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REVIEW PAPER

Passive Solar Greenhouse for Round The Year Vegetable Cultivation in Trans-Himalayan Ladakh Region, India

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ABSTRACT

The trans-Himalayan Ladakh region remains cut-off for over six months in a year due to heavy snowfall. Availability of locally grown fresh vegetables is restricted to summer months and therefore, there are seasonal differences in dietary intake of food. Passive solar greenhouse has played a significant role not only in production of leafy vegetables in sub-zero temperature during winter months but also helped in extending the growing season in Ladakh. It is now a common practice to raise vegetable nurseries in spring and grow leafy vegetables during winter months in the greenhouse. Each year an average of 733 greenhouses covering 44313.4 m^2 area are being established in Leh district. Passive solar greenhouse structures such as Ladakhi greenhouse, trench, polytrench, polyench, polycarbonate, FRP and polynet have been designed and tested in the inhospitable environment of trans–Himalaya. The greenhouse is used mainly during winter, and majority of farmers (91.7 %) do not use the structures in summer. Insect-pest, irrigation in winter and frequent replacement of cladding materials are the major problems being faced by the farmers in the region. There is a need to improvise the greenhouse design to make it economically viable and technologically feasible to grow a variety of crops, especially during winter months.

Keywords: High altitude; Himalaya; Leh-Ladakh; Protected cultivation, Greenhouse

1. INTRODUCTION

The high mountain region of Ladakh is characterised by a rugged topography at an average altitude of over 3000 m asl. It is separated from the Indian subcontinent by the Great Himalayan Range and edged by the Karakoram Range to the North[1]. The region is characterised by extreme temperature variations, low precipitation mostly in the form of snow, high wind velocity, sparse plant density, thin atmosphere with high UV-radiation and fragile ecosystem. The temperature drops down to -30ºC in winter[2]. Long harsh winters reduce the cropping season to just four to five months in a year. Single-cropping is dominant, as double-cropping is possible only in a limited area falling below an altitude of approximately 3000 m. Agriculture production is entirely based on irrigation. The region remains cut-off for over six months in a year due to heavy snowfall. Availability of locally grown fresh vegetables is restricted to summer months and therefore, there are seasonal differences in dietary intake of food[3]. The availability of fresh vegetable decreases significantly during the winter months, which has resulted in unbalanced diet. Micronutrient deficiencies including the lack of vitamin A, B6, B12 and folic acid are prevalent in the region. Seasonal shortfall and low dietary diversity among the local populace lead to micronutrient deficiencies, a phenomenon that has been described as 'hidden hunger'[1].

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Self-sufficiency in food is an important issue for the region. Filling the gap between the required quantity and the quantity locally produce is a difficult task. Importing goods to Ladakh necessitates the shipping of goods by truck across the Himalayas, with passes as high as 5300 m asl, covering the distance of Manali to Leh (480 km) or Srinagar to Leh (420 km) in summer[4]. However, during winter a limited quantity of fresh vegetable is brought in by air paying as much as Rs 80 per kg just for the air freight from Delhi to Leh. In January 2019 the Leh District Administration has fixed the retail price of the fresh vegetables such as tomato (Rs 110 per kg), okra (Rs 130 per kg), brinjal (Rs 115 per kg), cauliflower (Rs 110 per kg), green peas (Rs 115 per kg) and spinach (Rs 110 per kg). A market survey conducted in Leh market in February 2019 showed that cabbage and knol-khol were being sold at Rs 120 per kg. However, the locally grown stored vegetables were fetching a relatively lower retail price (cabbage: Rs 60; turnip: Rs 55; radish Rs 45; carrot Rs 60 per kg). In comparison the retail price of fresh vegetables in metropolitan city Delhi (Saket) was significantly low during the period (tomato: Rs 38-42; okra: Rs 67-74; brinjal: Rs 51-56; cauliflower: Rs 28-30; cabbage: Rs 12-13; green peas: Rs 75-83; spinach: Rs 17-19; radish Rs 30-33; carrot Rs 49-55 per kg)[5]. Therefore, the retail price of selected fresh vegetables (tomato, okra, brinjal, cauliflower, cabbage, peas and spinach) in February 2019 was Rs 43 per kg in Delhi as against Rs 115.7 per kg in Leh market. Hence, fresh vegetables were 2.7-fold costlier in

Leh as compared to Delhi. Therefore, meeting the increasing demand of fresh vegetable at an affordable price in this remote mountain area is a formidable challenge.

Passive solar greenhouse has played a significant role not only in production of leafy vegetables in sub-zero temperature during winter months but also helped in extending the growing season in Ladakh. The first greenhouse (glasshouse) in Ladakh was established in 1964 at Defence Institute of High Altitude Research (DIHAR), formerly Field Research Laboratory, for cultivation of vegetable during winter months[6]. Soon it was realised that it is difficult to setup a traditional greenhouse in the mountain terrain due to logistics, high cost, and requirement of expertise for installation. To overcome these problems, a low cost passive solar greenhouse, based on trench warfare, was then conceived in late 1960s at DIHAR[6]. However, in view of limitations of the trench greenhouse due to its openness and devoid of retention wall above the ground level made it vulnerable for trespassing by stray animal, the adoption rate of the trench greenhouse was not up to the expectations[7]. Later on a greenhouse with mud walls on three sides (north, east and west) and polyethylene cover on south facing side with a roof on north wall, popularly known as the Ladakhi greenhouse, became trendy due to its ease of construction and higher heat retention capability at night especially during winter months. It is now a common practice to grow leafy vegetables such as spinach, lettuce and coriander in Ladakhi greenhouse during winter months. Incentives are being given by the Government to farmers for establishment of passive solar greenhouses due to its efficacy. Greenhouse cultivation practices for Ladakh have been standardised for raising early nursery of vegetable crops, cultivation of leafy vegetables during extreme winters, and cultivation of tropical, subtropical, and temperate vegetables during summer[8]. Besides Ladakhi greenhouse, a large number of other passive solar greenhouse structures have been designed and tested in the rugged terrain. Against this backdrop, this review paper aims to summaries various aspects of passive solar greenhouses in trans-Himalayan Ladakh region and to identify scope for further research.

The environmental conditions and crop yield presented are based on greenhouses established at experimental farm of DIHAR in trans-Himalayan Ladakh, India (34°08.3'N; 77°34.3'E, elevation 3344 m) during 2014-2017. Temperature, humidity, light intensity and photosynthetically active radiation (PAR) were recorded in 2017. Temperature and relative humidity were recorded with hygro-thermometer (445702, Extech Instruments). The light intensity was recorded with light meter (HD450, Extech Instruments), and PAR was recorded with radiometer (PMA2100, Solar Light) with PAR detector (PMA2132). Key features, advantages, limitations and crop cycle were recorded based on continuous monitoring and observations both at farmer's field and at DIHAR experimental farm. Crop harvest is average value of two or more years. Crop yield may vary depending on place, weather condition and crop management system.

2. ENVIRONMENTAL CONDITIONS OF LEH LADAKH

The weather data of the experimental farm of DIHAR during the year 2017 is shown in Table 1. Temperature being the main limiting factor for growing of crops in open field condition, vegetables nursery are transplanted in May and crop are harvested before October in open field condition to avoid freeze injury. Therefore, greenhouse cultivation remains the only option to grow fresh vegetables in winter and spring.

Table 1. Weather data of Leh Ladakh in 2017 (elevation 3344 m)

Month	Temperature (°C)		Relative humidity (per cent)		Light intensity at noon (Lux)	PAR at noon (μmol/m²s)
	Max	Min	Max	Min		
January	-0.1±2.6	-11.4±4.1	37.2±1.4	30.0±0.8	61980.0±26230.0	1026.1±562.8
February	1.2±2.6	-9.8±7.3	36.9±1.0	25.9±6.7	88550.0±26530.2	1547.8±508.3
March	4.9±3.2	-6.0±3.7	34.8±2.3	25.2±0.7	120388.9±45998.0	1556.0±413.5
April	12.5±3.5	1.0±2.6	30.7±1.3	24.6±0.9	134075.0±34932.8	1804.1±409.1
May	16.4±2.7	4.8±3.2	30.0±2.0	21.3±0.9	101900.0±74504.2	1739.3±288.5
June	19.1±4.0	7.6±2.4	26.5±1.8	20.3±0.9	113950.0±43828.6	1362.1±571.6
July	25.1±4.0	13.0±2.9	24.0±1.3	20.0±0.2	111242.9±44532.8	1612.7±485.1
August	25.8±2.3	12.6±2.2	24.3±1.4	20.2±0.6	134266.7±4100.4	1900.7±34.5
September	20.8±2.0	6.8±2.3	27.3±1.1	20.5±0.6	130275.0±15116.3	1903.4±223.8
October	12.5±2.8	-3.9±1.5	31.0±1.6	23.4±1.6	99842.9±39247.5	1761.0±178.3
November	7.9±3.8	-7.7±2.9	34.3±1.0	25.8±0.8	72750.0±30628.8	1145.3±581.9
December	3.6±1.8	-10.8±2.4	36.1±1.0	27.5±1.4	64450.0±34337.6	1198.2±504.5
Average	12.5±9.1	-0.3±9.1	31.1±4.8	23.7±3.3	102855.9±26144.0	1546.4±300.6

3. TYPES OF PASSIVE SOLAR GREENHOUSES IN LADAKH

Various types of passive solar greenhouses are being studied in trans-Himalayan Ladakh. Some of the commonly known greenhouses are as follows:

3.1 Ladakhi Greenhouse

Small to medium sized greenhouses having mud walls on three sides (north, east and west) with polyethylene cover on south facing side and a roof on north wall are popularly known as the Ladakhi greenhouse. It is the most widely used passive solar greenhouse in Ladakh. It become popular due to its ease of construction and higher heat retention capability at night especially during winter. Modifications have been made in the Ladakhi greenhouse by various agencies and are named as GERES greenhouse, LEHO greenhouse, LREDA greenhouse, SKUAST-II etc. However, the mud wall on three sides, use of polyethylene sheet as cladding material, wooden angled roof on north wall are the common features in all these

Figure 1. A Ladakhi greenhouse.

greenhouses. The cladding material is removed from the greenhouse structure during summer months (June to October) due to excessive heat that builds up inside the greenhouse. The increased use of greenhouse has not only improved dietary intake of vegetables during the winter months but also opened a new economic opportunity for sale of early season vegetables by the local farmers.

3.1.1 Basic Components of Ladakhi Greenhouse

The Ladakhi greenhouse (Fig. 1) including modified designs in east-west orientation has five main components:

3.1.1.1 Mud Brick Wall

Mud brick walls on east, west and north sides where the amount of incident solar energy is limited. Single or double wall mud brick or rammed earth wall is common. Insulating materials such as straw, sawdust, dry leaves are stuffed between the cavities of the double wall of the greenhouse. The thickness of the wall varies from 1 foot to 3 feet, majority being 1 foot thick. The main function of the wall apart from the load bearing is its ability to absorb solar energy during the day and release the conserved heat inside the greenhouse during night.

3.1.1.2 Polyethylene Sheet

A translucent UV-stabilised polyethylene sheet covering the south face of the greenhouse transmits majority of incident solar radiation into the greenhouse. This warms the interior space and is absorbed by the plants, the ground and the walls. The polyethylene sheet is set at an angle and is supported by a wooden or metallic frame. The angle of the polyethylene cover is calculated in a manner so that maximum solar radiation is transmitted inside the greenhouse and the snow that falls on it slides off.

3.1.1.3 Roof

A sloped (to the north) wooden roof on the north side of the greenhouse regulates solar radiation absorption on the surface inside. In summer, when the sun is high in the sky, the roof partly shades the greenhouse and reduces overheating. During winter, when the sun is at low elevation, it allows solar radiation absorption inside the greenhouse. The wooden roof is covered with a layer of straw and earth for insulation.

3.1.1.4 Door

A wooden door is located on the east wall, opposite the wind direction, to avoid air infiltration.

3.1.1.5 Ventilation

The air inside the greenhouse becomes very hot on sunny days. Manually operated ventilators are provided either on the roof or on west wall. The door on the east wall is also used for ventilation during daytime.

3.1.2 Advantages of Ladakhi Greenhouse

Ladakhi greenhouse has several advantages such as

- Construction cost of Ladakhi greenhouse is low to moderate depending on the size of the greenhouse;
- The greenhouse is made of locally available resources except the cladding material;
- The earth walls on three sides and the floor store heat during day and release at night. Therefore, it remains much warmer as compared to all polycarbonate or FRP greenhouse with no heat retention walls.

3.1.3 Limitations of Ladakhi Greenhouse

The major limitations of Ladakhi greenhouse are

- The temperature inside the greenhouse often drops to sub-zero degree Celsius at night in December and January, which limits growing of only freeze tolerant leafy vegetables;
- Vegetables such as Cole crops (cauliflower, cabbage, broccoli), cucurbits (pumpkin, squash), and Solanaceous (tomato, capsicum) cannot be grown due to freezing temperature at night inside the greenhouse during winter months;
- The cladding material needs to be removed from the greenhouse structure during summer months (June to October) due to excessive heat that builds up inside the greenhouse. Temperature as high as 64 degree Ceisius have been recorded in May inside the greenhouse[9];
- Average service span of polyethylene sheet is 3-5 years. High wind speed, uneven surface of supporting frames, frequent removal and extreme climatic condition reduces the durability of the cladding material;
- Rain and high humidity inside the greenhouse causes damage to the mud walls and the roof. High humidity inside the greenhouse also results in growth of moulds and fungus on wooden structures. Therefore, the mud walls and roof need frequent repair and maintenance;
- The wooden frame of door and ventilators is deformed due to high moisture and heavy load of the walls. The deformity leads to improper closing of the doors and ventilators resulting in heat leaks from the gaps. In most of the greenhouses the plastic siding is not properly secured resulting in infiltration of outside air into the greenhouse;
- Use of polyethylene sheet as cladding material is not suitable for regions receiving heavy snowfall, such as Changthang valley. The structure collapses due to sheer

Figure 2. A trench greenhouse in Leh, Ladakh

load of the snow;

- The average service period of a greenhouse is 10 years. The walls, wooden frame and wooden roof need major repair in intervals to keep the greenhouse functional;
- Majority of the farmers (over 91%) do not use greenhouse during summer months. Due to removal of polyethylene sheet during summer, there is no additional benefit from the structure as compared to open field conditions.

3.2 Trench Greenhouse

Trench greenhouse is a passive greenhouse for vegetable cultivation in Ladakh region[10]. It is an underground rectangular trench (30'×10'×3'; L×W×D) in north-south orientation with stone wall on four sides (Fig. 2). Five cylindrical galvanised iron pipes (5 cm diameter, 13' long) are placed horizontally in east-west direction at 6 feet gap on top of the trench at ground level to hold the cladding material. UV stabilised 120 GSM translucent polyethylene sheet is covered on top of the trench during October to May. In harsh winter, an additional polyethylene sheet is placed on top of the translucent cladding material at night to retain heat inside the trench. Stones/ sandbags are placed on edges of the polyethylene to check blowing off the sheet by strong wind. The cladding material is partly open in May and October and fully removed during summer months (June to September) to control the excessive heat build up inside the trench[6]. Trench greenhouse is now widely recognised as the most economical and easy to establish passive solar greenhouse for Ladakh region[6,7,11,12].

3.2.1 Advantages of Trench Greenhouse

The advantages of Trench greenhouse are

- Construction cost of Trench greenhouse is significantly low as compared to traditional greenhouses. Construction cost can be recovered within one or two years;
- Since the greenhouse is below ground level, there is almost nothing that needs to be maintained;
- Since the Trench greenhouse is beneath the surface, the thermal mass of the earth acts as an insulator. The temperature remains warm in winter and cool in summer;
- The Trench protects the crop from strong wind. Wind in association with rain causes maximum damage at the time of flowering. Wind increases the water requirement of the crop by evapotranspiration due to removal of humid air near the leaves;
- Traditional above-ground greenhouses are bulky structures that obstruct the views. Therefore, underground greenhouses are better in terms of visual appeal.

3.2.2 Limitations of Trench Greenhouse

Major limitations of Trench greenhouse include

- Trench greenhouse is open and devoid of retention wall above the ground level, thus making it vulnerable for trespassing by stray animal;
- The temperature inside the trench greenhouse often drops to sub-zero degree Celsius at night in December and January, which limits growing of only freeze tolerant leafy vegetables;
- The cladding material (polyethylene sheet) needs to be removed from the trench during summer months (June to October) due to excessive heat that builds up inside the greenhouse;
- Average service span of polyethylene sheet is 3-5 years. High wind speed and placing of stone on the edges of the polyethylene to check blowing off the sheet by strong wind results in reduced durability of cladding material;
- Use of polyethylene sheet as cladding material is not suitable for regions receiving heavy snowfall. The structure collapse due to load of the snow.

3.2.3 Temperature inside Trench Greenhouse

The air temperature inside a Trench greenhouse remains 20.7±2.8 °C warmer during day and 7.0±1.2 °C at night in winter (mid October to early March). In spring (from late March to early May) the air temperature inside the trench remains 15.6±0.4 °C warmer during day and 5.0±0.8 °C at night[6].

Figure 3. A polytrench greenhouse in winter.

3.2.4 Marketable Yield and Production of Vegetable Seedling in Trench Greenhouse

The marketable yield of leafy vegetable during winter; tropical and sub-tropical vegetables in summer and production of vegetable seedlings in spring have recently been reported by Angmo[6], *et al*. From a single Trench greenhouse 64±4 kg spinach is obtained in winter; 160.4±22.9 kg tomato in summer; and 13000-39000 vegetable seedlings were raised in spring in a year.

Table 2. Temperature and relative humidity inside Polytrench greenhouse

Month	Temperature (°c)				Relative humidity (%)			
	Inside greenhouse		Difference (Greenhouse -open)		Inside greenhouse		Difference (Greenhouse -open)	
	Max	Min	Max	Min	Max	Min	Max	Min
January	18.9±5.4	-7.7±2.7	19.0±2.9	3.7±1.4	88.3±6.4	57.1±7.1	51.1±5.0	27.0±6.3
February	23.1±8.7	-3.7±3.0	21.9±6.0	6.1±4.2	92.3±5.5	52.7±9.0	55.5±4.5	26.8±2.3
March	33.3±5.9	0.5±3.1	28.4±2.7	6.5±0.6	89.4±9.6	43.3±18.4	54.5±7.3	18.1±17.8
April	35.1±5.6	5.2±2.1	22.7±2.1	4.2±0.5	81.2±10.7	22.5±10.0	50.5±9.3	-2.1±9.0
May	35.3±2.5	6.8±2.9	18.9±0.3	2.0±0.3	66.4±8.4	15.2±0.8	36.4±6.4	-6.0±0.0
June	36.8±3.8	10.1±2.7	17.7±0.2	2.5±0.4	72.7±8.7	21.7±6.5	46.2±6.9	1.4±5.5
July	38.6±4.1	14.8±1.8	13.5±0.1	1.8±1.1	69.0±13.6	22.6±9.6	45.0±12.2	2.5±9.4
August	37.6±4.3	13.0±2.5	11.8±2.0	0.4±0.3	69.0±11.2	23.9±14.0	44.7±9.8	3.6±13.4
September	31.3±2.9	9.2±1.9	10.5±0.8	2.3±0.4	73.3±12.0	23.1±8.4	45.9±11.0	2.6±7.8
October	31.0±2.0	3.1±2.2	18.5±0.8	7.0±0.7	74.7±11.3	24.5±11.4	43.8±9.7	1.1±9.8
November	26.0±4.8	-1.9±2.6	18.2±1.0	5.8±0.4	90.9±4.4	53.9±11.5	56.6±3.4	28.1±10.7
December	18.3±4.6	-5.3±0.9	14.7±2.8	5.5±1.4	94.4±2.6	69.2±6.8	58.2±1.6	41.7±5.5
Average	30.4±7.2	3.7±7.4	18.0±5.0	4.0±2.2	80.1±10.4	35.8±18.2	49.0±6.5	12.0±15.5

3.3 Polytrench Greenhouse

Polytrench is an improvised Trench greenhouse (30'×10'×3'; L×W×D) in north-south direction (Fig. 3). It aims to overcome some of the limitations of Trench greenhouse design, particularly its openness and the absence of retention wall above the ground level that makes it vulnerable for trespassing by stray animal. It has a tunnel shaped galvanised steel frame over the trench on which the cladding material (polyethylene) is fixed. A door with entrance path on the north side allows entry of farm workers inside the greenhouse. There is no need to remove the cladding material even in summer months. Natural ventilation occurs when the door is kept open and the polyethylene sheet is slightly lifted from the south side of the greenhouse.

3.3.1 Advantages of Polytrench Greenhouse over Trench Greenhouse

Polytrench greenhouse offers all the advantages of Trench greenhouse. Besides, it has several advantages over a Trench greenhouse such as

- Lifting the polyethylene sheet from south facing frame and keeping the door open provides natural ventilation during summer, hence there is no need to remove the cladding material completely;
- The door and tunnel shaped frame above the Trench give protection against trespassing by stray animal;
- Farm workers enter the greenhouse through the door, unlike Trench Greenhouse where farm workers have to descend inside by leaping to carry out farming activities;
- Higher temperature inside Polytrench results in higher yield of warm season crops such as tomato, capsicum and brinjal in summer;
- The tunnel shaped frame gives protection from snow load, which otherwise results in collapse of the structure. The arched roof design allows snow to slip off naturally and there is no need to remove snow from the cladding material.

3.3.2 Limitations of Polytrench Greenhouse over Trench Greenhouse

Limitations of Polytrench greenhouse are

- The raised surface area of the Polytrench greenhouse from ground level results in more heat loss at night as compared to Trench greenhouse, therefore, it is much colder inside the Polytrench greenhouse at night in winter;
- Due to lower temperature, lesser harvest of leafy vegetables is obtained in winter.

3.3.3 Temperature and Relative Humidity inside Polytrench Greenhouse

The air temperature inside a Polytrench greenhouse remained below freezing from November to February (Table 2). It remained 18.5±2.9 °C warmer during day and 5.3±1.1 °C at night in winter (November to February). In summer (June to September) the air temperature inside the Polytrench remains 13.4±3.1 °C warmer during day and 1.8±0.9 °C at night. The average PAR inside the greenhouse has been recorded 813.2±253.4 (Table 3) as against 1546.4±300.6 μmol/m^2s in open condition.

Table 3. Light intensity and PAR inside a Polytrench greenhouse at noon

Month	Light intensity (Lux)		PAR (µmol/m²s)	
	Inside greenhouse	Difference (Open-greenhouse)	Inside greenhouse	Difference (Open-greenhouse)
January	33990.3±14384.7	27989.7±11845.3	462.7±253.8	563.3±309.0
February	54002.5±16179.6	34547.5±10350.7	734.5±241.2	813.4±267.1
March	62646.1±23935.7	57742.8±22062.3	690.2±183.4	865.8±230.1
April	75796.4±19660.5	58278.6±15272.3	1035.4±234.8	768.6±174.3
May	29651.1±21679.4	72248.9±52824.7	1072.3±177.8	666.9±110.6
June	55113.8±21198.4	58836.2±22630.2	939.7±394.3	422.4±177.3
July	56542.7±22635.2	54700.1±21897.6	1011.4±304.2	601.3±180.9
August	62536.4±1909.8	71730.3±2190.6	1024.7±18.5	876.0±15.9
September	57873.0±6715.2	72402.0±8401.1	1041.4±122.4	862.0±101.4
October	57862.7±24655.0	41980.1±17887.5	879.5±82.5	881.5±82.7
November	23339.6±9826.3	49410.4±20802.5	423.7±215.3	721.5±366.6
December	29317.8±15619.9	35132.2±18717.7	442.4±186.2	755.8±318.2
Average	49889.4±16514.7	52916.4±15407.7	813.2±253.4	733.2±145.3

Table 4. Marketable yield and production of vegetable seedlings (per Polytrench greenhouse; 30'×10'×3'; L×W×D)

Season	Type of crop	Crop	Variety	Yield/ number
Winter (Mid October to early March)	Leafy vegetable	Spinach	Delta	22.5±4.2 kg
Spring (Late March to early May)	Vegetable seedlings	Cabbage	Golden Acre	18540±1605 nos
		Cauliflower	Shentha	15530±1275 nos
		Tomato	Tolstoi	24505±2605 nos
Summer (Mid May to early October)	Warm season crops	Capsicum	California Wonder	42.3±6.6 kg
		Tomato	Tolstoi	171.4±12.6 kg

Figure 4. A polyench greenhouse in winter.

3.3.4 Marketable Yield and Production of Vegetable Seedlings in Polytrench Greenhouse

The marketable yield of leafy vegetables during winter; tropical and sub-tropical vegetables during summer; and production of vegetable seedlings in spring time are shown in Table 4.

3.4 Polyench Greenhouse

Polyench is a semi-underground (1 m below ground level) passive solar greenhouse (75'×25'×10'; L×W×H) in east-west orientation. It has 2' 4'' thick double wall on three sides (north, east and west) made of mud bricks with straw stuffed between the two walls for insulation. The wall on north side is 8' height, and has a wooden roof (5' width) with soil on top of it (Fig. 4). It is covered with UV stabilised 120 GSM translucent polyethylene sheet on wooden poles on south facing side. Ventilator are placed at roof and walls. The Polyench is covered with polyethylene sheet during October to May. Sandbags/stones are placed on edges of the polyethylene to check blowing off the sheet by strong wind. The cladding material is partly opened in May and October and is completely removed during summer months (June to September) to control the excessive heat build up inside the polyench. It is comparatively easy to construct the greenhouse and it has higher heat retention at night. The greenhouse is made of locally available resources, except the polyethylene cladding material. It is one of the most effective passive solar greenhouse for growing vegetables in winter[13-14].

3.4.1 Temperature and Relative Humidity inside Polyench Greenhouse

The air temperature inside a Polyench greenhouse remained below freezing temperature in January (Table 5). It remained 22.3±4.1°C warmer during day and 10.9±1.1°C at night in winter (November to February). In summer (June to September) the air temperature inside the Polyench remains 3.1±0.5°C warmer during day and 0.5±0.2°C at night. The average PAR inside the greenhouse was 1107.6±546.2 (Table 6) as against 1546.4±300.6 µmol/m²s in open condition.

3.4.2 Marketable Yield and Production of Vegetable Seedlings in a Polyench Greenhouse

The marketable yield of leafy vegetables during winter; tropical and sub-tropical vegetables in summer; and production of vegetable seedlings in spring are shown in Table 7.

3.5 Polynet Greenhouse

It is a dual purpose greenhouse (90'×27'×9'; L×W×H) in east-west orientation. It is used for drying fruits in

Table 5. Temperature and relative humidity inside Polyench greenhouse

Month	Temperature (°C)				Relative humidity (per cent)			
	Inside greenhouse		Difference (Greenhouse -open)		Inside greenhouse		Difference (Greenhouse -open)	
	Max	Min	Max	Min	Max	Min	Max	Min
January	24.6±3.1	-2.1±1.8	24.5±1.2	9.3±2.3	72.0±4.8	38.4±8.8	34.8±3.5	8.4±8.1
February	25.9±3.7	1.6±2.3	24.7±1.4	12.1±5.0	82.5±4.1	36.7±8.8	45.7±3.1	10.7±2.1
March	36.0±5.1	6.3±2.4	31.1±1.6	12.3±0.8	88.8±3.8	37.1±9.6	54.0±1.4	12.0±8.9
April	35.8±5.1	9.2±2.3	23.3±1.5	8.2±0.3	77.0±7.8	29.5±13.5	46.3±6.4	4.9±12.6
May	36.8±3.1	9.9±1.2	20.3±1.4	5.1±0.1	63.1±11.7	16.1±2.3	33.1±9.7	-5.2±1.5
June	22.0±4.4	8.2±2.2	9.9±0.5	0.6±0.2	65.4±17.6	17.4±3.5	38.8±15.8	-2.9±2.6
July	28.4±3.6	13.3±2.5	3.3±0.5	0.3±0.4	57.2±15.5	21.2±10.2	33.2±14.2	1.2±10.0
August	29.2±2.9	13.1±2.4	3.4±0.6	0.5±0.1	58.2±7.7	18.9±6.9	33.9±6.3	-1.3±6.3
September	23.7±3.5	7.5±1.7	2.9±1.5	0.7±0.6	59.4±9.1	19.2±6.4	32.1±8.0	-1.3±5.8
October	25.7±5.9	1.6±2.3	13.2±3.2	5.5±0.8	46.9±10.5	17.2±4.6	16.0±8.9	-6.2±3.0
November	30.9±5.7	4.0±2.3	23.1±1.8	11.7±0.6	78.3±8.9	41.6±8.3	44.0±7.9	15.9±7.5
December	20.1±6.6	0.2±1.8	16.5±4.7	11.0±0.6	83.1±6.5	52.2±15.7	47.0±5.6	24.8±14.3
Average	28.3±5.3	6.1±5.0	16.4±9.8	6.4±4.9	69.3±12.8	28.8±12.1	38.2±10.0	5.1±9.5

Table 6. Light intensity and PAR inside a polyench greenhouse at noon

Month	Light intensity (Lux)		PAR (µmol/m²s)	
	Inside greenhouse	Difference (Open-greenhouse)	Inside greenhouse	Difference (Open-greenhouse)
January	32309.6±13673.45	29670.4±12556.5	497.2±272.7	528.9±290.1
February	46877.4±14044.8	41672.6±12485.4	837.2±274.9	710.7±233.4
March	82413.4±31488.4	37975.5±14509.6	681.3±181.1	874.6±232.4
April	82042.7±21280.8	52032.3±13652.1	1235.2±280.1	568.8±129.0
May	54367.8±39751.0	47532.2±34753.2	956.8±158.7	782.5±129.8
June	112320.3±44471.1	1629.7±3757.6	1341.7±563.1	20.4±8.6
July	84486.5±33821.7	26756.4±10711.1	1575.6±465.3	37.1±19.8
August	108523.1±3314.2	25743.6±786.2	1824.1±33.1	76.6±1.4
September	124198.9±14411.3	6076.1±705.0	1884.4±221.6	19.0±2.2
October	83554.5±35602.2	16288.3±6940.4	1619.8±152.0	141.3±13.3
November	31722.0±13355.4	41028.0±17273.4	499.4±253.7	645.9±328.1
December	38144.6±20322.6	26305.4±14014.9	337.9±142.3	860.3±362.2
Average	73413.4±3225.1	29392.3±15796	1107.6±546.2	438.8±351.6

summer and growing leafy vegetables in spring and winter (Fig. 5). It is covered with UV stabilised 120 GSM translucent polyethylene sheet. Unlike Ladakhi greenhouse, the wall are made of concrete material (stone and cement), and the east and west walls are half opened (i.e. at 3-4 feet height.). The north wall is 8' height and 2' thick, and the east and west wall are 1' 6'' thick. The wooden roof is 6' width covered with soil on top of it. Red shade net (60%) is placed below the polyethylene sheet on galvanised steel frame. Lifting the polyethylene sheet from east and west side walls during summer provides natural ventilation. There is no need to completely remove the polyethylene sheet.

3.5.1 Advantages of Polynet Greenhouse

The advantages of Polynet greenhouse include

- It is a dual-purpose greenhouse, can be used for drying fruits in summer and growing crops in spring and winter;
- Lifting the polyethylene sheet from east and west side walls during summer provides natural ventilation, hence, there is no need to completely remove the cladding material;
- The colored shade net gives shading effect during day time, and allows higher heat retention at night, hence, there is no extreme temperature variation inside the greenhouse;
- The colored shade net results in higher humidity inside the greenhouse and therefore reduces number of irrigation.

3.5.2 Limitations of Polynet Greenhouse

The major limitations of polynet greenhouse are

- Temperature inside the greenhouse often drops to -5 °C or less at night in December and January, which limits growing of only freeze tolerant leafy vegetables;
- The shading effect of colored net allows growing of only leafy vegetables (such as spinach) inside the greenhouse;
- High humidity inside the greenhouse results in growth of moulds and fungus on the wooden surface, therefore, reduces the service life of the wooden roof, and needs replacement after 5-6 years.

Table 7. Marketable yield and production of vegetable seedlings (per Polyench greenhouse; 75'×25'×10'; L×W×H)

Season	Type of crop	Crop	Variety	Yield/ number
Winter (Mid October to early March)	Leafy vegetable	Spinach	Delta	189.5±22.1 kg
Spring (Late March to early May)	Vegetable seedlings	Brinjal	Janak	100538±7838 nos
		Tomato	Tolstoi	177531±4751 nos
Summer (Mid May to early October)	Warm season crops	Brinjal	Janak	60.6±8.55 kg
		Chilli	Saundarya	30.3±9.8 kg

Figure 5. A polynet greenhouse in winter.

3.5.4 Marketable Yield and Production of Vegetable Seedlings in Polynet Greenhouse

The marketable yield of leafy vegetables during winter; tropical and sub-tropical vegetables in summer; and production of flower seedlings in spring are shown in Table 10.

3.6 Polycarbonate Greenhouse

It is a passive solar greenhouse (120'×30'×10'; L×W×H) with triple layer 8 mm thick polycarbonate sheet on all the four sides and the roof (Fig. 6). The polycarbonate sheet is fixed on galvanised steel frame on 2' concrete wall above ground level on all four sides. The roof has slope on north and south sides. It is useful for growing warm-season crops during summer months, and for vegetable nursery raising in spring. The greenhouse is superior to Trench and Polyench for growing tomato in summer[15].

Table 8. Temperature and relative humidity inside Polynet greenhouse

Month	Temperature (°C)				Relative humidity (per cent)			
	Inside greenhouse		Difference (Greenhouse -Open)		Inside greenhouse		Difference (Greenhouse -Open)	
	Max	Min	Max	Min	Max	Min	Max	Min
January	21.5±7.9	-2.7±2.0	21.6±5.4	8.8±2.0	93.5±1.0	54.2±9.6	56.3±0.4	24.1±8.9
February	27.9±9.7	0.5±2.5	26.7±7.1	10.3±4.8	93.1±2.2	50.2±11.4	56.2±1.1	24.2±4.7
March	33.9±6.5	4.7±3.3	29.0±3.3	10.7±0.4	91.0±5.6	37.2±10.3	56.2±3.3	12.1±9.6
April	32.4±5.8	8.7±2.0	20.0±2.3	7.7±0.6	85.1±6.0	31.3±18.7	54.4±4.7	6.7±17.7
May	35.8±2.7	10.6±1.8	19.4±0.0	5.8±1.4	83.7±5.9	31.1±10.2	53.7±4.0	9.8±9.4
June	36.9±3.0	12.7±2.0	17.8±1.0	5.1±0.3	80.7±3.4	26.3±9.5	54.1±1.6	6.0±8.6
July	38.1±5.2	16.2±1.8	13.0±1.1	3.2±1.1	74.5±15.7	27.2±11.7	50.4±14.4	7.2±11.5
August	43.1±4.3	16.9±2.1	17.3±2.0	4.3±0.1	54.3±7.7	16.1±4.2	30.0±6.2	-4.1±3.7
September	38.2±5.3	13.9±1.8	17.4±3.3	7.1±0.4	51.1±10.9	16.2±3.5	23.7±9.8	-4.3±2.9
October	36.8±3.4	8.5±1.8	24.3±0.6	12.4±0.3	79.7±23.1	29.9±11.0	48.8±21.5	6.4±9.5
November	28.3±4.6	2.5±2.3	20.4±0.7	10.2±0.7	95.1±2.0	49.5±11.7	60.8±1.0	23.8±10.9
December	23.7±6.4	-0.5±1.7	20.1±4.6	10.3±0.7	95.9±0.8	64.5±12.4	59.7±0.2	37.0±11.0
Average	33.0±6.5	7.7±6.7	20.6±4.4	8.0±2.9	81.5±15.1	36.1±15.3	50.4±11.5	12.4±12.5

3.5.3 Temperature and Relative Humidity Inside Polynet Greenhouse

The minimum air temperature inside a Polynet greenhouse remained below freezing temperature in December and January (Table 8). It remains 22.2±3.1°C warmer during day and 9.9±0.8°C at night in winter (November to February). In summer (June to September) the air temperature inside the Polynet remains 16.4±2.3°C warmer during day and 4.9±1.6°C at night. The average PAR inside the greenhouse has been recorded 344.7±96.9 (Table 9) as against 1546.4±300.6 µmol/ m^2s in open condition.

3.6.1 Advantages of Polycarbonate Greenhouse

Advantages of Polycarbonate greenhouse are

- Service life of a Polycarbonate greenhouse is 15-20 years with minor repair and maintenance. The polycarbonate cladding material is not affected by high humidity and temperature inside the greenhouse;
- Temperature inside the greenhouse is maintained through natural ventilation.

Table 9. Light intensity and PAR inside a polynet greenhouse at noon

Month	Light intensity (Lux)		PAR (µmol/m²s)	
	Inside Greenhouse	Difference (Open-Greenhouse)	Inside Greenhouse	Difference (Open-Greenhouse)
January	8968.2±3795.4	53011.8±22434.6	167.1±91.6	859.0±471.2
February	17663.8±5292.2	70886.1±21238.0	369.9±121.5	1177.9±386.8
March	26126.9±9982.5	94261.9±36015.4	357.9±95.1	1198.1±318.4
April	24811.0±6435.6	10926.4±28497.2	410.2±93.0	1393.8±316.1
May	17002.4±12431.3	84897.6±62072.8	411.5±68.2	1327.8±220.2
June	25406.5±9772.1	88543.5±34056.5	427.8±179.5	934.3±392.1
July	22743.4±9104.7	88499.4±35428.1	412.1±123.9	1200.6±361.1
August	21044.5±642.7	113222.2±3457.7	400.5±7.3	1500.2±27.2
September	18999.5±2204.6	111275.6±12911.7	418.7±49.2	1484.6±174.6
October	18716.6±7975.0	81126.3±34567.5	359.4±33.7	1401.6±131.6
November	12095.4±5092.4	60654.6±25536.4	213.2±108.3	932.1±473.6
December	9651.5±5142.1	54798.5±29195.5	187.9±79.1	1010.2±425.3
Average	18602.5±5904.3	84203.3±21216.0	344.7±96.9	1201.7±225.8

Table 10. Marketable yield and production of flower seedlings (per Polynet greenhouse; 90'×27'×9'; L×W×H)

Season	Type of crop	Crop	Variety	Yield/ number
Winter (Mid October to early March)	Leafy vegetable	Spinach	Delta	232±47.6 kg
Spring (Late March to early May)	Flower seedlings	Aster	-	336960±8824 nos
		Bells of Ireland	-	115680±6109 nos
		Calendula	-	430080±65167 nos
		Marigold	-	202800±42426 nos
		Nasturtium	-	102240±10182 nos
		Small Marigold	-	219360±21722 nos
Summer (Mid May to July)	Leafy vegetables	Spinach	Delta	260.7±43.1 kg

Figure 6. A Polycarbonate greenhouse in winter.

3.6.2 Limitations of Polycarbonate Greenhouse

Polycarbonate greenhouse has following limitations

- The temperature inside the greenhouse often drops to -8 °C or less at night in December and January, which limits growing of only freeze tolerant leafy vegetables;
- Only leafy vegetables can be grown in winter months; plant growth is recorded much slower than that of Polyench or Trench greenhouse;
- The greenhouse structure is not easy to establish and it requires qualified personnel to establish the structure;
- High material and installation cost.

3.6.3 Temperature and Relative Humidity inside a Polycarbonate Greenhouse

The air temperature inside a polycarbonate greenhouse remained below freezing temperature during November-February (Table 11). It remained 23.6±4.9 °C warmer during day and 6.4±0.7 °C at night in winter (November to February). In summer (June to September) the air temperature inside the polycarbonate remains 14.2±2.0 °C warmer during day and 1.9±0.6°C at night. The average PAR inside the greenhouse has been recorded 730.2±233.8 (Table 12) as against 1546.4±300.6 µmol/m²s in open condition.

3.6.4 Marketable Yield and Production of Vegetable Seedlings in Polycarbonate Greenhouse

The marketable yield of leafy vegetables during winter; tropical and sub-tropical vegetables in summer; and production of vegetable seedlings in spring are shown in Table 13.

3.7 FRP Greenhouse

It is a passive solar greenhouse (100'×30'×11'; L×W×H) in east-west orientation with fiber-reinforced polymer (FRP) sheet on all the four sides and the roof (Fig. 7). The FRP sheet is fixed on galvanised steel frame on 2' concrete wall above ground level on all four sides. The roof has slope on north and south sides. It is useful for growing warm-season crops during summer months, and for vegetable nursery raising in spring.

3.7.1 Limitations of FRP Greenhouse

Limitations of FRP greenhouse are

- FRP sheet looses transparency after 4-5 years and need replacement. Over 75 % PAR is blocked in a five-year-old structure, and crop often showed poor growth and development;

Table 11. Temperature and relative humidity inside Polycarbonate greenhouse

Month	Temperature (°C)				Relative humidity (%)			
	Inside Greenhouse		Difference (Greenhouse -Open)		Inside Greenhouse		Difference (Greenhouse -Open)	
	Max	Min	Max	Min	Max	Min	Max	Min
January	25.3±3.3	-6.1±1.3	25.4±0.7	5.3±2.8	72.1±4.4	30.9±9.5	34.8±3.0	0.9±8.7
February	29.9±4.8	-3.1±2.3	28.7±2.2	6.7±2.0	73.4±11.0	27.3±9.2	36.6±9.9	1.4±2.5
March	34.2±5.6	1.3±2.4	29.3±2.4	7.3±1.3	58.9±17.2	20.1±11.4	24.1±14.9	-5.0±10.8
April	36.4±5.7	5.1±2.2	23.9±2.2	4.1±0.4	49.0±8.4	15.0±0.0	18.3±7.1	-9.6±0.9
May	33.7±3.9	5.6±1.8	17.2±1.2	0.8±0.4	68.4±4.5	16.0±5.2	38.4±2.5	-5.3±4.3
June	36.1±4.4	9.8±2.0	17.0±0.5	2.2±0.3	67.1±7.8	16.2±1.9	40.6±5.9	-4.1±1.0
July	39.3±4.8	15.0±1.9	14.2±0.7	1.9±1.0	70.5±13.3	18.9±6.2	46.5±11.9	-1.2±6.0
August	37.9±3.3	13.6±2.5	12.1±1.0	1.0±0.3	71.6±8.8	17.7±4.9	47.3±7.4	-2.5±4.3
September	34.5±4.0	9.1±1.5	13.6±2.0	2.3±0.8	75.1±8.8	17.7±5.4	47.7±7.7	-2.9±4.8
October	33.9±3.0	2.3±2.3	21.4±0.2	6.2±0.8	65.5±7.0	15.2±0.4	34.5±5.4	-8.3±1.2
November	31.0±5.2	-0.8±1.9	23.1±1.4	6.9±1.0	81.5±13.6	31.0±19.9	47.2±12.6	5.2±19.1
December	20.8±5.5	-4.1±1.7	17.1±3.7	6.7±0.7	81.9±4.1	34.1±8.2	45.7±3.2	6.6±6.8
Average	32.7±5.3	3.9±6.9	20.3±5.9	4.3±2.7	69.6±9.1	21.7±7.1	38.5±9.6	-2.1±4.9

Table 12. Light intensity and PAR inside a Polycarbonate greenhouse at noon

Month	Light intensity (Lux)		PAR (µmol/m²s)	
	Inside Greenhouse	Difference (Open- Greenhouse)	Inside Greenhouse	Difference (Open- Greenhouse)
January	19208.9±8129.2	42771.1±18100.8	374.2±205.2	651.9±357.6
February	38531.2±11544.2	50018.8±14986.0	728.3±239.2	819.5±269.1
March	58784.7±22460.4	61604.2±23537.6	592.4±157.4	963.6±256.1
April	76219.7±19770.3	57855.3±15162.5	972.3±220.5	831.7±188.6
May	57010.4±41683.2	44889.6±32821.0	1145.8±190.0	593.4±98.4
June	43983.9±16917.5	69966.0±26911.1	675.8±283.6	686.3±288.0
July	59760.6±23923.4	51482.2±20609.4	692.5±208.3	920.2±276.8
August	60784.9±1856.3	73481.8±2244.1	951.0±17.2	949.7±17.2
September	60297.2±6996.5	69977.8±8119.8	904.6±106.3	998.8±117.5
October	41645.2±17744.8	58197.6±24797.7	785.6±73.7	975.3±91.5
November	36374.3±15314.1	36375.6±15314.7	500.9±254.5	644.4±327.4
December	25528.4±13601.0	38921.6±20736.6	439.0±184.8	759.2±319.6
Average	48177.5±16683.4	54628.2±12608.7	730.2±233.8	816.2±146.3

Table 13. Marketable yield and production of vegetable seedlings (per Polycarbonate greenhouse; 120'×30'×10'; L×W×H)

Season	Type of crop	Crop	Variety	Yield/ number
Winter (Mid October to early March)	Leafy vegetable	Spinach	Delta	189.9±43.2 kg
Spring (Late March to early May)	Vegetable seedlings	Onion	Liberty	252840.0±815.6 nos
Summer (Mid May to early October)	Warm season crops	Capsicum	California Wonder	255.3±48.0 kg

Figure 7. A FRP greenhouse in winter.

average PAR inside the greenhouse has been recorded 364.6±158.4 (Table 15) as against 1546.4±300.6 μmol/m^{2}s in open condition.

3.7.3 Marketable Yield and Production of Vegetable Seedlings in FRP Greenhouse

The marketable yield of leafy vegetables during winter; tropical and sub-tropical vegetables in summer; and production of vegetable seedlings in spring are shown in Table 16.

4. PROMOTION OF PASSIVE SOLAR GREENHOUSE IN LADAKH

Realising the importance of greenhouse in Ladakh, there is a campaign for the promotion of passive solar greenhouse in the region. Incentives are being given in the form of subsidy by the Government, besides imparting trainings on greenhouse cultivation. Horticulture Department, Agriculture Department, and Ladakh Renewable Energy Development Agency (LREDA) are the main agencies providing incentives to the farmers for adoption of passive solar greenhouse. Local non-governmental organisations (NGOs) also joined in campaign for promotion of greenhouse. Each year an average of 733 greenhouses covering 44313.4 m^2 area have been established between 2010 and 2018 in Leh district with the support of the Government (Table 17).

Table 14. Temperature and relative humidity inside FRP greenhouse

Month	Temperature (°C)				Relative humidity (%)			
	Inside Greenhouse		Difference (Greenhouse -Open)		Inside Greenhouse		Difference (Greenhouse -Open)	
	Max	Min	Max	Min	Max	Min	Max	Min
January	19.0±3.4	-8.9±2.0	19.1±0.8	2.5±2.1	83.4±2.3	42.7±8.4	46.1±1.0	12.7±7.6
February	20.0±4.8	-5.3±2.3	18.8±2.2	4.5±5.0	90.5±4.7	40.0±6.4	53.6±3.7	14.0±0.4
March	25.4±2.6	-1.9±1.9	20.5±0.6	4.1±1.6	93.9±2.2	37.4±7.3	59.0±0.2	12.2±6.6
April	29.7±2.6	3.8±2.1	17.2±0.9	2.8±0.5	85.2±6.6	26.1±6.4	54.5±5.2	1.5±5.5
May	32.3±2.2	4.2±2.1	15.7±0.5	0.6±1.5	84.4±5.8	22.7±7.6	54.4±3.8	1.4±6.7
June	36.8±4.5	9.9±1.7	17.7±0.5	2.3±0.6	77.2±7.8	22.5±9.4	50.7±6.0	2.2±8.5
July	35.1±4.6	14.4±1.4	10.0±0.6	1.4±1.5	88.7±5.6	46.3±14.7	64.6±4.3	26.2±14.5
August	33.2±3.3	13.0±2.1	7.4±1.0	0.4±0.1	90.2±3.6	39.1±11.6	65.9±2.2	18.8±11.0
September	33.9±5.3	9.4±1.3	13.1±3.3	2.6±0.9	61.2±18.1	18.8±8.4	33.9±17.0	-1.7±7.8
October	34.4±3.8	3.0±2.9	21.9±1.0	6.9±1.4	74.8±5.4	15.1±0.2	43.8±3.8	-8.4±1.3
November	23.3±4.0	-2.2±3.0	15.4±0.2	5.5±0.0	91.0±6.6	37.5±8.8	56.7±5.7	11.7±8.0
December	15.9±4.6	-6.1±1.7	12.3±2.8	4.7±0.7	94.0±2.4	51.9±14.0	57.9±1.4	24.4±12.6
Average	28.2±7.2	2.8±7.8	15.8±4.4	3.1±2.2	84.5±9.5	33.3±11.8	53.5±9.0	9.6±10.7

- The temperature inside the greenhouse often drops to -10 °C or less at night in December and January, which limits growing of only freeze tolerant leafy vegetables;
- Only leafy vegetables can be grown in winter months; plant growth is recorded much slower than that of Polyench or Trench greenhouse;
- The greenhouse structure is not easy to establish and requires qualified personnel to establish the structure;
- High material and installation cost.

3.7.2 Temperature and Relative Humidity inside FRP Greenhouse

The air temperature inside a FRP greenhouse remained below freezing temperature during November to March (Table 14). It remains 16.4±3.2°C warmer during day and 6.3±0.7°C at night in winter (November to February). In summer (June to September) the air temperature inside the greenhouse remains 12.0±4.5°C warmer during day and 1.7±1.0°C at night. The

5. USE OF GREENHOUSE BY FARMERS

Almost every household in Ladakh owns a greenhouse. However, majority of the greenhouse are small in size and are designed to meet the vegetable requirement of a small family[6]. A door-to-door survey involving interviews with 157 farmers

Table 15. Light intensity and PAR inside FRP greenhouse at noon

Month	Light intensity (Lux)		PAR (µmol/m²s)	
	Inside Greenhouse	Difference (Open-Greenhouse)	Inside Greenhouse	Difference (Open-Greenhouse)
January	10009.7±4236.1	51970.3±21993.9	179.2±98.3	846.9±464.5
February	19789.5±5929.1	68760.4±20601.1	320.0±105.1	1227.8±403.2
March	27545.9±10524.7	92842.9±35473.3	220.2±58.5	1335.8±355.0
April	37638.7±9762.9	96436.3±25169.9	612.7±138.9	1191.4±270.1
May	18075.6±13215.9	83824.4±61288.2	503.8±83.5	1235.9±205.0
June	23012.7±8851.4	90937.3±34977.2	434.8±182.5	927.3±389.1
July	25856.7±10350.9	85386.2±34181.8	376.3±113.2	1236.4±371.9
August	30692.3±937.3	103574.3±3163.1	445.2±8.1	1455.6±26.4
September	38722.1±4493.1	91552.9±10623.2	601.1±70.7	1302.3±153.2
October	20162.3±8591.0	79680.6±33951.5	322.3±30.3	1438.7±135.0
November	9903.3±4169.4	62846.7±26459.4	160.1±81.4	985.2±500.5
December	15391.0±8200.0	49059.0±26137.6	200.1±84.3	998.1±420.2
Average	23066.7±9487.8	79739.3±17763.1	364.6±158.4	1181.8±199.3

Table 16. Marketable yield and production of vegetable seedlings (per FRP greenhouse; 100'×30'×11'; L×W×H)

Season	Type of crop	Crop	Variety	Yield/ number
Winter (Mid October to early March)	Leafy vegetable	Spinach	Delta	119.7±20.4 kg
Spring (Late March to early May)	Vegetable seedlings	Cabbage	Golden Acre	171496.8±11433.1 nos
		Cauliflower	Shentha	180654.4±12043.6 nos
		Tomato	Tolstoi	328424.8±6475.1 nos
Summer (Mid May to early October)	Warm season crops	Cucumber	Japanese Long Green	1232.5±525.6 kg

(108 women, 49 men, average age 53 year) across seven villages (Gonpa, Saboo, Saspol, Thiksey, Chamshen, Sumoor, Hunder) were conducted in 2017 and 2018. A structured open ended schedule was used to the obtain data on size and number of greenhouse, usage, cropping pattern and difficulties being faced in greenhouse cultivation. The survey suggested that passive solar greenhouse is being used mainly during winter months and for raising of seedlings in spring. However, majority of the farmers (91.7%) do not use the greenhouse during summer months. Insect-pest, irrigation in winter and frequent replacement of cladding materials are the major problems being faced by the farmers. Therefore, there is an immense scope to improve the greenhouse designs so that the constraints to grow a variety of crops is overcome. Key findings of the survey are shown in Table 18.

6. CONCLUSION

A number of passive solar greenhouse structures have been designed and tested in the inhospitable environment of trans–Himalaya. Almost every household in Ladakh owns a greenhouse. Greenhouse cultivation is popular among farmers for growing of leafy vegetables during winter and raising of nursery in spring. However, the existing structures are not suitable to grow crops other than leafy vegetables and selected root crops in winter. Majority of farmers do not use the greenhouse in summer due to excessive heat that builds up inside the greenhouse. There is a need to improvise the greenhouse design to make it economically viable and technologically feasible to grow a variety of crops, especially during winter months.

Table 17. Number of passive solar greenhouses established with support from various Government agencies in Leh district during 2010-18

Greenhouse type	Greenhouse size (L×W)	Year								
		2018	2017	2016	2015	2014	2013	2012	2011	2010
Ladakhi greenhouse with roof	100′×22′	-	12	14	06	09	07	09	09	09
	63′×22′	-	-	-	-	-	100	100	550	-
	42′×18′	20	-	-	-	-	-	-	-	-
	32′×18′	230	596	115	29	250	576	19	17	38
Ladakhi greenhouse without roof	32′×18′	-	-	-	-	-	1000	1000	500	-
Tubular greenhouse (polyhouse)	31′×13′	218	1043	-	44	75	-	-	-	-
Total		468	1651	129	79	334	1683	1128	1076	47

Table 18. Use of passive solar passive greenhouse by farmers in trans-Himalayan Leh Ladakh

Query	Farmer's response (per cent)	Inference
Number of greenhouse owned	One greenhouse (92.4 %); more than 1 greenhouse (7.6 %)	Majority of the households have one greenhouse
Incentives (subsidy) received from various agencies for establishment of greenhouse	Incentives received from Government agencies (92.4 %); incentives received from NGOs (3.8 %); incentives not received (3.8 %)	Majority of the households (92.4 %) received monetary incentives from Government agencies for establishment of greenhouse
Size of greenhouse (length × width; unit: feet)	32′×18′ (56.3 %); 31′×13′ (23.9 %); 100′×32′ (3.6 %); 65′×24′ (3.0 %); 32′×16′ (1.8 %); 100′×23′ (1.8 %); 30′×15′ (1.8 %); others (7.8 %)	Majority of the greenhouses established were small to medium size
Sale of greenhouse produce for income generation	Yes (59.8 %); No (40.2 %)	Majority of the households sold greenhouse produce for additional income generation
Cladding material (polyethylene sheet) is removed during summer months	Yes (96.2 %); partly removed (3.8 %)	Cladding material is removed during summer months (6-7 months) by majority of the farmers
Reason for removing cladding material during summer months	High temperature inside the greenhouse (93.0 %); high wind speed (7.0 %)	High temperature that buildup inside the greenhouse is the main reason for removing the cladding material in summer
Crops grown inside greenhouse during summer months	Yes (8.3 %); No (91.7 %)	Majority of the farmers (91.7 %) do not use greenhouse for growing crops in summer
Crops grown during winter (100% respondent)	Spinach (97.3 %); coriander (84.0 %); mint (38.6 %); turnip (28.6 %); celery (17.3 %); lettuce (14.0 %); radish (6.6 %); carrot (3.3 %)	Majority of farmers grow only leafy vegetables in winter months
Seedlings raised in spring (22.9% respondent)	Onion (80.5 %), cabbage (58.3 %), cauliflower (36.1%), knol-khol (30.5 %), tomato (13.8 %)	Onion and cabbage seedlings are mostly raised in the greenhouse
Crops grown during summer (8.3% respondents)	Tomato; capsicum; brinjal; cucumber; bottle gourd; spinach; others	Tomato, capsicum and brinjal were the most widely grown crops in summer
Plan to construct greenhouse in coming two years	Yes (49.6 %); No (50.4 %)	50% of the farmers wants to establish more greenhouse in coming years
Main constraints in greenhouse cultivation	Insect-pest (27.7 %); water scarcity in winter (15.9%); frequent replacement of cladding material (8.3 %); others (25.2 %); no problem (22.9 %)	Insect-pest, irrigation in winter and frequent replacement of cladding materials are the major problems being faced by the farmers

Conflict of Interest: None

REFERENCES

1. Dame, J. & Nüsser, M. Food security in high mountain regions: Agricultural production and the impact of food subsidies in Ladakh, Northern India. *Food Sec*., 2011, **3**, 179-94. doi: 10.1007/s12571-011-0127-2.
2. Stobdan, T.; Dolkar, P.; Chaurasia, O.P. & Kumar, B. Seabuckthorn (*Hippophae rhamnoides* L.) in Trans-Himalayan Ladakh, India. *Def. Life Sci. J*., 2017, **2**, 46-53. doi: 10.14429/dlsj.2.11074.
3. Stobdan, T.; Angmo, S.; Angchok, D.; Paljor, E.; Dawa, T.; Tsetan, T. & Chaurasia, O.P. Vegetable production scenario in trans-Himalayan Leh Ladakh region, India. *Def. Life Sci. J*., 2018, **3**, 85-92. doi: 10.14429/dlsj.3.11661.
4. Pelliciardi, V. From self-sufficiency to dependence on imported food-grain in Leh district (Ladakh, Indian trans-Himalaya). *Eur. J. Sustain. Dev.*, 2013, **2**, 109-22. doi: 10.14207/ejsd.2013.v2n3p109.
5. www.market.todaypricerates.com (accessed on 24 Feb 2019).
6. Angmo, S.; Angmo, P.; Dolkar, D.; Norbu, T.; Paljor, E.; Kumar, B. & Stobdan, T. All year round vegetable cultivation in trenches in cold arid trans-Himalayan Ladakh. *Def. Life Sci. J*., 2017, **2**, 5-58. doi: 10.14429/dlsj.2.11001.
7. Angchok, D. & Srivastava, R.B. Technology intervention and repercussion among high altitude community of Ladakh: A case study of trench greenhouse. *Indian Res. J. Exten. Educ*., 2012, **1**, 268-71.
8. Mishra, G.P.; Singh, N.; Kumar, H. & Singh, S.B. Protected cultivation for food and nutritional security at Ladakh. *Def. Sci. J*., 2010, **60**, 219-25. doi: 10.14429/dsj.60.343.
9. Raj, A.; Kanwar, M.S. & Namgyal, D. Temperature and

humidity regimes in different types of greenhouse in Ladakh. In: Protected structure for high Himalayas design and application. High mountain arid agriculture research institute, India, 2016. pp 81-7.

10. Dwivedi, S.K., Paljor, E. & Ahmed, Z. Designing and evaluation of a low cost underground (Trench) greenhouse structure for crop production in cold arid zones. *J. Rural Tech*., 2016, **3**, 34-6.
11. Singh, B. Studies on suitability of various structures for winter vegetable production at sub zero temperatures. *Acta Hort*., 2000, **517**, 309-14.
12. Akbar, P.I.; Kanwar, M.S.; Mir, M.S. & Hussain, A. Protected vegetable cultivation technology for cold arid agro-ecosystem of Ladakh. *Int. J. Hortic.*, 2013, **3**, 109-13.
    doi: 10.5376/ijh.2013.03.0019.
13. Singh, N. & Ahmed, Z. Double-walled polyench greenhouse. *Indian Hortic*., 2007, May-Jun: 8-9.
14. Singh, N. & Nazir, S. Polyench: A cost effective greenhouse for Ladakh. In: protected structure for high Himalayas design and application. High mountain arid agriculture research institute, India, 2016. pp 81-7.
15. Singh, R.; Mishra, G.P.; Ahmed, Z. & Singh, S.B. Effect of various greenhouse structures on yield and quality of different table tomato (*Lycopersicon esculentum*) varieties under cold arid desert of trans-Himalayas. *Indian J. Agr. Sci*., 2009, **79**, 243-7.

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