solarization of Bed

About 15-20 cm raised beds are prepared with the width of 90-100 cm and leave the path of 50 cm in between beds. After bed preparation and application of organic manures *viz.*, vermicompost and FYM etc. it should be disinfected through fumigation with formalin 4% solution @ 4 litres per m^2 in the month of May–July. Thereafter, the beds should be covered with white and transparent polythene sheet of 100 micron (400 gauge) thickness. The doors and ventilators of the protected structure should also be closed. Polyethylene cover is removed after 15 days of formaldehyde treatment and the doors and ventilators are also opened. To remove the trapped formaldehyde fumes completely, the beds are hoed again and again. Temperature rises up to 60-70 °C during solarization process and it process kills harmful organisms, bacteria, fungal spores, nematodes and weeds.

11.8.3 Fertilizer Application and Fertigation

Before fumigation, organic manures *viz.*, vermicompost or FYM etc. are applied @ 10–15 kg/m^2 area of the growing bed depending on fertility status. The organic manure should be well decomposed and mixed thoroughly in beds. Inorganic fertilizer *i.e.* 19:19:19 (N:P:K) is added after fumigation @ 7 g/m2 in furrows close to the growing beds (Singh et al. 2015). Fertigation allows the adjustment of the amount and concentration of the applied nutrients according to the crop's needs throughout the growing season. External supply of nutrients has become important because of poor fertility status of the soil which is not able to meet the entire nutrient requirement of the crop (Rajiv and Tomar 2022).

The crop is fertigated with water soluble fertilizer (WSF) through drip fertigation as per dosage and schedule given in Table 11.5. The plants are also sprayed with mixture of micronutrient solution @ 0.3% starting from 60 DAT. Total two-three spray of micronutrients are to be given at an interval of 30 days in tomato. Whereas, in case of capsicum and cucumber, the micronutrient foliar spray can be started earlier. If required, the crop may be fertigated with calcium nitrate at 15 days interval in deficiency symptoms of calcium. The deficiency of micronutrients adversely affects the production as well as quality of vegetables (Singh et al. 2022).

Modified from Singh et al. (2015).

Table 11.5 Fertigation schedule for different crops under protected cultivation

Crop	Crop stage	NPK (water soluble)	Dose (g/500 m2)	Fertigation schedule
Tomato	Planting to first flowering	19:19:19	250	Twice a week, starting from 25 days after transplanting
	First flowering to fruit set	19:19:19	100	
		46:0:0	175	
		0:0:50	275	
	Fruit set to harvesting peak	19:19:19	100	
		46:0:0	250	
		0:0:50	275	
	Topping until crop end	19:19:19	50	
		46:0:0	125	
		0:0:50	150	
Capsicum	Planting till fruit setting	19:19:19	500	Twice a week
		0: 0: 50	25	
	Fruit set until first picking	19:19:19	500	
		46:0:0	100	
		0:0:50	250	
	Afterwards first picking and up to season end	19:19:19	4500	
		46:0:0	500	
		0:0:50	250	
Cucumber	0–14 days after transplanting	19:19:19	500	Twice a week
	14–35 days after transplanting	13:0:45	200	
		46:0:0	100	
	35 - till the end of crop	13:0:45	500	
		46:0:0	150	

11.8.4 Mulching

The growing beds are covered with silver/black polyethylene sheet of 400 gauge (100 micron) having 1.2 meter width before transplanting the plants. Edges of the sheet are buried with the help of soil. Thereafter, holes of 5 cm diameter are made on the mulching sheet using a mulching hole machine or sharp pipe at recommended spacing for the crop.

11.8.5 Spacing

The seedlings are transplanted in two rows per bed in zigzag/triangular manner. Usually, the spacing in tomato, capsicum and parthenocarpic cucumber is kept 60 x 45 cm, 45 x 30 cm and 60 x 60 cm, respectively.

11.8.6 Plant Canopy Architecture Management

The vapour concentration, temperature and radiation regime in the plant environment is significantly influenced by architecture of canopy. Interception and transmission of soil temperature and soil heat flow are also affected. It indirectly affects the plant physiological processes, transpiration, photosynthesis, cell enlargement, growth and multiplication of insects and photo-morphogenesis. The productivity and quality of produce is higher under greenhouse conditions, since near to optimum growing conditions are maintained as per the requirement of the crops unlike the open field conditions. The diffused light passing inside the greenhouse through transparent cladding materials tends the crop plants to grow upwards and utilize the vertical space inside the structure. The number of plants per unit area could be increased leading to get more productivity (Patil et al. 2019). Management of plant structure is significant activity during production of greenhouse crops. Desirable changes in plant structure can be achieved as details given below:

11.8.6.1 Capsicum

Pruning/pinching starts from 15–20 days after transplanting and it should be done at weekly intervals. Initially get 2–3 branches at 5–6 node. Remove weaker one again allow 2 stems per basal stem that is total 4 stems. Remove all flowers initially for one month and side shoots at weekly intervals. Plants training start 30 days after transplanting through a plastic twine or tressiling yarn. Each branch should have separate twine/yarn. Tie the twine/yarn to the GI wire provided at truss over the bed (Patil et al. 2019).

According to ICAR-Indian Institute of Vegetable Research (IIVR), Varanasi studies, the cv. Indra was able to produce most of 'A' grade fruits (3–4 lobes weighing 150 g and more) under two-stem canopy management practices in comparison to three-stem and unpruned plants systems (Table 11.6). Studies revealed that choice of training system in capsicum might depend upon market aimed (Anonymous 2019).

11.8.6.2 Tomato

Usually, pruning starts 20–30 DAT and it should be done at weekly intervals. In general, there are two systems (one-stem and two-stem) of management of canopy architecture in tomato (Fig. 11.18). In one-stem system, the sprouted side shoots are removed when they attain 5–10 cm length and a single main stem is leaved on each plant. Whereas, in case of two-stem management system, the side shoot is permitted to grow as a second stem just below the first floral truss and remaining side shoots on both stems are removed periodically. Studies conducted by ICAR-Indian Institute of vegetable Research (IIVR), Varanasi revealed that two-stem training system results in higher no. of clusters, no. of fruits per cluster and fruit yield/plant (Table 11.7) in cv. NS-4266 (Krishna et al. 2020). Similarly, the higher productivity was found in Heemsohna when the plants are maintained with two-stem system (Anonymous 2019). Remove the older leaves continuously (Fig. 11.19).

Table 11.6 Influence of canopy architecture management on fruit size in capsicum

Variety	Canopy architecture management		
	Two-stem	Three-stem	Unpruned (control)
Indra	200 g	110 g	70 g
Orobelle	110 g	90 g	60 g
Indus-1201	90 g	80 g	60 g

Modified from Anonymous (2019)

Fig. 11.18 Single stem *v/s* Double stem training system in tomato

Table 11.7 Effect of training system on tomato performance under polyhouse conditions

Training system	No. of clusters per plant	No. of fruits per cluster	Fruit weight (g)	Fruit yield (kg/plant)
One-stem	13.89	6.54	68.73	7.07
Two-stem	18.94	6.90	62.85	10.36
Unpruned (control)	11.83	5.56	55.61	5.26
CD 0.05	2.11	0.87	5.62	0.67

Source: Krishna et al. (2020)

Fig. 11.19 Deleafing in tomato

11.8.6.3 Cucumber

Plants produce abundant leaves and vines and direction less vine growth during the initial growth. Therefore, train lengthy vines for productivity and canopy maintenance and prune to maintain predictable growth and development. Usually, there are three training systems *viz.*, umbrella, v-system and single stem to achieve certain architecture or structure.

In case of umbrella training system, the main stem along with supporting string is permitted to develop vertically up to the overhead wire (2 m above the ground level). The apical bud is removed after producing two leaves above the overhead wire. Two healthy and vigourous lateral branches at the top of the vine are allowed to grow along the wire for about 15 cm and trained to grow down wards. All other laterals are removed. Whereas, in v-system, the main stem is permitted to grow along with supporting string and the growing point is removed at the sixth leaf stage (45-60 cm plant height). The two emerging lateral branches are then trained into a 'v-shape' on to the overhead wire. In single stem system, the main stem is allowed to grow as in case of the umbrella system and when the plant reaches the overhead wire, whole vine is lowered and trained to moved own ward. This system can accommodate more plants at the spacing of 60x45cm. For pruning, as the plant grows up the string, remove all the lateral buds up to the sixth node (a node being where a leaf joins the stem). In addition to the lateral buds, all the fruits should also be removed up to this point (Patil et al. 2019).

11.8.7 Harvesting and Yield

Usually, harvesting is depending on variety, distance from market and type of protected structure, however, fruit starts at 70–80 DAT and continues up to 170–180 days in tomato. Whereas, parthenocarpic cucumber cultivated under protected cultivation gives first fruit harvest at 35–40 days after transplanting. Fruit yield of tomato, capsicum and parthenocarpic cucumber under protected cultivation can be achieved up to 170–180 t/ha (17–18 kg/m^2 or 5.7–6.0 kg/plant), 100–120 t/ha (10–12 kg/m^2 or 4–5 kg/plant) and 300–400 t/ ha (30–40 kg/m^2), respectively depending upon management of crop and type of protected structure. In tomato, the average fruit weight varies from 100 g during initial harvesting to 60 g during last harvesting. Harvesting of fruits may be done usually at weekly interval or earlier (Singh et al. 2015).

11.8.8 Diseases Management

11.8.8.1 Downy Mildew

The symptoms are angular lesions that are limited by the leaf veins. Early lesions are light green in appearance and become chlorotic and finally necrotic as host plant cells die.

Management The crop should be sprayed with mancozeb @ 2 g/litre of water twice at 10 days interval.

11.8.8.2 Powdery Mildew (*Erysiphe polygoni* D.C.)

The white powdery spots are appearance on upper surface of leaves. Affected leaves lose their chlorophyll and dry up.

Management: Spray the crop with carbendazim @ 2g/litre of water. Fungicidal spray of kerathane is also effective. It can be controlled by avoid the late sown crop, foliar spray of onion extract @ 5% and spray the crop with wettable sulphur @ 1.0 kg/ha.

11.8.8.3 Wilt (*Fusarium oxysporum*)

It is a serious disease in vegetable crops and affected plants show yellowing, drooping of leaves, thereafter drying and finally plant dies.

Management: It can be effectively controlled through integrated approaches of soil solarization, healthy seed, crop rotation and treatment of seeds with *Trichoderma viridae* @ 4 g/kg seed subsequently use of *Trichoderma viridae* @ 4 kg/ha + 80 kg FYM in soil or treatment of seed with *Pseudomonas fluorescens* @ 10 g/kg seed subsequently soil application of *Pseudomonas fluorescens* @ 5 kg/ha + 100 kg FYM or treatment of seed with *Pseudomonas fluorescens* @ 10 g/kg seed subsequently use of neem cake @ 150 kg/ha in soil.

11.8.8.4 Mosaic Virus

Firstly, the greenish yellow to dark green mottling is developed in youngest leaves. Leaves are often stunted, crinkled, distorted, and curled downward. In severe cases, all except the youngest leaves at the runner tips (rosettes) may rapidly turn brown and die.

Management: Use insect proof nethouse for seedlings growing, eradication of early infected plants, two border rows with sorghum, pearl millet or maize can reduce the disease spread. Alternate hosts should remove. Spray seedlings with acephate (0.15%) prior to transplanting. Spray the crop with imidacloprid @ 1ml/3 litre of water or acephate (0.15%) at 15 days intervals after transplanting till flowering stage. Chemical spray followed by neem seed kernel extract (2%) is also effective in rotation with insecticides.

11.8.8.5 Some Approaches for IDM Practices

11.8.8.5.1 Soil Solarization

It is a technique of hydro/thermal soil heating in which moist soil is covered with polyethylene sheet for the period of 4–6 weeks during summer months. It should be adopted mandatory in protected cultivation.

11.8.8.5.2 Resistant or Tolerant Cultivars

Use of resistant varieties for plant disease management is considered as a ‘painless method’ because it does not require any extra expenditure for disease control. It can avoid the health hazards caused by the indiscriminate application of pesticides. It also checks environmental pollution caused by these agrichemicals. Tomato hybrid Arka Rakshak is resistant/tolerant to bacterial wilt and early blight.

11.8.9 Pest Management

The natural enemies, which manage the pest outsides conditions, are not available under protected conditions. Hence, in the greenhouse pest situations often develop quickly and some time may be more serious in comparison to outsides conditions. In India, the insect-pests scenario under protected conditions has been presented in Table 11.8.

11.8.9.1 Fruit Fly

Females fly lay eggs below epidermis of young fruits. Later on maggots feed on pulp afterward fruits starts rotting and get drop.

Management Neem oil @ 3.0% should be applied. Pheromone traps are hanged to trap and kill the insects during adults starts appear. Collect all infested fruits regularly and destroy them. Crop should be sprayed with fenthion (0.05%) or fenitrothion (0.05%).

11.8.9.2 White Fly

It acts as a vector and transmits the leaf curl virus from infected plant to healthy plant.

Management Seeds should be treated with imadacloprid 70 WS @ 3–5 g/kg of seed and nursery should be raised under insect proof nethouse (50-60mesh).

Table 11.8 Pests scenario under protected conditions

Category	Pest	Keeper
Aphids	*Aphis gossypii*	Capsicum
	Myzus persicae	Capsicum
Caterpillars	*Helicoverpa armigera*	Capsicum, tomato
	Spodoptera litura	Tomato, capsicum, cucumber
Leaf-miner	*Liriomyza trifolii*	Tomato, cucumber
Mites	*Polyphagotarsonemus latus (yellow mite)*	Capsicum
	Tetranychus urticae (spider mite)	Tomato, capsicum, cucumber
	Tetranychus neocalidonicus	Cucumber
White flies	*Bemisia tabaci*	Capsicum
	Trialeurodes vaporariorum	Tomato, cucumber, capsicum

Modified from Saha et al. (2015)

11.8.9.3 Nematode

It is a serious pest in protected cultivation. In case of heavy infestation, the roots shows welling's close to the root tips (Fig. 11.20).

Management Nematode can be managed through the soil solarization and application of multiplex niyantran (*Poaecilomyces lilacinus*), a promising bio-control agent, @ 5 kg/ha + 250 kg FYM or neemcake @ 250–400 kg/ha.

AICRP on Nematodes has recommended that the fumigation with metham sodium @ 30 ml/m^2 with polythene mulch for 15 days + neem cake 200 g/m^2 + *Pseudomonas fluorescens* 50 g/m^2 mixed 15 days prior to transplanting tomato reduced nematodes by 80%, gall index by 51% and increased yield by 49% in polyhouses. Combined application of neem cake @ 200 g/m^2 and *Paecilomyces lilacinus* @ 50 g/m^2 or *Trichoderma harzianum* @ 50 g/m^2 at 15 days before transplanting is an effective bio-management practice for root-knot nematode infesting cucumber under polyhouse conditions.

11.8.9.4 Cutworms

The caterpillar of this insect attacks on young plant/seedlings and cut them at ground level.

Management Soil should be drenched with chlorpyriphos 20% EC (1–2 ml/litre of water) at the time of preparation of field for transplanting.

11.8.9.5 Some Approaches for IPM Practices

11.8.9.5.1 Sticky Traps

Sticky traps can be incorporated in management practices of various pests like whiteflies, leaf miners and thrips. Blue and yellow coloured traps are used to monitor thrips and white fly - leaf minor infestation, respectively.

Fig. 11.20 Nematode infected cucumber (Source: AICRP on Nematodes)

11.8.9.5.2 Pheromones

There are three different types of pheromones *viz.*, aggregation (attract many individuals together), sex pheromones (attract one sex of a species to the other sex), and trail pheromones (attract pests into traps and interrupt mating). Pheromone is logical chemicals produced by animals to signal each other.

11.8.9.5.3 Bio-Pesticides

Bio-pesticides are products of microbial and plant origin based pesticides. Aphids can be controlled by clip off the heavily infested parts, pressurized water spray and foliar spray the crop with extract of neem seed kernel @ 3% or neem oil @ 1% or *verticillium lecanii* @ 3 ml/litre of water, which may be repeated three times at 15 days interval. Leaf-eating caterpillars can be controlled by foliar spray of *Bacillus thuringienses* (B.T.) @ 1 kg/ha or NPV @ 250 LE/ha. Mites (*Petrobia latens*) can be controlled by foliar spray of neem oil @ 1%. All soil insects can be managed by soil application of *Beauveria bassiana* @ 4 kg/ha + 80 kg FYM or neem cake @ 400 kg/ha.

11.8.9.5.4 Biological Control

In this method, natural enemies like predators, parasitoids and pathogens managed pest population. In tomato crop, egg parasitoid i.e., *Trichogramma chilonis* @ 50,000/ha in 6 releases starting from 45 days after transplanting or larval parasitoid i.e. *Campoletis chlorideae* @ 15,000 adults/ha or nuclear polyhedrosis virus of *H. armigera* (HaNPV) @ 250–300 larval equivalent (LE)/ha can be used for effective management of tomato fruit borer.

11.8.9.5.5 Trap Cropping

It is a specific companion planting approach of vegetative diversification. This technique has an enormous capability to attract and safeguard natural enemies. In tomato crop, the marigold and arugula are used as trap crop for management of *Helicoverpa armigera* and *Lygus* spp., respectively. The sunflower and sorghum crops can be grown as trap crop in capsicum for management of *Halyomorpha halys* and brown marmorated stink bug (Panwar et al. 2021).

11.8.10 CO_2 Enrichment

Periodical or continuous enhancement of CO_2 inside the greenhouses can lead to quality of produce and production (Shanchez-Guerrero et al. 2005). The CO_2 concentration may drops below the atmospheric level inside the greenhouses if CO_2 utilization through photosynthesis is greater than the provide amount by the vents. Improved ventilation system or CO_2 enhancement is possible solution to overcome such type of problem (Kittas et al. 2013).

11.8.11 Fruit Setting

Productivity of vegetable crops under protected conditions is totally associated with the realization of fruit-set and fruit-set is related to pollination. Due to high humidity and limited air movement under protected structures, the assistance is needed for pollination and it may be boosted by bumblebees or mechanical vibration. Mechanical vibration is a virtuous exercise; however, it is tedious. Bumble bees are the most efficient and are used in greenhouses worldwide. The advantages of pollination through bumble bees are depletion in labour expenses, greater fruit quality, higher productivity, and healthy product (Kittas et al. 2013).

11.9 Constraints in Protected Cultivation Systems

Though, numerous boom stories of protected cultivation technology have been described from various scientists and sectors as well. However, from the view point of Singh 2019, the constraints in protected cultivation systems are as follows:

1. Protected cultivation is correlated with very high beginning value.
2. Requirement of regular and uninterrupted power supply for climate-controlled greenhouses.
3. Being expensive, the cladding material is not readily available in needed standard.
4. Non-availability of tools and implements for facilitating crop production operations under greenhouse.
5. Region specific technologies are needed in absence of climate-controlled greenhouses.
6. Inadequate or scanty breeding work programs for evolution of appropriate hybrids/varieties of vegetable crops for greenhouse cultivation.
7. There is a problem of pollination in greenhouse crops in tomato and cucurbits.
8. Increasing threat of bio-stresses in greenhouse cultivation particularly root-knot nematodes and *Fusarium* wilt remain unsolved.

11.10 Opportunities in Protected Cultivation Technology

Singh 2019; Tomar et al. 2019; Singh and Choudhary 2019 have suggested the opportunities in protected cultivation technology as follow:

1. Adequate land, water and human resources are available.
2. Hard working and skilled labour force is available.
3. Less prone to main bacterial, viral and fungal diseases in arid and semi-arid regions, it becomes supportive for protected cultivation of vegetable crops.
4. An excellent network of road, rail and air is available for fast transportation of the commodities. Dedicated freight corridor will also be helpful.
5. Research and extension institutions are available to back up the protected vegetables research and development programme.
6. Protected cultivation offers very congenial environment for producing healthy, virus free, and genetically pure hybrid seed with higher seed yield per unit area.
7. Protected cultivation technology can attract to the youth towards farming sector.

11.11 Conclusion

The challenge of high demand from consumers for a year-round supply of quality vegetables can be met by growing under protected conditions or growing in two or more locations with complementary harvesting periods. Low tunnel, hydroponics, aeroponics, plug tray seedlings raising, and soilless cultivation are some important protected cultivation technologies. It offers several advantages to produce vegetables of high quality and yields, thus using the land and other resources more efficiently. Though, numerous boom stories of protected cultivation technology have been described from various scientists and sectors as well. However, very high beginning value, irregular power supply, pollination in greenhouse crops, and inadequate availability of appropriate hybrids/varieties of vegetable crops for greenhouse cultivation are also some constraints. On the other hand, the adequate land, water and human resources, hardworking and skilled labour force, excellent transportation facility, and available research and extension institutions are the opportunities in protected cultivation technology.

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