Defence Life Science Journal, Vol. 5, No. 4, October 2020, pp. 292-298, DOI : 10.14429/dlsj.5.15817

Growing Cabbage (*Brassica oleracea* var *capitata* L.) in Cold Winter under Passive Solar Greenhouse in Trans-Himalayan Ladakh Region

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ABSTRACT

Greenhouse experiments were conducted in three seasons (2017-18, 2018-19, 2019-20) to study the feasibility to grow cabbage, a temperature sensitive crop, during freezing winter months at high altitude (elevation 3340 m) trans-Himalayan Ladakh region. Three varieties *viz.* Golden Acre, Videshi and Megaton were studied under an improvised passive solar greenhouse. Head was formed in all the varieties despite the temperature extremes (0.0±1.6 to 39.5±0.9 ºC) inside the greenhouse. The mean marketable head weight ranged from 428.6±72.1 g to 831.2±193.0 g, depending on the variety. The mean head weight of Golden Acre was 831 g, which is 15-fold higher as compared to that of the crop grown under traditional greenhouse in Ladakh. However, the marketable head weight was lower as compared to the yield potential of the varieties. It took 133-163 days for Golden Acre to reach maturity for harvest as compared to the expected 60-65 days. Dramatic declines in intercellular CO_2 concentration, photosynthesis rate and water-use efficiency were observed at 2:00 PM, which indicated that the plants were severely affected by high temperatures inside the greenhouse. High temperature inside the greenhouse resulted in bolting, head-splitting and loose head forming, and it ranged from 8-36% of the crop depending on the year and variety. The study suggested that cabbage can be successfully grown under improvised passive solar greenhouse during severe winter months in the trans-Himalayan Ladakh.

Keywords: Diurnal temperature variation; Protected cultivation; High altitude agriculture

1. INTRODUCTION

The high mountain Ladakh region, situated at an average altitude of over 3000 m asl, is characterised by extreme temperature variations, low precipitation, sparse plant density, thin atmosphere with high UV-radiation and fragile ecosystem. The temperature drops down to -30 ºC in winter. Long harsh winters reduce the cropping season to just four to five months in a year, and the region remains cut-off for over six months in a year due to heavy snowfall. The availability of locally grown fresh vegetables is restricted to summer months, and therefore, there are seasonal differences in dietary intake of food[1]. Self-sufficiency in fresh vegetable is an important issue for the region. During winter a limited quantity of fresh vegetables is brought in by air paying as much as Rs 80-110 per kg just for the air freight from Delhi to Leh. Therefore, fresh vegetables are 2.7-fold costlier in Ladakh as compared to metropolitan city Delhi[2]. Meeting the demand of fresh vegetables during winter months at an affordable price is, therefore, a formidable challenge in this remote mountain area.

A large number of passive solar greenhouse structures have been designed and tested in the region to produce fresh vegetables during winter months. Almost every household in Ladakh now owns a greenhouse. However, the temperature inside the traditional passive solar greenhouse often drops to sub-zero degree Celsius at night during winter months, which limits growing of only freeze tolerant leafy vegetables such as spinach, beet leaf, coriander and lettuce[2]. However, the microclimate conditions inside the greenhouse are not suitable for growing temperature sensitive crops.

Cabbage is a temperature sensitive cool-season biennial crop grown for its tightly packed leaves called head[3,4]. The optimum temperature range for cabbage production is 15°C to 25 °C[4]. Head development is sensitive to temperature extremes. Temperature higher than 25 °C results in reduced or stop development of cabbage-heads[3,5]. The yield gets reduced by roughly 10% for every 10 days that the temperature reached 30 °C or above during the growing season[6]. Exposure of plant to low temperature leads to untimely inflorescence development[5,7]. Cabbage is a popular summer crop in Ladakh. The nursery is transplanted in early May and the crop reaches harvestable stage in July-September[1]. However, cabbage is not grown during winter months[8], and therefore, there is scarcity of this vegetable in the region. In February 2019 the retail price of fresh cabbage was Rs 120 per kg in Leh town as compared to Rs 12-13 per kg in Delhi due to high air cargo charges[2]. In view of the need of fresh-market cabbage during winter months, studies have been conducted to determine feasibility to grow the crop inside greenhouses. However, under the traditional passive solar greenhouses very small cabbage-heads (4.4 g - 82.1 g) are formed[8]. Accordingly, the present study was aimed to determine the feasibility of growing cabbage during winter months in an improvised passive solar greenhouse in the trans-Himalayan Ladakh region.

Received : 07 May 2020, Revised : 30 July 2020
Accepted : 05 October 2020, Online published : 15 October 2020

2. MATERIALS AND METHODS

2.1 Study Site and Growing Conditions

Greenhouse experiments were conducted in three seasons (2017-18, 2018-19, 2019-20). Cabbage was grown in an improvised passive solar greenhouse (IP Greenhouse) at the Defence Institute of High Altitude Research in trans-Himalayan Ladakh, India (34°08.2'N; 77°34.3'E, elevation 3340 m). IP Greenhouse is a medium sized (90'×27'×9'; L×W×H) passive solar greenhouse in east-west orientation having cement plastered stone wall on three sides (east and west wall: 1'6'' thick; north wall: 2' thick). It is covered with a clear UV-stabilised 16-mm triple layer polycarbonate panel on the south-facing side. A portion of the east and west walls are covered with the cladding material (i.e. at 4' height). It has a sloped (to the north) wooden roof which is covered with a layer of straw and soil for insulation on the north side of the greenhouse. Temperature is maintained with manually operated ventilators on the south-facing and the west frame. No supplementary lighting and heating were provided. The structure was not covered with any thermal blanket, even in the peak winter. Temperature and relative humidity were recorded daily with a hygro-thermometer (445702, Extech Instruments). Photosynthetically active radiation (PAR) was recorded with a radiometer (PMA2100, Solar Light) with a PAR detector (PMA2132). The weather data of the greenhouse are shown in Table 1.

2.2 Experimental Design

The experiment was conducted with three commercial varieties- Golden Acre, Videshi and Megaton. Randomised block experimental design was used with three replications. Each replication plot was 2.8 m × 1.7 m in size. Each replicate consisted of 24 plants spaced at 35 cm × 35 cm. Farmyard manure (3.4 kg/m^2) was applied at the time of field preparation. No Pesticide, fungicides and weedicide were used throughout the growing season. Irrigation was done by flooding at one week interval during initial plant establishment time followed by three weeks interval at later stages. Seedlings raised in a passive solar greenhouse were transplanted manually on 16 Oct 2017, 01 Oct 2018, and 4 Oct 2019. Weeding was done twice during the growing season.

2.3 Growth and Yield Attributes

Data were recorded on the number of leaves, leaf area, relative growth rate (RGR), leaf weight ratio (LWR), specific leaf area (SLA), net assimilation rate (NAR) and chlorophyll content at 0-30, 30-60, 60-90 and 90-120 days after transplanting (DAT). RGR, SLA, LWR and NAR were determined as described by Hunt[9] *et al*. Head weight at fresh market maturity was recorded three times in a season. All heads were trimmed to market standards and weighed. At harvest, the plants were assessed for head quality defects. The number of bolt, split and loose heads were counted and expressed as a percentage of the total heads harvested per plot. Photosynthesis parameters of variety Golden Acre were studied on clear sky day in mid-December using a Portable Photosynthesis System (CIRAS-3, PP Systems, USA). The data were recorded on fully expanded leaf. Five replicates per treatment were recorded.

2.4 Statistical Analysis

All the experiments were performed in triplicates. The experimental results were expressed as mean ± standard deviation (SD) using statistical analysis with SPSS (Statistical Program for Social Sciences, SPSS Corporation, Chicago, Illinois, USA). One way analysis of variance (ANOVA) and post hoc analysis with 2-sided Tukey's HSD at $p \leq 0.05$ level were performed.

3. RESULTS AND DISCUSSION

3.1 Growth Attributes

The growth of cabbage plants was determined by their RGR. The RGR describes the rate of increase in plant mass per unit plant mass already present. The RGR followed a decreasing trend with time in all three varieties (Table 2). The mean RGR at 0-30 DAT, 30-60 DAT, 60-90 DAT and 90-120 DAT was 98.4±5.6 mg g^{-1} d^{-1}, 72.9±10.2 mg g^{-1} d^{-1}, 17.6±4.5 mg g^{-1} d^{-1} and 24.7±10.4 mg g^{-1} d^{-1}, respectively. The lowest RGR was recorded at 60-90 DAT which could be due to low night time temperature during the period. Therefore, temperature appears to be an important factor contributing to variation in RGR. SLA, which reflects the expected return on previously captured resources, was recorded highest at 0-30 DAT and then recorded low as the leaf matures. Lower SLA suggested that retention of the captured resources is a higher priority at later growth stages. Similar observation was recorded by Xu and Leskovar[10]. The NAR, which refers to the net efficiency of plant photosynthesis vary with growth stages in all three varieties. The mean NAR increased from 0.64±0.10 mg g^{-1} d^{-1} at 0-30 DAT to 1.54±0.44 mg cm^{-2} d^{-1} at 30-60 DAT and then again decreased to 0.41±0.05 mg g^{-1} d^{-1} and 0.81±0.27 mg cm^{-2} d^{-1} at 60-90 and 90-120 DAT, respectively. A significant varietal difference in NAR was observed at later growth stages among the three commercial varieties.

The optimum temperature range for cabbage production is 15 °C to 25 °C[4]. Head development is reported to be very sensitive to temperature extremes. Temperatures higher than 25 °C results in reduced development of cabbage-heads and spoil its quality[3]. Bewick[5] reported that cabbage growth stops above 25 °C. Exposure of plant to low temperature leads to bolting[5,7]. The mean minimum and maximum temperature recorded inside the greenhouse was 5.1±3.0 °C and 32.1±4.1°C in 2017-18; 4.9±1.8 °C and 32.4±5.2 °C in 2018-19; 5.6±1.9°C and 30.6±6.2 °C in 2019-20 growing period. Despite the average air temperature beyond the ideal range of 15-25 °C, marketable heads were formed in all three varieties (Fig. 1). The crop survived occasional sub zero degree Celsius at night inside the greenhouse which is in agreement with the previous report that the head of early varieties can bear -3 °C to -5 °C while the medium and late varieties can bear up to -5 °C to -8 °C[4].

3.2 Photosynthetic Parameters

The change in intercellular CO_2 concentration (Ci), photosynthetic rate (A), transpiration rate (E) and water-use efficiency (WUE) measured at different time intervals are shown in Fig. 2. Ci, which essentially indicates the CO_2 substrate available for photosynthetic assimilation, was maximum (393.6±15.2 µmol mol^{-1}) at 10 AM and lowest (316.6±17.9

Table 1. Microclimate inside the improvised passive solar greenhouse during winter season in trans-Himalayan Ladakh region

Year	Month	Temperature in open field (ºC)		Temperature inside greenhouse (ºC)		Temperature difference (GH-Open)		Relative humidity inside greenhouse (%)		PAR at 12 noon inside greenhouse (µmol/m²s)
		Max	Min	Max	Min	Max	Min	Max	Min	
2017-18 (16 Oct 2017 to 21 Mar 2018)	October	11.6±1.8	-4.6±0.5	38.8±2.7	10.4±0.9	27.2±0.9	15.0±0.4	87.4±3.5	22.1±4.0	833.2±83.5
	November	7.9±3.8	-7.7±2.9	33.0±6.2	5.3±2.5	25.1±2.4	13.0±0.4	90.5±5.7	34.8±17.3	458.6±268.4
	December	3.6±1.8	-10.8±2.4	26.8±8.3	3.1±1.1	23.2±6.5	13.9±1.3	96.5±2.5	62.5±15.9	484.3±239.1
	January	2.2±2.4	-13.6±2.7	30.3±4.2	1.8±1.1	28.1±1.8	15.4±1.6	96.0±2.4	57.9±7.5	570.0±89.5
	February	4.1±2.4	-8.8±2.9	30.0±5.6	4.1±2.0	25.9±3.2	12.9±0.9	95.8±1.5	50.3±10.1	312.6±151.2
	March	7.5±1.9	-5.5±2.1	33.6±5.1	6.0±1.6	26.1±3.2	11.5±0.5	93.9±5.1	39.1±12.1	269.3±33.5
	Mean	**6.2±3.5**	**-8.4±3.5**	**32.1±4.1**	**5.1±3.0**	**25.9±1.7**	**13.6±1.5**	**93.4±3.7**	**44.5±15.2**	**488.0±202.7**
2018-19 (1 Oct 2018 to 20 Mar 2019)	October	12.0±2.8	-1.6±3.2	39.5±0.9	10.5±2.3	27.5±1.9	12.1±0.9	92.1±12.6	30.9±8.6	652.1±263.4
	November	7.4±2.2	-6.5±2.4	31.6±6.6	7.2±2.1	24.2±4.4	13.7±0.3	95.6±5.2	50.4±7.7	308.2±49.6
	December	2.7±3.0	-12.7±3.2	28.3±5.1	1.8±1.3	25.6±2.1	14.5±1.9	97.9±1.3	56.7±5.2	224.6±103.3
	January	-0.9±2.5	-12.9±2.8	27.0±4.8	0.2±1.7	27.9±2.3	13.1±1.1	98.4±0.8	64.5±9.2	234.9±126.6
	February	0.5±2.4	-9.1±4.7	24.8±7.0	2.8±1.7	24.3±4.6	11.9±3.0	97.2±1.8	59.5±19.2	296.4±204.7
	March	3.2±2.7	-8.3±3.3	42.9±6.8	6.7±1.6	39.7±4.1	15.0±1.7	87.9±3.4	26.9±10.9	372.5±151.4
	Mean	**4.2±2.6**	**-8.5±3.3**	**32.4±5.2**	**4.9±1.8**	**28.2±3.2**	**13.4±1.5**	**94.9±4.2**	**48.2±10.2**	**348.5±149.4**
2019-20 (4 Oct 2019 to 15 Mar 2020)	October	13.9±2.5	-1.2±2.6	38.5±3.8	11.6±1.8	24.6±1.8	12.8±0.8	89.6±6.9	26.1±6.4	471.6±147.9
	November	7.9±3.3	-4.9±3.2	32.1±6.2	7.4±2.1	24.2±2.9	12.3±1.1	94.0±5.7	44.6±15.7	463.6±116.5
	December	0.0±2.4	-12.9±4.1	26.1±8.3	2.3±1.8	26.1±5.9	15.2±2.3	95.9±2.5	60.1±14.5	258.2±173.9
	January	-2.9±1.1	-14.1±3.0	18.9±7.1	0.0±1.6	21.8±6.0	14.1±1.4	95.2±2.1	69.2±13.3	260.4±25.9
	February	3.7±3.5	-10.5±5.4	32.1±4.4	4.7±2.5	28.4±0.9	15.2±2.9	89.6±3.8	46.7±12.0	370.9±154.3
	March	7.1±0.7	-5.8±2.7	35.8±7.1	7.3±1.4	28.7±6.4	13.1±1.3	78.2±12.2	23.7±8.2	321.5±131.2
	Mean	**5.0±2.3**	**-8.2±3.5**	**30.6±6.2**	**5.6±1.9**	**25.6±4.0**	**13.8±1.6**	**90.4±5.5**	**45.1±11.7**	**357.7±94.2**

Values represented as mean ± SD

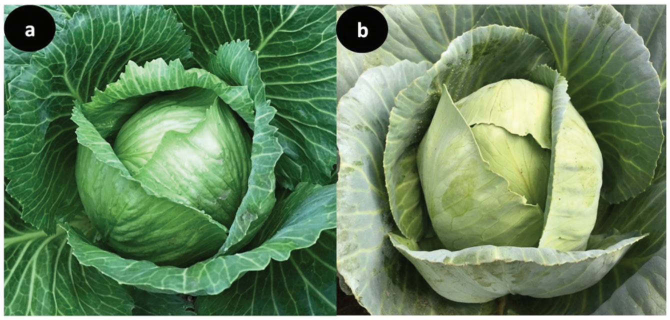

Figure 1. Marketable cabbage-heads of (a) Megaton and (b) Videshi formed inside the greenhouse

μmol mol^{-1}) at 2:00 PM. Low Ci at 2:00 PM may be due to high temperature (34.9 °C) and vapour pressure difference (VPD) of 0.56 kPa. High temperature inside the greenhouse resulted in high transpiration rate at 12:00 noon and 2:00 PM. A sharp increase in VPD and E above 25 °C has also been reported in Chinese cabbage[11]. The highest photosynthetic rate (17.4±6.1 μmol CO_2 m^{-2} s^{-1}) was observed at 10 AM which could be due to high Ci coupled with low VPD (0.25 kPa) and cool temperature (13.2 °C). The photosynthetic rate was observed the lowest (7.7±3.9 μmol CO_2 m^{-2} s^{-1}) at 4:00 PM, due in part to low PAR (244 μmol m^{-2} s^{-1}). Dramatic declines in WUE at 2:00 PM and 4:00 PM was observed which indicated that the plants were severely affected negatively by high temperatures. Similar observation was reported in Chinese cabbage at above 30 °C[11].

3.3 Marketable Yield

Harvesting was carried out between 25 February-21 March in 2018, 12-20 March in 2019 and 7-15 March in 2020. The mean marketable head weight of the variety Golden Acre, Videshi and Megaton was 0.83±0.2 kg, 0.43±0.07 kg, and 0.80±0.05 kg, respectively during the three year study period (Table 3). The marketable head weight was significantly lower as compared to the yield potential of the varieties. The yield potential of variety Golden Acre is 1-1.5 kg and that of Megaton is 3-4 kg. Besides, it took more number of days to harvest as compared to the expected days to harvest for each variety. Golden Acre is an early maturing variety and the expected number of days to maturity is 60-65 days. In contrast, it took 133-163 days to harvest from the date of transplanting. Low head weight and longer days to harvest in the present study may be due to high diurnal temperature variation inside the greenhouse. High day temperatures reduce the yield and quality of the heads. It has been observed that cabbage grown at 25°C has a lower dry matter content, reduced growth rate and lower water use efficiency than cabbage grown at 20 °C[3]. Warland[6] *et al* reported that the yield decrease by 10% for every 10 days that the temperature exceeds 30 °C. Higher yield and head quality is expected if excessive heat that builds up inside the greenhouse is controlled through ventilation. However, the yield obtained in the present study was significantly higher than that of crop grown under traditional greenhouses in Ladakh. Kanwar[8] *et al*. studied feasibility of growing three varieties of cabbage in five traditional greenhouses during winter months. However, the mean head weight obtained was 42.6 g, 40.7 g, and 47.8 g in Golden Acre, KGMR-1 and Pride of India, respectively. The highest yield obtained for Golden Acre was 55 g in Chinese type greenhouse. In comparison, the mean head weight of Golden Acre in the present study was 831 g, which is 15-fold higher as compared to the previous report in traditional greenhouses. The main difference between the traditional greenhouses and

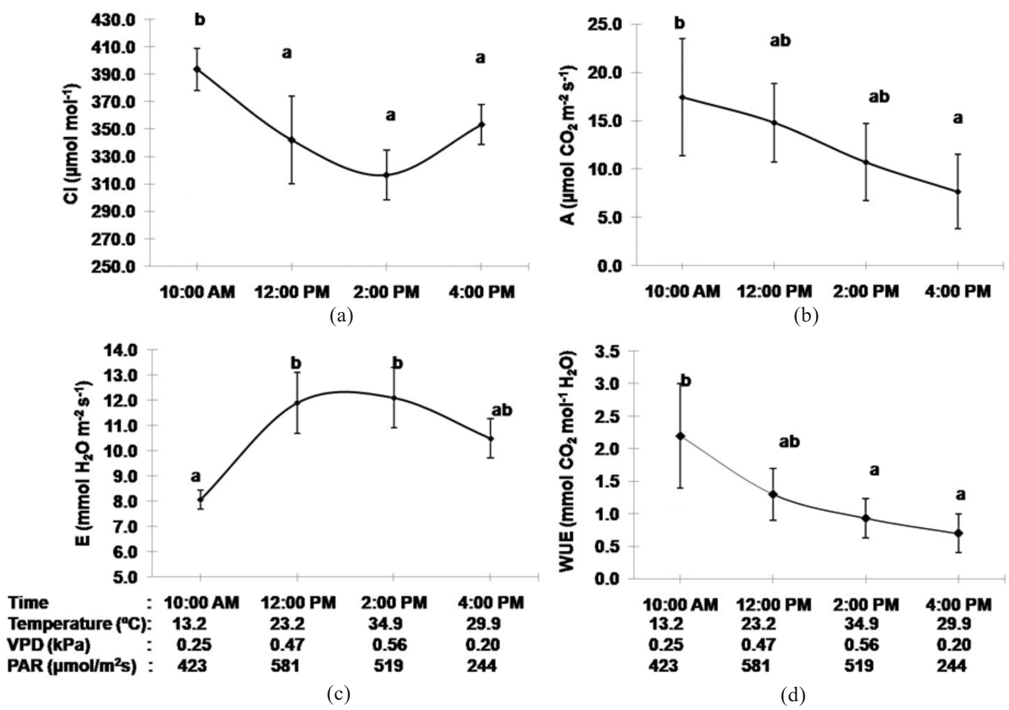

Figure 2. Relationship between temperature/ vapour pressure difference (VPD)/ photosynthetically active radiation (PAR) and (a) intercellular CO_2 concentration (Ci); (b) photosynthesis rate (A); (c) transpiration rate (E); and (d) water-use efficiency (WUE) in cabbage (Golden Acre) leaves inside greenhouse in mid-December.

Table 2. Growth parameters of three commercial varieties of cabbage harvested in 2017-18 winter seasons in trans-Himalayan Ladakh

Parameters	DAT	Golden Acre	Videshi	Megaton	Mean of three varieties
Number of leaf	30	$8.3\pm0.8_X{}^a$	$8.2\pm0.5_X{}^a$	$8.3\pm1.0_X{}^a$	$8.3\pm0.1_X$
	60	$12.0\pm1.3_Y{}^a$	$11.3\pm0.8_Y{}^a$	$11.7\pm1.9_Y{}^a$	$11.7\pm0.4_Y$
	90	$13.3\pm0.8_{YZ}{}^a$	$12.5\pm1.0_{YZ}{}^a$	$13.3\pm1.0_{YZ}{}^a$	$13.0\pm0.5_{YZ}$
	120	$14.0\pm1.1_Z{}^a$	$13.3\pm0.5_Z{}^a$	$14.2\pm1.5_Z{}^a$	$13.8\pm0.5_Z$
Leaf area (LA)	30	$632.4\pm155.8_A{}^{ab}$	$393.5\pm60.3_A{}^a$	$771.7\pm16.0_A{}^b$	$599.2\pm191.3_A$
	60	$1493.4\pm211.6_{AB}{}^a$	$1473.8\pm14.0_B{}^a$	$1680.8\pm65.8_B{}^a$	$1549.3\pm114.3_{AB}$
	90	$2293.2\pm230.9_{BC}{}^a$	$1881.2\pm55.6_C{}^a$	$2754.6\pm200.4_C{}^b$	$2309.7\pm436.9_{BC}$
	120	$2938.9\pm654.3_C{}^{ab}$	$2293.3\pm248.9_D{}^a$	$3743.3\pm215.3_D{}^b$	$2991.8\pm726.4_C$
RGR	0-30	$101.5\pm27.7_Y{}^a$	$92.0\pm19.0_Y{}^a$	$101.8\pm10.2_Z{}^a$	$98.4\pm5.6_Z$
	30-60	$68.3\pm16.2_Y{}^a$	$84.6\pm12.2_Y{}^a$	$65.7\pm1.2_Y{}^a$	$72.9\pm10.2_Y$
	60-90	$16.6\pm0.5_X{}^a$	$13.7\pm1.1_X{}^a$	$22.5\pm2.8_X{}^b$	$17.6\pm4.5_X$
	90-120	$24.3\pm1.6_X{}^a$	$14.5\pm2.9_X{}^a$	$35.3\pm5.6_X{}^b$	$24.7\pm10.4_X$
SLA	0-30	$193.6\pm35.5_B{}^a$	$182.1\pm45.3_B{}^a$	$257.8\pm2.4_D{}^b$	$211.2\pm40.8_B$
	30-60	$72.6\pm0.3_A{}^b$	$53.5\pm3.5_A{}^a$	$78.3\pm3.1_B{}^b$	$68.1\pm13.0_A$
	60-90	$73.7\pm4.8_A{}^b$	$52.4\pm0.8_A{}^a$	$88.3\pm5.7_C{}^c$	$71.5\pm18.1_A$
	90-120	$70.1\pm11.2_A{}^b$	$53.2\pm2.7_A{}^a$	$62.1\pm2.0_A{}^{ab}$	$61.9\pm8.5_A$
LWR	0-30	$0.80\pm0.00_Z{}^a$	$0.79\pm0.02_Z{}^a$	$0.75\pm0.01_Y{}^a$	$0.78\pm0.03_Z$
	30-60	$0.67\pm0.15_{YZ}{}^a$	$0.78\pm0.01_Z{}^a$	$0.75\pm0.02_Y{}^a$	$0.74\pm0.06_{YZ}$
	60-90	$0.60\pm0.00_Y{}^a$	$0.68\pm0.01_Y{}^b$	$0.55\pm0.04_X{}^a$	$0.61\pm0.07_{XY}$
	90-120	$0.40\pm0.00_X{}^a$	$0.53\pm0.01_X{}^b$	$0.55\pm0.04_X{}^b$	$0.49\pm0.08_X$
LAR	0-30	$157.5\pm29.9_B{}^a$	$144.5\pm39.6_B{}^a$	$192.9\pm0.2_D{}^a$	$165.0\pm25.0_B$
	30-60	$48.6\pm9.3_A{}^{ab}$	$42.1\pm2.0_A{}^a$	$58.5\pm3.3_C{}^b$	$49.7\pm8.3_A$
	60-90	$45.1\pm2.9_A{}^b$	$35.6\pm0.2_A{}^a$	$48.7\pm1.1_B{}^b$	$43.1\pm6.8_A$
	90-120	$27.6\pm4.4_A{}^a$	$28.0\pm1.3_A{}^a$	$34.2\pm1.3_A{}^a$	$29.9\pm3.7_A$
NAR	0-30	$0.70\pm0.30_X{}^a$	$0.69\pm0.31_X{}^a$	$0.53\pm0.05_X{}^a$	$0.64\pm0.10_X$
	30-60	$1.50\pm0.66_Y{}^a$	$2.00\pm0.19_Y{}^a$	$1.12\pm0.09_Y{}^a$	$1.54\pm0.44_Y$
	60-90	$0.37\pm0.06_X{}^a$	$0.39\pm0.04_X{}^a$	$0.46\pm0.06_X{}^a$	$0.41\pm0.05_X$
	90-120	$0.90\pm0.10_X{}^b$	$0.51\pm0.08_X{}^a$	$1.03\pm0.13_Y{}^b$	$0.81\pm0.27_X$
Chlorophyll content (SPAD)	30	$49.0\pm1.8_A{}^a$	$50.0\pm4.2_A{}^a$	$46.2\pm5.7_A{}^a$	$48.4\pm2.0_A$
	60	$50.3\pm3.3_A{}^{ab}$	$52.4\pm5.8_A{}^b$	$45.5\pm3.6_A{}^a$	$49.4\pm3.5_A$
	90	$55.6\pm6.6_A{}^a$	$60.0\pm10.0_A{}^a$	$52.1\pm8.1_A{}^a$	$55.9\pm4.0_A$
	120	$54.6\pm5.4_A{}^a$	$55.9\pm8.1_A{}^a$	$49.3\pm8.2_A{}^a$	$53.3\pm3.5_A$

Values represented as mean ± SD

For each row, different lowercase letters indicate significantly different at $p \leq 0.05$, as measured by Tukey's test between different variety at a given time period

For each column, different uppercase letters indicate significantly different at $p \leq 0.05$, as measured by Tukey's test within a variety at different DAT

LA: leaf area (cm^2); RGR: relative growth rate ($mg\ g^{-1}\ d^{-1}$); SLA: specific leaf area ($cm^2 g^{-1}$); LWR: leaf weight ratio (g / g^{-1}); LAR: leaf area ratio ($cm^{-2}\ g^{-1}$); NAR: net assimilation rate ($mg\ cm^{-2}\ d^{-1}$)

the IP greenhouse of the present study was the use of different covering materials. In the traditional greenhouses 150 micron UV stabilised polyethylene sheet is used[8] as covering material, while in the present study a clear UV-stabilised 16-mm triple layer polycarbonate panel was used. The difference in the covering material resulted in a variation of 7-8 °C in night temperature inside the greenhouses.

3.4 Physiological Disorder

Physiological disorders of cabbage heads can greatly affect both the quality and commercial value of cabbage. The occurrence of bolt, split and loose heads were observed in the greenhouse-grown crop, and it ranged from 8-35% of the harvested head during the three year trial (Table 3). Head defects are related to temperature fluctuations outside the optimum range during a particular stage of development. The optimum temperature range for cabbage head formation is 15-20 °C[4]. Pre-mature bolting occurs when plants are exposed to high temperature and long photoperiod[4]. Bolting was observed in two of the three varieties tested. In Golden Acre, which is an early variety, 8.7±9.0% of the heads showed signs of bolting. Similarly, in the late variety Megaton 10.2±8.8% of the heads showed bolting. Similarly, high temperature inside the greenhouse at later growth stages resulted in head splitting.

Table 3. Cabbage yield and physiological disorders in three winter seasons in trans-Himalayan Ladakh

Variety	Year	Yield parameters			Physiological disorder (%)			
		Gross weight (g)	Marketable weight (g)	Harvest index (%)	Bolting	Head splitting	Loose head	Total
Golden Acre	2018	$1347.0\pm40.5_{AB}^{a}$	$895.0\pm50.0_{A}^{a}$	$76.0\pm9.0_{B}^{a}$	0_{A}^{a}	$2.0\pm0.0_{AB}^{a}$	$6.0\pm2.0_{A}^{a}$	$8.0\pm2.0_{A}^{a}$
	2019	$1361.3\pm136_{AB}^{a}$	$614.3\pm281.0_{A}^{a}$	$66.8\pm4.2_{AB}^{a}$	$18.0\pm10.0_{C}^{b}$	$5.5\pm1.5_{BC}^{ab}$	$6.2\pm2.1_{A}^{a}$	$29.7\pm9.4_{CD}^{b}$
	2020	$1530.7\pm225_{AB}^{a}$	$984.2\pm386.6_{A}^{a}$	$67.4\pm5.1_{AB}^{a}$	$8.2\pm0.2_{B}^{ab}$	$4.0\pm1.4_{ABC}^{b}$	$6.3\pm2.1_{A}^{a}$	$18.5\pm0.9_{ABC}^{ab}$
	Mean	1413.0±102.2	831.2±193.0	70.1±5.1	8.7±9.0	3.8±1.8	6.2±0.2	18.7±10.9
Videshi	2018	$829.3\pm70.2_{A}^{a}$	$430.0\pm30.1_{A}^{a}$	$65.\ \pm7.2_{AB}^{a}$	0	0	$35.0\pm6.0_{B}^{b}$	$35.0\pm6.0_{CD}^{b}$
	2019	$1237.3\pm386.6_{AB}^{a}$	$500.0\pm129.1_{A}^{a}$	$65.6\pm7.3_{AB}^{a}$	0	0	$36.1\pm8.0_{B}^{b}$	$36.1\pm8.0_{D}^{b}$
	2020	$1301.0\pm128.2_{AB}^{a}$	$355.9\pm192.2_{A}^{a}$	$65.3\pm2.0_{AB}^{a}$	0	0	$12.2\pm3.9_{A}^{a}$	$12.2\pm3.8_{AB}^{a}$
	Mean	1122.5±255.9	428.6±72.1	65.3±0.3	0	0	27.8±13.5	27.8±13.5
Megaton	2018	$1456.7\pm57.8_{AB}^{a}$	$790.1\pm110.0_{A}^{a}$	$67.7\pm2.5_{AB}^{b}$	0_{A}^{a}	0_{A}^{a}	$10.0\pm2.0_{A}^{a}$	$10.0\pm2.0_{A}^{a}$
	2019	$1907.3\pm725.7_{B}^{a}$	$864.3\pm359.1_{A}^{a}$	$55.6\pm2.1_{A}^{a}$	$14.0\pm2.0_{C}^{b}$	$4.9\pm2.9_{BC}^{ab}$	$8.4\pm4.2_{A}^{a}$	$27.3\pm0.7_{BCD}^{b}$
	2020	$1636.1\pm229.3_{AB}^{a}$	$757.1\pm496.6_{A}^{a}$	$53.2\pm1.0_{A}^{a}$	$16.2\pm3.8_{C}^{b}$	$8.4\pm4.2_{C}^{b}$	$6.3\pm2.1_{A}^{a}$	$30.9\pm10.0_{CD}^{b}$
	Mean	1666.7±226.9	803.8±54.9	58.8±7.8	10.2±8.8	4.4±4.2	8.2±1.9	22.7±11.2

Values represented as mean ± SD
For each column different lowercase letters indicate significantly different at $p \leq 0.05$ as measured by Tukey's test within a variety in different year
For each column different uppercase letters indicate significantly different at $p \leq 0.05$ as measured by Tukey's test between different varieties in different years

Splitting was observed in 3.8±1.8 % of the heads in Golden Acre and 4.4±4.2 % of Megaton. It is commonly believed that cracking or splitting occurs as a result of environmental factors such as sudden increase in the soil moisture content, differentials between day and night humidity, temperature fluctuations, and light exposure[12]. Loose head was one of the major physiological defects observed in the greenhouse-grown cabbage. High percentage of the harvested heads were loose in all the three varieties (Videshi: 27.8±13.5%; Megaton: 8.2±1.9; Golden Acre: 6.2±0.2%). Loose head formation may be due to high day temperature inside the greenhouse. Daily temperatures above 25 °C and frequent irrigations lead to the formation of plants with many leaves but loose heads[13].

4. CONCLUSION

Cabbage, a temperature sensitive crop, is traditionally not grown in Ladakh region during winter months due to freezing temperature. Feasibility of growing cabbage was, therefore, studied during winter months in an improved passive solar greenhouse. A trial conducted over three years suggested that cabbage can be successfully grown during extreme winter months under passive solar greenhouse conditions in the trans-Himalaya. Head was formed in all the varieties despite the temperature extremes (0.0±1.6 °C to 39.5±0.9 °C) inside the greenhouse. The mean marketable head weight ranged from 428.6±72.1 g to 831.2±193.0 g depending on the variety. Higher yield and head quality is expected if excessive heat that builds up inside the greenhouse are controlled through ventilation.

Conflict of Interest: None

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ACKNOWLEDGEMENTS

The study was supported by the Defence Research and Development Organisation (DRDO), Ministry of Defence, Government of India. PA and TD are grateful to DRDO for providing a research fellowship.

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