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Size of Passive Solar Greenhouse Determine Growth and Yield of Cauliflower and Cabbage During Winter in High Mountain Ladakh Region, India

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ABSTRACT

The length and span of passive solar greenhouse are important factors that determine greenhouse microclimate. However, there are no established length and span recommendations for guiding construction of passive solar greenhouse in high altitude regions, especially above 3000 *m* asl. Majority of the farmers in trans-Himalayan regions have preference for low-cost small size (<10 *m* length) passive solar greenhouses. We studied two different sized greenhouses and found that a large greenhouse (27.4 *m* length, 8.2 *m* width) was better than a small greenhouse (9.8 *m* length, 5.5 *m* width) for growing cauliflower and cabbage in winter. The large greenhouse remained 1.5±0.3 to 7.4±2.1 °C warmer during daytime, and 0.6±0.1 to 1.5±0.8 °C warmer at night. All the recorded plant growth parameters were higher in the large greenhouse. The mean marketable weight of cauliflower cv. Shantha was 599±35 *g* in the large greenhouse as against 537±42 *g* in the small greenhouse. Similarly, the marketable weight of cabbage cv. Golden Acre in the large greenhouse was significantly higher (619±53 *g*) than the small greenhouse (523±121 *g*). Therefore, large passive solar greenhouses are recommended for farmers in high altitude trans-Himalayan Ladakh regions.

Keywords: Cole crops; Greenhouse span; High altitude; Microclimate; Protected cultivation

1. INTRODUCTION

Low-cost passive solar greenhouses are commonly used in the high mountain regions, especially above 3000 m asl, for raising of seedlings in spring and production of leafy vegetables in winter. However, sub-zero temperature inside the greenhouse in winter months, and overheating during summer are serious problems in these greenhouses, which confines the use of such greenhouses to a few months in a year.[1] In recent years improvised passive solar greenhouses have been developed for high mountain trans-Himalayan Ladakh region wherein vegetables can be grown all year round with no auxiliary heating or cooling. Growing of a variety of vegetables such as cabbage, kohlrabi and cauliflower[2] in winter have been demonstrated, which otherwise cannot be grown in the traditional low-cost greenhouses.

Majority of the farmers in high mountain regions have preference for low-cost small size (<10 m length) passive solar greenhouses. A survey conducted in Ladakh region suggested that the majority (56.3 %) of the farmers have a low cost small size greenhouse (9.8 *m* x 5.5 *m*). Only 3 % of the farmers have medium size (19.8 *m* x 7.3 *m*), while a small section (1.8 %) has large size (30.5 *m* x 7.0 *m*) passive solar greenhouses.[1] Preferences for small greenhouse are due to small land holding, socio-economic condition, and general perception that smaller greenhouse are warmer as compared to large sized greenhouse. The length and span of passive solar greenhouse are important factors that determine greenhouse microclimate.[3-4]

The optimal length of Chinese solar greenhouse ranged from 50 *m* to 100 *m*. The optimal greenhouse length is about 90 *m* in Lanzhou, China. Longer greenhouse results in lower greenhouse temperature, while shorter greenhouse causes shadow on the standing crop due to east and west walls.[3] The spans of Chinese solar greenhouses ranged from 5.5 *m* to 24 *m* depending on the region and construction methods.[4] Higher air temperatures have been recorded in greenhouses with lesser spans-6 *m* in north of 40 ºN in China[5], 6.9 *m* in Shaanxi Province of China[6] as compared to greenhouses with larger spans. In contrast, higher temperatures have been reported in greenhouse with larger span-14 *m* in Liaoning Province of China.[4] For Inner Mongolia and Gansu Province of China 10 *m* span is recommended for good thermal performance.[7-8] Therefore, contrasting results on greenhouse air temperature have been reported

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from different regions. Besides, most of the studies on the effect of greenhouse length and span focus primarily on greenhouse microclimate.[3-4] Limited studies have been carried out on crop yield under different sizes of greenhouses. In view of the contrasting results on greenhouse air temperature from different regions, and limited data on crop yield, it was felt that there is a need to undertake studies on crop yield in different sizes of passive solar greenhouses in high mountain regions. This information is important since it provides a reference for small and marginal farmers in the high mountain regions in selecting the most appropriate greenhouse size for growing vegetables in winter. To the best of our knowledge there are no established length and span recommendations for guiding construction of small size (<30 *m* length) passive solar greenhouse in high altitude regions, especially above 3000 *m* asl.

2. METHODOLOGY

2.1 Study Site and Greenhouse Structures

The study was carried out in Ladakh, India at an elevation 3340 *m* asl. Two improvised passive solar greenhouses differing in length and span were used in the study. The length and span of the large greenhouse was 27.4 *m* and 8.2 *m*, while that of the small greenhouse was 9.8 *m* and 5.5 *m*, respectively. The greenhouse has east-west orientation with cement plastered 2 feet thick stone wall on three sides. The south-facing side is covered with a clear UV-stabilized 16-*mm* triple layer polycarbonate sheet. It has a sloped (to the north) PUF (80 *mm* thick) roof on the north side of the greenhouse. The dimension of each greenhouse is shown in Table 1. Temperature is maintained by opening of the door on the east wall, and ventilators on the south-facing roof and the west wall. No additional lighting, heating and cooling were provided. Thermal blanket was not used all throughout the growing season. Hourly temperature was recorded daily, and the mean hourly temperature from 10:00 AM to 5:00 PM was considered daytime temperature while temperature from 6:00 PM to 8:00 AM was taken as the nighttime temperature. The temperature inside the two greenhouses is shown in Table 2.

Table 1. Dimensions of the two different sizes passive solar greenhouses

Parameters	Large Greenhouse	Small Greenhouse
Length (m)	27.4	9.8
Span (m)	8.2	5.5
Ridge height (m)	3.0	2.9
North wall height (m)	2.6	2.6
North roof width (m)	1.7	1.16
South lighting roof length (m)	26.2	8.5
South lighting roof width (m)	5.8	4.6

2.2 Crop and Experimental Design

Cauliflower cv. Shentha and cabbage cv. Golden Acre were studied during the winter season (2018-19) in the two different sizes of greenhouse. There were two rows in each greenhouse, running parallel to the north wall from east to west. Six replication plots in each greenhouse were taken. The plants were spaced at 35×35 *cm*. Seedlings were transplanted on 1st Oct 2018. Farmyard manure (3.0 kg/m^2) was applied during field preparation. A handful of vermicompost (50 *g*) was applied at the root zone after the first and second weeding. Pesticides and fertilizer were not used. Flood irrigation was done at 15 days interval. However, in December and January irrigation was done once a month. Weeding was carried manually two times.

2.3 Growth and Yield Attributes

Plant growth parameters were recorded at 30, 60 and 90 days after transplanting (DAT) on five randomly selected plants in each treatment. The date of first and

Table 2. Day and nighttime temperature differences inside the two different sizes passive solar greenhouses in trans-Himalayan Ladakh

Month	Daytime temperature (°C)			Nighttime temperature (°C)		
	Large Greenhouse	Small Greenhouse	Difference	Large Greenhouse	Small Greenhouse	Difference
October	38.3±5.9	36.7±4.9	2.8±0.6	13.8±2.8	12.7±3.1	1.1±0.1
November	31.8±7.7	29.8±7.5	2.6±0.7	8.6±2.6	7.6±2.3	1.0±0.2
December	25.0±6.3	22.7±5.8	2.7±0.7	4.5±2.4	3.6±2.1	0.9±0.3
January	22.5±5.6	21.6±5.1	1.5±0.3	4.2±2.1	3.8±1.9	0.6±0.1
February	30.4±5.2	29.1±4.7	1.6±0.4	6.5±3.1	5.9±2.9	0.6±0.2
March	45.3±4.4	37.9±2.8	7.4±2.1	14.0±4.4	12.5±3.6	1.5±0.8

Large Greenhouse: 90'×27'; Small Greenhouse: 32'×18'
Values represented as mean ± SD

last harvest, number of harvests, and yield per plant were recorded. Effects of directional position within the greenhouse on plant growth and yield was determined by taking data separately from the two rows at the north and south side of the greenhouse. Chlorophyll was measured with Chlorophyll Meter SPAD-502 (Konica Minolta Sensing Inc., Japan).

2.4 Statistical Analysis

The experimental results were expressed as mean ± standard deviation (SD) using statistical analysis with SPSS. Significance of differences between means was determined by Independent Student t-test between the two greenhouses.

3. RESULTS AND DISCUSSION

3.1 Microclimate Inside the Greenhouses

The mean daytime temperature ranged between 22.5±5.6 °C (January) and 45.3±4.4 °C (March) inside the large greenhouse, while the night temperature ranged between 4.2±2.1 °C (January) and 14.0±4.4 °C (March). The large greenhouse remained 1.5±0.3 to 7.4±2.1 °C warmer during daytime, and 0.6±0.1 to 1.5±0.8 °C warmer at night as compared to the small greenhouse. The results suggested that the heat storage capacity is greater than the total heat dissipation in the large greenhouse. Gao[3], *et al.* studied the effect of greenhouse length on heat storage/ release capacity. When the greenhouse is longer than 90 *m*, the total heat dissipation is greater than the heat storage capacity. The opposite was observed in greenhouses shorter than 90 *m*. Contrasting results in the present study as that of previous report[3] could be due to differences in geographical area, design and construction material, and the length of the greenhouse. We studied small greenhouses (<30 *m* length, <7.5 *m* span), while Chinese greenhouses are 50 m to 100m length and 5.5 *m* to 24 *m* span.[3-4]

Table 3. Growth parameters of cauliflower cv. Shantha grown in two different sizes passive solar greenhouses in trans-Himalayan Ladakh

Parameters	Intervals	Large Greenhouse			Small Greenhouse		
		South	North	Mean	South	North	Mean
Plant height (cm)	0 Day	9.3±0.9			9.3±0.9		
	30 DAT	41.8±4.3***	44.0±7.6***	42.9±5.6***	16.0±5.4***	18.0±5.4***	17.0±4.9***
	60 DAT	63.9±5.5***	65.3±3.5***	64.6±4.1***	28.6±3.9***	36.6±10.9***	32.6±8.1***
	90 DAT	77.6±4.1***	79.4±0.6***	78.5±2.8***	36.0±6.7***	40.6±10.4***	38.3±8.2***
No. of leaves	0 Day	4.0±1.0			4.0±1.0		
	30 DAT	9.7±1.5**	9.7±0.6**	9.7±1.0**	5.3±1.5**	6.7±0.6**	6.0±1.3**
	60 DAT	13.0±1.0**	13.3±0.6**	13.2±0.8	9.0±1.0**	10.0±1.0**	9.0±1.8**
	90 DAT	15.3±0.6**	15.0±1.0**	15.2±0.8**	11.3±0.6**	11.7±1.2**	10.2±0.8**
Leaf thickness (mm)	0 Day	0.28±0.06			0.28±0.06		
	30 DAT	0.26±0.04	0.26±0.03	0.26±0.03	0.25±0.07	0.25±0.03	0.25±0.04
	60 DAT	0.29±0.01	0.28±0.02	0.28±0.02	0.28±0.06	0.25±0.08	0.26±0.07
	90 DAT	0.27±0.01	0.27±0.02	0.27±0.01	0.26±0.00	0.27±0.01	0.26±0.01
Stem diameter (mm)	0 Day	1.2±0.1			1.2±0.1		
	30 DAT	10.1±1.2***	10.1±2.1***	10.1±1.4	3.1±1.4***	4.9±1.2***	3.7±1.3
	60 DAT	10.8±1.1**	11.3±2.0**	11.1±1.5	7.1±3.0**	8.9±0.6**	8.8±2.9
	90 DAT	11.6±1.1	12.5±1.4	12.0±1.2	9.0±3.1	11.9±2.6	10.4±3.4
Chlorophyll (SPAD)	0 Day	33.0±1.5			33.0±1.5		
	30 DAT	56.5±7.2	55.9±2.2	56.2±4.6	49.0±7.1	47.0±3.2	48.0±5.1
	60 DAT	57.2±4.2**	58.5±2.3**	57.9±3.1	47.7±5.1**	39.3±3.0**	43.5±5.9
	90 DAT	55.7±4.3*	53.7±1.9*	54.7±3.2*	38.8±5.3*	46.1±0.7*	42.5±5.2*

Large Greenhouse: 90'×27'; Small Greenhouse: 32'×18'

Values represented as mean ± SD;

*Significant at p ≤ 0.05, **Significant at p ≤ 0.01, ***Significant at p ≤ 0.001, as measured by Independent Student t-test between the two greenhouses within the same crop

3.2 Growth Attributes

The size of the greenhouse exhibited a significant effect on growth of cauliflower (Table 3) and cabbage (Table 4). All the recorded plant growth parameters were higher in the large greenhouse. Plant height was 104.9 % and 34.2 % higher at 90 DAT in cauliflower and cabbage, respectively in the large greenhouse. Similarly, the number of leaves in cauliflower and cabbage were 49.0 % and 11.4 % higher in the large greenhouse. Stem diameter was 15.4 % and 32.6 % higher in cauliflower and cabbage, respectively in the large greenhouse. Similar trend was observed in leaf thickness and chlorophyll contents. Significantly higher growth in the large greenhouse may be due to more favourable temperature than that of the small greenhouse.

3.3 Marketable Yield

Early and greater marketable yield was observed in the large greenhouse (Table 5). Cauliflower and cabbage were harvested earlier by 7 and 3 days, respectively in the large greenhouse. The mean marketable weight of cauliflower was 599±35 *g* in the large greenhouse, which was significantly higher than that of the small greenhouse (537±42 *g*). Curd formation in cauliflower is very sensitive to temperature extremes. Normal curds are formed at 10-25 ºC.[9] No curd is formed at 25.0 ºC or above.[10] However, in the present study normal curds were formed even though the day temperature remained above 25 ºC on most of the days. The marketable weight of cabbage (619±53 *g*) in the large greenhouse was also significantly higher than that of the small greenhouse (523±121 *g*). Head development is very sensitive to temperature extremes. Cabbage growth stops above 25 ºC.[11] Exposure of plants to low temperature results in bolting.[11-12] However, in the current study cabbage heads were formed despite the temperature extremes. Higher marketable yield in the large greenhouse may be the result of more favorable temperature inside the greenhouse.

Table 4. Growth parameters of cabbage cv. Golden Acre grown in two different sizes passive solar greenhouses in trans-Himalayan Ladakh

Parameters	Intervals	Large Greenhouse			Small Greenhouse		
		South	North	Mean	South	North	Mean
Plant height (cm)	0 Day	12.7±1.2			12.7±1.2		
	30 DAT	27.7±6.1***	28.3±4.6***	28.9±4.9***	20.4±3.4***	20.2±1.1***	20.3±2.3***
	60 DAT	38.6±0.6***	39.2±1.3***	38.9±0.9***	26.5±3.4***	32.8±2.8***	29.6±4.4***
	90 DAT	43.4±3.1***	45.2±2.0***	44.3±2.5***	30.3±3.1***	35.6±3.98***	33.0±4.3***
No. of leaves	0 Day	3.3±1.2			3.3±1.2		
	30 DAT	8.7±3.1	10.3±0.6	9.5±2.2	8.0±1.0	8.0±1.0	8.0±0.9
	60 DAT	10.0±2.6	12.7±0.6	11.3±2.3	10.0±1.7	11.3±0.6	10.7±1.4
	90 DAT	11.7±2.1	15.7±1.5	13.7±2.7	11.7±1.2	13.0±1.0	12.3±1.4
Leaf thickness (mm)	0 Day	0.20±0.07			0.20±0.07		
	30 DAT	0.28±0.01**	0.29±0.01**	0.29±0.01**	0.23±0.02**	0.26±0.07**	0.24±0.05**
	60 DAT	0.29±0.01**	0.30±0.01	0.30±0.01**	0.26±0.09**	0.29±0.03	0.27±0.06**
	90 DAT	0.26±0.03	0.27±0.01	0.26±0.02	0.25±0.08	0.25±0.01	0.25±0.01
Stem diameter (mm)	0 Day	1.18±0.1			1.18±0.1		
	30 DAT	8.7±2.2***	9.6±2.1***	9.2±2.0***	2.7±0.6***	2.8±0.5***	2.7±0.5***
	60 DAT	10.2±2.4***	10.8±1.9***	10.5±2.0***	5.07±1.1***	5.9±0.9***	5.5±1.0***
	90 DAT	11.2±2.4**	11.5±1.6**	11.4±1.8**	8.71±3.9**	8.5±1.1**	8.6±2.6**
Chlorophyll (SPAD)	0 Day	21.2±2.2			21.2±2.2		
	30 DAT	47.3±5.4**	55.5±4.7***	51.4±6.4***	40.6±2.63**	39.4±2.8***	40.0±2.5
	60 DAT	53.4±2.8**	57.3±3.7***	55.4±3.7**	48.4±8.0**	46.8±5.5***	47.6±6.2**
	90 DAT	52.4±2.1**	54.8±1.6***	53.6±2.1***	47.3±3.2**	46.2±1.3***	46.7±2.2***

Large Greenhouse: 90’×27’; Small Greenhouse: 32’×18’
Values represented as mean ± SD;
*Significant at p ≤ 0.05, **Significant at p ≤ 0.01, ***Significant at p ≤ 0.001, as measured by Independent Student t-test between the two greenhouses within the same crop

Table 5. Marketable weight of cauliflower and cabbage in two different sizes passive solar greenhouses in trans-Himalayan Ladakh

Crop	Greenhouse	First harvest (DAT)	Last harvest (DAT)	Marketable weight (g)		
				North	South	Mean
Cauliflower cv. Shantha	Large	141	151	605±31**	593±42**	599±35***
	Small	148	151	538±52**	535±35**	537±42***
Cabbage cv. Golden Acre	Large	166	171	627±54**	610±57	619±53**
	Small	169	171	516±83**	530±160	523±121**

Large Greenhouse: 90'×27'; Small Greenhouse: 32'×18'

Values represented as mean ± SD;

*Significant at p ≤ 0.05, **Significant at p ≤ 0.01, ***Significant at p ≤ 0.001, as measured by Independent Student t-test between the two greenhouses within the same crop

3.4 Effects of Greenhouse Directional Position on Growth and Marketable Yield

The directional position within the greenhouse did not show a significant effect on plant growth (Table 3-4) and yield (Table 5). The plant height, number of leaves and stem diameter in cauliflower and cabbage were recorded higher in plants near the north wall in both the greenhouses, but the differences were not significant. No increasing or decreasing trend was observed in leaf thickness and chlorophyll contents.

4. CONCLUSION

Majority of the farmers in high mountain regions have preference for low-cost small size passive solar greenhouses. However, the result of the present study suggested that a large greenhouse was better than the small greenhouse for growing cauliflower and cabbage in winter. The mean marketable weight of cauliflower was 599±35 *g* in the large greenhouse, which was significantly higher than that of the small greenhouse (537±42 *g*). The marketable weight of cabbage (619±53 *g*) in the large greenhouse was also significantly higher than that of the small greenhouse (523±121 *g*). Therefore, larger size passive solar greenhouses are recommended for farmers in high altitude regions, especially above 3000 *m* asl.

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He conceived the study and contributed in manuscript preparation.