Defence Life Science Journal, Vol. 8, No. 3, July 2023, pp. 209-216, DOI : 10.14429/dlsj.8.18752

Effect of Cladding Material and Date of Transplanting on Growth and Yield of Greenhouse Broccoli During Winter in High Altitude Ladakh, India

Tsering Dolma, Anand K. Katiyar, Rohit Kumar, O.P. Chaurasia and Tsering Stobdan*

Defence Institute of High Altitude Research, Leh Ladakh–194 101, India

**Email: stobdan.dihar@gov.in*

ABSTRACT

Broccoli is a cool-season crop. The optimum temperature for initiation of flowering and head growth is 15-20°C. Due to subfreezing temperatures at night, the crop is not traditionally cultivated in winter in the high-altitude Ladakh region. We found that growing broccoli in a passive solar greenhouse in winter is feasible. The choice of greenhouse cladding material and the date of transplanting are important factors that need to be considered. The mean marketable head weight of the cv. Fiesta and KTS-1 in a passive solar trench greenhouse with polycarbonate cladding material transplanted on 8 September were 403±106 and 169±100 g, respectively. Delayed transplanting on 8 October did not produce any marketable head. Covering the greenhouse with a polyethylene sheet did not result in marketable heads on both transplanting dates. We anticipate our study to be a starting point for researchers and the farming community to optimize the greenhouse production of broccoli during freezing winter-months in high-altitude regions.

Keywords: *Brassica oleracea*; Greenhouse; Growing degree days; Heat unit; Protected cultivation

1. INTRODUCTION

Broccoli (*Brassica oleracea* L. var. *italica* Plenck) is a major vegetable crop worldwide and is grown for the fresh vegetable market and processed food industry[1]. It is a high-value crop valued for its chemopreventive effect[2-3].

Broccoli is a cool-season crop and highly sensitive to temperature. The optimum temperature for initiation of heading (flowering) and head growth is 15-20°C. The crop needs a prolonged thermal time to head initiation if exposed to higher or lower temperatures than the optimum in the course of its growth cycle. Head initiation or head growth does not occur at temperatures lower than 0 °C or higher than 25-30 °C[1], and development is predominantly governed by temperature rather than photoperiod[4]. Temperatures above 25 °C adversely affect broccoli quality. Most broccoli germplasms require vernalization at temperatures below 23 °C. However, some broccoli germplasms do not require vernalization, but floral development at temperatures above 30 °C results in undesirable traits making the broccoli products unmarketable[5-7]. Of late, significant development have been made in developing heat-tolerant breeding lines[8].

Broccoli is a sought-after summer crop in the high-mountain Ladakh region. The seedling is transplanted in early May, and the plant attains the harvestable stage in July-September[9]. However, broccoli is not grown in the region during winter due to freezing temperatures. The current study was thus conducted with the objectives: (1) to find out the practicality of cultivating broccoli in winter in a passive solar trench greenhouse in the Ladakh region; (2) to study the effect of greenhouse cladding material on the growth and yield of broccoli; (3) to evaluate the effect of two transplanting dates on growth and yield of greenhouse broccoli; (4) to determine growing degree days (GDDs) in harvesting greenhouse broccoli.

Received : 14 December 2022, Revised : 12 May 2023
Accepted : 22 May 2023, Online published : 12 October 2023

2. MATERIALS AND METHODS

2.1 Study site and production environments

The investigation was conducted in the Ladakh region (34°08.2'N; 77°34.3'E, 3340 m AMSL). Two cultivars of broccoli were grown in two passive solar Polytrench greenhouses covered with different cladding materials. Polytrench is a trench (30 feet length×10 feet width×3 depth) in a north-south orientation. It has an above-ground tunnel-shaped frame on which the covering material is fixed. The two greenhouses were established nearby with similar shapes and sizes other than the cladding material. The first Polytrench was covered with translucent polyethylene (120 grams per square meter) (PT-Polyethylene), while the second was covered with 16 mm clear three-layer polycarbonate (PT-Polycarbonate).

2.2 Experimental design

Two cultivars of broccoli – Fiesta and KTS-1 were used. Three replication plots were taken for each cultivar

in the two greenhouses. Each replication plot was 2.5×1.3 m consisting of 18 plants at 35×35 cm spacing. The same cultural practices were followed in the two greenhouses. FYM (3 kg per m^2) was applied during field preparation. Vermicompost (500 g per plot) was applied after the first and second weeding at 30 and 60 days after transplanting (DAT). Seedlings were transplanted on two different dates at one month interval- 8 September and 8 October 2020. Irrigation was provided by flooding twice a week in September and October, 15 days intervals in November, and once in December.

2.3 Determination of Growing Degree Days (GDD)

GDD from transplanting to floral initiation (TFI) and floral initiation to harvest maturity (FIHM) were computed using the formula[10].

$$GDD = \sum \left[\frac{Tmax + Tmin}{2} - Tbase \right]$$

where *T*max and *T*min are the maximum and minimum daily temperature, respectively, and *T*base is the base temperature of 4.5 ºC[11]. The light intensity was measured with a light meter, and photosynthetically active radiation (PAR) was recorded with a radiometer. The meteorological data of the three growing environments are presented in Tables 1 & 2.

2.4 Growth and Yield Attributes

Plant growth parameters were recorded at 0, 30, 60, and 90 DAT. The relative growth rate (RGR), leaf weight ratio (LWR), specific leaf area (SLA), and net assimilation rate (NAR) from TFI and FIHM were recorded as described previously[12]. Weekly spear diameters were also recorded after spear initiation. Marketable weight was recorded thrice.

2.5 Statistical Analysis

The experimental results were expressed as mean±standard deviation using statistical analysis with SPSS. One-way

Table 1. Temperature and relative humidity inside two greenhouses and open-field in the Ladakh region

Parameter	Month/ Mean	Polytrench-Polycarbonate		Polytrench-Polyethylene		Open-field	
		Max	Min	Max	Min	Max	Min
Maximum and minimum temperature (ºC)	September	38.8±1.8	18.6±2.1	36.5±2.3	10.7±2.4	21.9±4.6	7.2±3.8
	October	32.8±2.4	10.5±2.4	30.8±1.9	3.2±1.8	15.7±3.4	-2.6±2.0
	November	25.0±4.9	3.8±2.4	23.4±5.6	-3.9±2.7	6.7±3.5	-7.6±2.7
	December	23.1±4.1	0.7±3.0	22.4±4.1	-7.2±3.7	2.4±3.4	-12.8±5.1
	January	24.6±2.9	-1.7±1.5	21.4±3.2	-8.5±1.7	0.8±2.0	-15.3±2.4
	February	31.6±3.9	2.8±2.3	27.8±3.5	-5.3±3.1	5.5±2.7	-9.8±3.4
	*Mean	29.1±7.0	7.5±7.0	27.6±6.7	-0.2±7.1	10.7±8.4	-5.0±8.1
	**Mean	26.8±5.3	3.0±4.5	24.8±5.2	-4.5±4.7	5.7±5.6	-10.0±5.2
Maximum and minimum relative humidity (%)	September	85.8±1.2	15.4±0.7	60.1±9.0	15.0±0.0	40.9±9.7	11.4±3.0
	October	92.5±11.4	34.1±13.4	64.1±10.9	16.5±4.0	33.0±11.9	10.3±3.9
	November	93.9±2.6	51.6±15.2	78.0±6.8	31.5±15.4	52.6±16.6	20.5±8.6
	December	91.4±15.5	62.5±7.2	71.0±8.1	34.5±9.6	60.6±13.6	25.9±8.0
	January	92.3±2.5	54.4±7.2	65.6±4.3	26.8±7.7	60.6±14.7	27.4±11.5
	February	88.9±1.6	46.4±4.2	66.6±3.2	20.7±6.8	51.5±13.8	19.8±5.7
	*Mean	91.3±10.4	43.3±20.3	69.0±10.9	25.3±12.8	48.1±16.7	17.7±8.9
	**Mean	92.1±9.5	51.5±13.3	69.8±9.0	27.0±11.8	52.7±17.0	21.1±9.7

*Mean: 1st transplant- seedlings transplanted on 8 September and final harvest on 28 December 2020

**Mean: 2nd transplant- seedlings transplanted on 8 October and final harvest on 20 February 2021

Table 2. Light intensity, PAR and UV-B at noon inside two greenhouses and open-field in the Ladakh region

Parameter	Month/ Mean	Polytrench-Polycarbonate	Polytrench-Polyethylene	Open-field
Light intensity (kilolux)	September	59.4±8.[a]	62.5±4.8[b]	95.0±9.2[c]
	October	38.4±5.9[a]	49.1±2.[b]	73.9±8.9[c]
	November	27.8±7.1[a]	30.0±7.5[b]	64.2±9.5[c]
	December	22.0±3.8 [a]	23.8±8.3[a]	58.3±8.9[b]
	January	21.0±9.7[a]	26.9±1.9[b]	46.3±7.8[c]
	February	34.9±4.4[a]	37.9±5.7[b]	67.2±8.9[c]
	*Mean	36.9±16.9[a]	41.4±17.7[b]	72.9±16.1[c]
	**Mean	26.4±6.4[a]	29.7±6.[b]	59.0±9.2[c]
PAR (µmol/m^{2}s)	September	799.9±219.6[a]	885.9±103.4[b]	1245.9±216.9[c]
	October	654.2±34.9[a]	705.0±54.3[b]	1238.8±14.9[c]
	November	347.6±180.6[a]	432.2±115.4[b]	812.9±330.9[c]
	December	282.4±87.2[a]	305.5±96.7[b]	632.6±154.8[c]
	January	222.2±55.7[a]	264.1±145.7[b]	658.4±293.5[c]
	February	596.4±109.8[a]	575.0±29.3[b]	762.6±391.4[c]
	*Mean	521.0±246.7[a]	582.2±262.3[b]	982.6±308.9[c]
	**Mean	362.1±164.4[a]	394.2±140.2[b]	716.6±85.3[c]
UV-B (µW/cm^2)	September	0.02±0.00[a]	1.57±0.16[b]	16.8±2.3[c]
	October	0.02±0.01[a]	2.05±0.2[b]	13.8±2.7[c]
	November	0.02±0.01[a]	0.50±0.28[a]	8.3±1.7[b]
	December	0.01±0.00[a]	0.73±0.54[b]	5.1±2.3[c]
	January	0.00±0.00[a]	0.40±0.16[a]	4.3±1.6[b]
	February	0.01±0.00[a]	0.92±0.04[b]	8.8±2.8[c]
	*Mean	0.02±0.01[a]	1.21±0.72[b]	11.0±5.3[c]
	**Mean	0.01±0.00[a]	0.64±0.23[b]	6.63±2.26[c]

*Mean: 1st transplant- seedlings transplanted on 8 September and final harvest on 28 December 2020
Mean:** 2nd transplant- seedlings transplanted on 8 October and final harvest on 20 February 2021
For each row different lowercase letters indicate significantly different at $p \leq 0.05$ as measured by Tukey's test

analysis of variance (ANOVA) and post hoc analysis with 2-sided Tukey's HSD at $p \leq 0.05$ level was performed.

3. RESULTS AND DISCUSSION

3.1 Microclimate in the two Polytrench greenhouses

The micro-climate inside the two Polytrench greenhouses and open fields are presented in Tables 1 & 2. A significant difference in the temperature was recorded in the two Polytrenches differing in cladding material. During the first transplanted cropping season, the mean maximum and minimum temperature in the greenhouse with polycarbonate sheet was 29.1±7.0 and 7.5±7.0, respectively. In comparison, the maximum temperature inside the greenhouse with polyethylene sheet was 2.8±2.3ºC lower during day time, while the minimum temperature was 7.7±0.9ºC colder at night. The maximum and minimum temperature inside the PT-Polycarbonate was warmer by 18.7±4.0ºC and 12.3±2.6ºC, respectively, as compared to the open field. The difference in temperature inside the two greenhouses was due to the use of different covering materials. Polycarbonate has better thermal efficiency as compared to polyethylene. Similarly, the mean maximum and minimum relative humidity inside the PT-Polycarbonate was 91.3±10.4 and 43.3±20.3% as against 69.0±10.9 and 25.3±12.8%, respectively, in PT-Polyethylene. A significant difference in PAR was observed between the two greenhouses. At noon the mean PAR inside PT-Polycarbonate was 521.0±246.7 µmol/m^{2}s as against 582.2±262.3 µmol/m^{2}s inside the PT-Polyethylene. In comparison, the open-field PAR was

982.6±308.9 µmol/m^{2}s. The two Polytrenches also vary significantly in light intensity and UV-B transmittance.

3.2 Growth Attributes

The growth of two cultivars of broccoli plants is presented in Table 3. The crop height, number of leaves, and stem diameter were significantly higher in PT-Polycarbonate at 30 DAT in both varieties. The RGR of plants grown under PT-Polyethylene was significantly low than that of the plant grown under PT-Polycarbonate greenhouse conditions. During TFI of the 1st transplant, the RGR of cv Fiesta under PT-Polycarbonate was 52.6±5.9 against 40.4±3.6 mg g^{-1}d^{-1} in PT-Polyethylene. A similar observation was recorded in the cv. KTS-1.

SLA was significantly higher in PT-Polycarbonate than PT-Polyethylene in both the cultivars during TFI in 1st transplant. Lower SLA in PT-Polyethylene indicated that holding the captured resource is a higher priority. The NAR did not follow a trend in both cultivars under the two greenhouse conditions. The notable cultivar difference in NAR was observed in Fiesta during TFI, while no significant difference was observed in cv KTS-1.

Similarly, the LAR of both the varieties transplanted on 8 September (1st transplant) were significantly higher in the crop grown under the PT-Polycarbonate greenhouse than that of the PT-Polyethylene greenhouse. Lower growth inside the PT-Polyethylene greenhouse may be due to colder night temperatures. Plants transplanted late (2nd transplant) showed lower plant growth than those transplanted earlier (1st transplant). The mean maximum and minimum temperature of 2nd transplant crop duration was significantly lower than that of the 1st transplanted crop duration. In the sub-optimal temperature range, the RGR reduces at lower average temperatures[13].

The weekly increase in head diameter of both cultivars is presented in Table 4. A significant increase in head diameter was recorded in cv. Fiesta and KTS-1 under PT-Polycarbonate in the first transplant. However, bolting or no head initiation was recorded in the 2nd transplant as well as under PT-Polyethylene.

3.3 Days and Heat Unit Requirements for the First Harvest

Production environment and cultivar had significant effects on the number of days required for floral initiation and harvest (Table 5). Fiesta and KTS-1 required 56 and 58 days, respectively, for floral initiation in PT-Polycarbonate in 1st transplant, while it needed 75 and 112 days in the PT-Polyethylene greenhouse. Late transplanting (2nd transplant) delayed floral initiation by 46 and 40 days in cv. Fiesta and KTS-1, respectively, in the PT-Polycarbonate greenhouse. The GDDs for floral initiation ranged from 991.6-985.5ºC days. The cultivars required 101 days and 1384.2ºC GDDs for the first harvest

Table 3. Growth parameters of two commercial varieties transplanted on two different dates inside two Polytrench greenhouses in the Ladakh region

Growth parameter	Time period	Fiesta				KTS-1			
		1st transplant		2nd transplant		1st transplant		2nd transplant	
		Polytrench-Polycarbonate	Polytrench-Polyethylene	Polytrench-Polycarbonate	Polytrench-Polyethylene	Polytrench-Polycarbonate	Polytrench-Polyethylene	Polytrench-Polycarbonate	Polytrench-Polyethylene
Plant height (cm)	30 DAT	51.0±5.3***	35.1±5.1***	33.2±5.0*	21.6±1.4*	39.3±1.6**	30.4±1.8**	27.8±3.1*	19.5±3.2*
	60 DAT	84.4±2.0***	64.7±1.1***	41.9±7.1*	28.3±3.1*	79.0±5.9**	58.2±4.3**	43.9±6.5**	20.5±1.5**
	90 DAT	88.8±0.4***	67.5±3.5***	43.6±7.0*	28.9±2.8*	83.4±6.0**	60.8±2.6**	45.7±6.7**	21.1±1.5**
No. of leaves	30 DAT	9.7±1.2***	8.3±1.5***	7.3±0.6	7.0±1.7	9.7±1.5	8.3±0.6	7.7±0.6	7.3±1.5
	60 DAT	21.3±1.2***	14.7±1.5***	10.3±0.6	9.0±2.6	17.3±1.5	13.3±3.2	10.0±1.0*	8.0±1.0*
	90 DAT	23.3±3.1***	16.0±1.0***	13.7±3.2	10.3±2.5	20.3±1.5	15.3±4.9	15.3±0.6***	9.3±0.6***
Leaf thickness (mm)	30 DAT	0.26±0.03	0.30±0.0.02	0.22±0.03	0.25±0.01	0.29±0.06	0.27±0.05	0.19±0.03*	0.24±0.01*
	60 DAT	0.22±0.03	0.25±0.01	0.15±0.02**	0.29±0.04**	0.23±0.05	0.23±0.01	0.20±0.02**	0.29±0.02**
	90 DAT	0.19±0.03	0.25±0.02	0.25±0.01**	0.48±0.05**	0.23±0.03	0.23±0.02	0.22±0.01***	0.43±0.02***
Stem diameter (mm)	30 DAT	13.7±0.8*	7.3±0.9*	4.92±0.13	4.09±0.53	9.0±0.6**	6.70±0.41**	4.30±1.21	2.76±0.65
	60 DAT	18.6±0.9*	14.0±1.6*	7.29±1.00	5.75±0.87	16.1±2.8	14.6±1.0	6.89±1.07*	3.96±0.63*
	90 DAT	21.3±2.0*	15.7±0.6*	8.06±1.24	6.36±0.55	17.8±3.4	15.8±1.4	8.24±1.29*	4.55±0.83*

Chlorophyll (SPAD)	30 DAT	56.7±10.4	58.7±0.8	50.5±2.0	56.4±0.4	44.6±2.9	46.6±3.2	43.7±3.4*	54.1±2.0*
	60 DAT	68.1±2.2	67.3±0.2	60.7±3.9	66.3±3.9	54.8±2.7	55.9±4.4	46.7±3.4*	56.4±5.5*
	90 DAT	68.1±1.9	73.5±3.7	64.8±3.6*	51.4±6.0*	63.7±0.7	60.1±3.1	57.7±7.8	55.5±3.2
RGR	TFI	52.6±5.9*	40.4±3.6$^{*}_{***}$	24.7±3.1	No initiation	47.5±3.6***	24.4±1.7$^{***}_{***}$	23.6±2.4	No initiation
	FIHM	8.9±0.4	Not matured	9.8±1.3	-	9.3±0.8	Not matured	13.1±2.9	-
LAR	TFI	108.5±14.2**	57.5±2.0**	50.9±7.0	No initiation	95.8±13.3**	64.6±7.2**	65.4±7.1	No initiation
	FIHM	55.8±4.7	Not matured	38.2±2.5$_{*}$	-	76.8±21.7	Not matured	31.84±1.68$_{*}$	-
SLA	TFI	154.78±42.4*	74.50±0.89*	78.68±8.60$_{*}$	No initiation	130.88±13.42***	86.78±8.43***	93.83±6.7$_{*}$	No initiation
	FIHM	105.07±3.12	Not matured	68.0±17.33$_{*}$	-	132.32±26.71	Not matured	105.21±5.30$_{*}$	-
LWR	TFI	0.72±0.10	0.77±0.03	0.65±0.03	No initiation	0.73±0.03	0.74±0.01	0.70±0.04	No initiation
	FIHM	0.53±0.03	Not matured	0.34±0.07	-	0.57±0.07	Not matured	0.30±0.03	-
NAR	TFI	0.49±0.12*	0.70±0.04$^{*}_{***}$	0.50±0.14	-	0.51±0.11	0.38±0.03$_{***}$	0.36±0.10	-
	FIHM	0.16±0.02	Not matured	0.26±0.05	-	0.13±0.04	Not matured	0.41±0.10	-

Values represented as mean ± SD; 1st transplant: seedlings transplanted on 8 September and final harvest on 28 December 2020; 2nd transplant: seedling transplanted on 8 October and final harvest on 20 February 2021; DAT: days after transplanting; TFI: transplanting to floral initiation; HIHM: floral initiation to harvest maturity; LA: leaf area (cm^2); RGR: relative growth rate (mg g^{-1} d^{-1}); SLA: specific leaf area (cm^2g^{-1}); LWR: leaf weight ratio (g/g^{-1}); LAR: leaf area ratio (cm^{-2} g^{-1}); NAR: net assimilation rate (mg cm^{-2} d^{-1}) Independent Student t-test: * significant at $p \leq 0.05$; **Significant at $p \leq 0.01$; ***Significant at $p \leq 0.001$; Superscript * showed significantly different within the same variety in Polytrench-Polycarbonate and Polytrench-Polyethylene on the same date of transplanting; Subscript * represents significantly different between the two varieties within the same greenhouse on the same date of transplanting

Table 4. Weekly head diameter (cm) of two broccoli varieties transplanted on two different dates inside two Polytrench greenhouses in the trans-Himalayan Ladakh region

1st transplant					2nd transplant				
Date after floral initiation	Fiesta		KTS-1		Date after floral initiation	Fiesta		KTS-1	
	Polytrench-Polycarbonate	Polytrench-Polyethylene	Polytrench-Polycarbonate	Polytrench-Polyethylene		Polytrench-Polycarbonate	Polytrench-Polyethylene	Polytrench-Polycarbonate	Polytrench-Polyethylene
11-11-2020	2.7±0.7^{a}	-	1.3±0.54^{a}	-	19-01-2021	-	No floral initiation	1.3±0.3^{a}	No floral initiation
17-11-2020	4.2±1.8^{a}	1.2±0.1^{a}	2.2±0.6^{ab}	1.2±0.1^{a}	22-01-2021	1.5±0.1^{a}	-	-	-
25-11-2020	5.8±2.1^{ab}	1.3±0.2^{a}	3.1±1.0^{ab}	1.3±0.2^{a}	26-01-2021	-	-	3.4±0.6^{b}	-
02-12-2020	8.2±2.8^{abc}	1.7±0.4^{a}	4.5±2.0^{abc}	1.6±0.4^{a}	29-01-2021	4.1±0.4^{b}	-	Bolting	-
09-12-2020	12.1±3.6^{bc}	1.8±0.4^{a}	7.6±2.8^{bc}	1.7±0.4^{a}	05-02-2020	Bolting	-	-	-
16-12-2020	14.1±2.5^{c}	Bolting	9.7±4.3^{c}	Bolting	-	-	-	-	-

Values represented as mean ± SD
1st transplant: seedlings transplanted on 8 September and final harvest on 28 December 2020
2nd transplant: seedling transplanted on 8 October and final harvest on 20 February 2021
For each column different superscripts represent significant different at $p \leq 0.05$ as measured by Tukey's test

Figure 1. Broccoli (cv. Fiesta) on 23 December grown inside PT-Polycarbonate (A) and PT-Polyethylene (B)

Table 5. Mean number of days and growing degree days to floral initiation, first harvest, and final harvest in the two Polytrench greenhouses in the Ladakh region

Days/ GDDs	Fiesta				KTS-1			
	1st transplant		2nd transplant		1st transplant		2nd transplant	
	Polytrench-Polycarbonate	Polytrench-Polyethylene	Polytrench-Polycarbonate	Polytrench-Polyethylene	Polytrench-Polycarbonate	Polytrench-Polyethylene	Polytrench-Polycarbonate	Polytrench-Polyethylene
Number of days to floral initiation	56***	75***	100	No floral initiation	58***	112***	98	No floral initiation
Number of days to first harvest	101	No harvest	No harvest	No harvest	101	No harvest	No harvest	No harvest
Number of days to final harvest	113	No harvest	No harvest	No harvest	113	No harvest	No harvest	No harvest
GDDs to floral initiation (°C days)	961.6***	970.6***	1036.5	No floral initiation	989.5***	946.4***	1014.7	No floral initiation
GDDs to first harvest (°C days)	1384.2	No harvest	No harvest	No harvest	1384.2	No harvest	No harvest	No harvest
GDDs to final harvest (°C days)	1459.9	No harvest	No harvest	No harvest	1459.9	No harvest	No harvest	No harvest

Independent Student t-test: * significant at $p \leq 0.05$; **Significant at $p \leq 0.01$; ***Significant at $p \leq 0.001$ within the same variety in Polytrench-Polycarbonate and Polytrench-Polyethylene on same date of transplanting
GDDs: Growing degree days
1st transplant: seedlings transplanted on 8 September and final harvest on 28 December 2020
2nd transplant: seedling transplanted on 8 October and final harvest on 20 February 2021

under PT-Polycarbonate in 1st transplant (8 September). Broccoli is a cool-season crop. The optimum temperature for floral initiation is 15-20°C. The plant requires a longer thermal time to head initiation if exposed to lower or higher temperatures than the optimum during growth. No floral initiation is expected if the temperature is below 0°C or more than 25-30 °C[1].

3.4 Marketable Yield

The head was formed in both cultivars when transplanted on 8 September in PT-Polycarbonate. However, no marketable head was formed in PT-Polyethylene. Plants transplanted late on 8 October did not result in head formation in both greenhouse types. The average marketable head weight of the cv. Fiesta and KTS-1 in PT-Polycarbonate in 1st transplant was 403±106 and 169±100 g, respectively

Table 6. Marketable yield and physiological disorders in two commercial broccoli varieties transplanted on two different dates inside two Polytrench greenhouse in the Ladakh region

Yield/ physiological disorder	Fiesta				KTS-1			
	1st transplant		2nd transplant		1st transplant		2nd transplant	
	Polytrench-Polycarbonate	Polytrench-Polyethylene	Polytrench-Polycarbonate	Polytrench-Polyethylene	Polytrench-Polycarbonate	Polytrench-Polyethylene	Polytrench-Polycarbonate	Polytrench-Polyethylene
Marketable yield (g)	403±106	-	-	-	169±100	-	-	-
Bolting (%)	16.6	-	33.3	-	11	-	55.6	-
Blindness (%)	-	100	66.7	100	-	100	44.4	100
Rotting (%)	-	-	-	-	16.7	-	-	-

1st transplant: seedlings transplanted on 8 September and final harvest on 28 December 2020
2nd transplant: seedling transplanted on 8 October and final harvest on 20 February 2021

(Table 6). The marketable head weight was remarkably lower than the yield potential of the cultivars, which may be the result of the high day temperature inside the greenhouse. Head growth of broccoli is also temperature dependent. The optimum condition for head growth is 15-20°C. No head growth is expected at temperatures below 0-5°C or above 25-30°C[1].

3.5 Physiological Disorder

Broccoli head physiological disorders are of major significance for the marketability of the heads. Bolting was observed in 16.6% of the plants in cv. Fiesta and 11% in cv. KTS-1 under PT-Polycarbonate during 1st transplant. However, late transplanting (2nd transplant) resulted in an increase in bolting percentage- 33.3% in cv. Fiesta and 55.6% in cv. KTS-1 in the same greenhouse. Late transplanting also resulted in an increase in blindness- 66.7% in cv. Fiesta, 44.4% in cv. KTS-1 under PT-Polycarbonate. No floral initiation was observed in the PT-Polyethylene greenhouse in both cultivars.

4. CONCLUSION

Broccoli is a high-value cool-season vegetable valued for its chemopreventive effect. It is known to be highly sensitive to temperature. Head initiation or head growth does not occur at temperatures lower than 0°C or higher than 25-30°C. The climatic condition of the high mountain Ladakh region in summer is congenial for growing broccoli, but it is not grown during the winter due to freezing temperatures. In this study, the practicality of producing broccoli in freezing winter was studied in passive solar greenhouses. We found that broccoli production is achievable in winter in a passive solar greenhouse with high-temperature fluctuation, -1.7°C at night to 38.8°C day temperature. The choice of greenhouse cladding material and the date of transplanting are important factors that need to be considered.

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CONTRIBUTORS

Ms Tsering Dolma is currently working as a Senior Research Fellow and pursuing her Ph.D. in the Plant Science Division, DRDO-Defence Institute of High Altitude Research, Leh. She received MSc (Botany) from HNB Gharwal University, Uttrakhand. Her area of expertise is greenhouse vegetable production.

She conducted the study, analysed the data, and contributed towards literature collection and manuscript preparation.

Dr Anand K Katiyar is working as Scientist 'E' at DRDO-Defence Institute of High Altitude Research, Leh. He obtained his MSc (Agricultural Extension) from Banaras Hindu University and Ph.D. from CSAUAT, Kanpur. He has research experience in agriculture extension in Ladakh region.

He contributed in experimental design and manuscript preparation.

Mr Rohit Kumar is Technical Officer 'A' in Horticulture Division at DRDO-Defence Institute of High Altitude Research, Leh. He received his BSc from Panjab University. His area of expertise is temperate horticultural crops.

He contributed towards data collection.

Dr O.P. Chaurasia is Scientist 'G' and Director, DRDO-Defence Institute of High Altitude Research, Leh. He obtained his PhD (Botany) from Magadh University Bodh Gaya, Bihar. He has extensively surveyed trans-Himalayan belts of Ladakh and Lahaul-Spiti and documented the fragile plant biodiversity and its ethnobotanical wealth.

He contributed in manuscript preparation.

Dr Tsering Stobdan is Scientist 'F' and Head, Horticulture Division at DRDO-Defence Institute of High Altitude Research, Leh. He received his PhD from Indian Agricultural Research Institute, New Delhi. His areas of expertise are temperate horticultural crops and protected cultivation.

He conceived the study and contributed in manuscript preparation.