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Performance of frost protection structures on yield and post-harvest quality of organically grown winter dawn strawberry

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■ **ABSTRACT :** Low tunnel protected cultivation of organically grown strawberry (winter dawn) was carried out to standardize the cladding material and the height of structure for enhancing the yield and post-harvest quality in Punjab North India. Three different design of low tunnels *i.e.* three different heights; 45 cm, 60 cm and 75 cm and three claddings; thin plastic film (50 microns), UV stabilised plastic sheet (200 microns) and non-woven film (20 GSM) were used in the trials. Microclimate parameters, soil moisture and soil temperature inside the installed structures were analyzed throughout the experiments. The maximum yield of crop, number of fruits (45), maximum weight (28g) was observed in the tunnel of size 45 cm with non-woven 20 GSM followed by UV 200 micron of 60 cm height and minimum values were observed in other structures and open. All the tunnels maintained favourable soil and canopy temperature for the growth of crop and it was observed that crop grown inside tunnels were protected from any kind of frost injury and exhibited better post-harvest quality than the strawberry grown in open.

■ **KEY WORDS :** Frost protection structures, Yield, Post-harvest quality, Organically grown winter dawn strawberry

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Strawberry fruit crop is widely grown all over the world. The fruit is widely appreciated for its characteristic aroma, bright red colour, juicy texture, and sweetness. In 2017, world production of strawberries was 9.22 million tones, led by China with 40 per cent of the total, and the United States with 16 per cent (FAOSTAT, 2017-18). In India the area and production of strawberry crop is 1000 Ha and 5000MT, respectively (Daugaard, 1999). Strawberry is cultivated in Himachal Pradesh, Uttarakhand, Kashmir UT and (Mahabaleshwar) Maharashtra. Recently winter cultivation is also practiced in the states of Uttar Pradesh, West Bengal, Delhi, Haryana, Punjab and Rajasthan. Ideal conditions for strawberry crop are optimum temperature for fruiting is around 15-20°C, Optimum temperature for fertilization between 12°C and 25°C, Relative humidity around 60-80 per cent. Strawberries are one of the first crops to make their appearance in spring. Strawberry is one of the most suited crops for cultivation in low tunnel due to its short stature, bearing habit and root phenology (Fereira *et al*., 2004). Low tunnel creates a favourable microclimate for plant growth and protect them from adverse climate conditions. The modification caused by the low tunnel provided a better microclimate inside the tunnel resulting in early vigorous crop growth and better yield (Dorg, 2003 and Gao *et al.*, 2005). Climate plays a

major role in determining regional and site suitability for strawberry production (Rysin *et al.,* 2015). The strawberry can be sensitive to variables such as frosts, extreme low temperatures during winters and short growing season. Therefore, growing strawberries under protection can be more advantageous as it allows shielding from hails, rain and effective frost management. As a result fruit sustain less damage under tunnels than in open fields (Jett, 2007). Strawberries are also cleaner with less surface moisture at harvest (Karlsson and Werner, 2011) and tunnels also increase the length of time during which strawberries can be harvested (Kadir *et al.*, 2006a and Rowley *et al.*, 2011). Strawberries grown under protective structures has also shown to promote earlier flowering and fruiting when compared to open-field production (Kadir *et al.*, 2006a). The more diffuse light conditions under tunnels may result in better light penetration to lower leaves, thereby increasing photosynthesis (Baeza and Lopez, 2012 and Demchak, 2009). One of the most important advantage is disease management due to lack of moisture accumulation on leaves in a sheltered environment (Burlakoti *et al.*, 2014; Daugaard, 1999 and Demchak, 2009). Growing strawberries inside greenhouse or high tunnel requires a large investment, which is not feasible for small-scale farmer. Whereas, the use of low tunnels can be a feasible alternative which could help farmer increase his profit margin and enhance his economic sustainability. Moreover, the application of low tunnels would result in high quality of product, since the tunnels protect the plants and fruits from the damage caused by hails and frost, high rainfall, besides reducing the occurrence of diseases, extending the harvest season and avoiding nutrient leaching (Resende *et al.*, 2010). In low tunnel system, strawberries are grown on raised beds with plastic mulch. Hoops are spaced evenly down the length of the bed (Demchak and Hanson, 2013; Gu *et al.*, 2017; Hoashi-Erhardt *et al*., 2013; Kadir *et al.*, 2006a and Lewers *et al.*, 2017). Low tunnels offer various unique advantages over high tunnel. Protecting strawberry plants from frost is essential because frost can decimate an entire berry crop, especially if the berries have been exposed to warming temperatures. Strawberry blossoms are most sensitive to frost right before and during opening. Frost protection of strawberries is less important when the flowers are still in tight clusters and just barely peaking from the crown. Keeping these into view, the present experiment was conducted to study performance of different low tunnels (Heights; 45 cm, 60 cm and 75 cm and cladding materials; UVS polythene 200, 17 GSM UVS non-woven and 50 clear film) with silver/black plastic mulch on production, post harvest quality and reduction in frost injury of strawberry.

METHODOLOGY

The research experiments were conducted at ICAR-CIPHET, Ludhiana. in the plasticulture park of the institute from September, 2019 to March, 2020. The experimental site is located at an elevation of 262 meters above sea level at 30.9010^{o} N latitude and 75.8573^{o} E longitude and comes under semi-arid region. The climate of the site can be characterized with minimum and maximum temperature ranging from 1^{o}C-45^{o}C with average annual rainfall of 726 mm. The selected region offers variable climate from semi arid to humid. The Strawberry Var. Winter Dawn was procured and supplied from Pune, Maharashtra India (Innovative Greenhouse Project Pvt Ltd). Soil characteristics were evaluated at the soil testing centre Punjab Agricultural University, Ludhiana.

Design, layout of statures and microclimate monitoring:

Three sizes of low tunnel were selected for the experiment *i.e.* 0.45m, 0.60 m and 0.75 m by keeping in view strawberry plant characteristics. G.I wire of 5mm thickness was use as building material for fabrication. All structures were fabricated with arc shape. Each tunnel made of 4.5 m with improved design over present low tunnel installations to add extra strength to developed structure. Star foundation of GI wire was provided at the bottom of tunnel for better stability. All the hoops of tunes were connected by 3 GI wire purlins to add strength against lateral movement under stress. The design of tunnel was made such that recommended side ventilation of 15-20 per cent could provided with ease in fixing cladding materials. The detailed engineering design of structure is shown in Fig. A. All tunnels were fabricated at engineering workshop of ICAR-CIPHET Ludhiana. The tunnels were installed on raised beds with E-W directions. Sliver on black plastic mulch sheet of 30 microns was used to lay on beds inside fabricated tunnels along with drip irrigation system. Each tunnel covered an area of 4.5 m^{2}. Three types of cladding material were

Fig. A : Installed different tunnels with control in experiment field

used to cover these 9 structures. Types of sheets used were thin plastic film (50 microns), thick plastic sheet (200 microns) and non-woven type sheet (20 GSM). These low tunnel coverings were held in place on top of the GI structure and were tied off on each end to the anchors in the ground.

Four beds identical in size having dimensions L=22.50 cm, W= 100 cm and H= 30 cm were prepared and 600 plants of strawberry were planted over these beds with spacing of 60 cm 60 cm. in the first week of October, 2019. The cultivation of organic strawberry cultivation is rare in India except in the north east. In order to gain high return from the product in the era where there is high demand for organic foods, organic trial has been planned in the study. FYM @ 0.6 kg per sq. m., vermin-compost @ 200 g per sq. m. and DAP @ 4 g per sq. m applied to all beds. Readings regarding temperature, relative humidity and light intensity were continuously recorded using data logger (sauermann KH 220), hygrometers and digital thermometers ate study microclimate of all tunnels. Soil moisture and temperature were also recorded during all experiment using digital recorders.

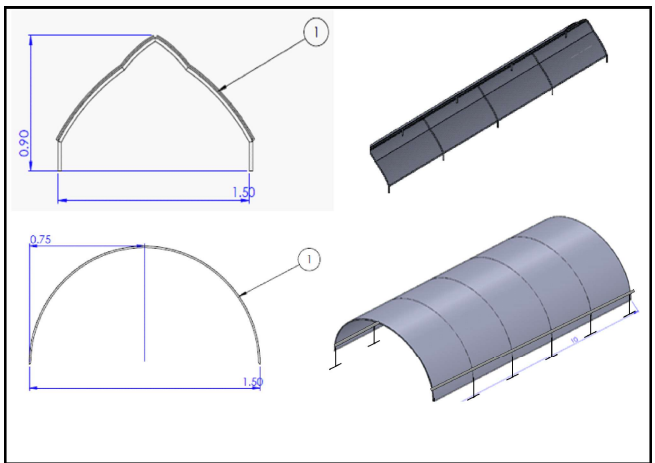

Fig. B : Low tunnel design used in installation of different structures

The crop was harvested at the maturation stage when fruit was ripe or exhibited dark red coloured fruit. Harvest was carried out every second day from the month of December 2019 to March 2020. The agronomic traits such as: height of plant, number of leaves and fruits damaged due to frost under low tunnel were recorded. In terms of production component, total number of fruits per plant, total mass of fruits per plant and the average mass of fruits were determined.The post harvest quality was also determined by measures of Total Soluble Solids (TSS) and sensory analysis; colour, taste, size, sweetness of the fruit by use of hedonic scale. Soil temperature and moisture content were also monitored on daily basis after certain time intervals and accordingly the drip irrigation system was made functional to fulfill water requirement of crop and desired soil moisture content to keep surface wet for better frost management during peak winter months.

Crop growth and post harvest parameters:

Number of fruits and flowers:

The number of fruits per plant was recorded twice a week from various plants under different types of low tunnel structure. The first harvest of crop was done in third week of December, 2019 and the harvest extended

till May 2020.

Yield: No. of fruits and weight :

The total yield of crop under different types of low tunnel structure was recorded by counting and weight using electronic digital scale.

TSS :

The refractometer, which optically measures the refractive index of juice, is the standard method used to measure TSS of fruit and vegetables. TSS or Brix represents the percentage by mass of total soluble solids of a pure aqueous sucrose solution (Pereira *et al.*, 2013).

Fruit length and width :

The dimensional parameters the fruit is measured by vernier scale in which longest dimension is length and smallest is width in mm.

Sensory evaluation :

Ten persons were selected to serve on a taste panel to evaluate the characteristics of harvested strawberry. All members of the panel were familiar with strawberry and had previous sensory evaluation experience. Following a training period, a score sheet was developed for 7 identifiable attributes— Colour of strawberry, taste, sweetness, smell, appearance, texture and size of fruit. The objective of the sensory evaluation was to provide an objective descriptive characterization of the sensory properties of these fruits and not to determine acceptability or preference. All the members evaluated two or three samples at a time. Samples of strawberry were presented at room temperature in random order. The members of panel performed their evaluations individually to eliminate the influence of other members on their scores. The tasters quantified the intensity of the chosen attributes on a 9-point category scale (0–9).

Height of structure	Cladding material	Treatments
H_2	M_2	H_2M_2
H_2	M_3	H_2M_3
H_3	M_1	H_3M_1
H_3	M_3	H_3M_3
H_1	M_1	H_1M_1
H_3	M_2	H_3M_2
H_1	M_2	H_1M_2
H_1	M_3	H_1M_3
H_2	M_1	H_2M_1
Control		

Where, (i) H_1 = 45 cm, H_2 = 60 cm and H_3 = 75 cm and
(ii) M_1 = Non-Woven type (20 µm), M_2 = UV Clear film (50 µm) and M_3 = UV Plastic sheet (200 µm)

Design of experiment :

Randomised factorial design with the help of Minitab (2019) software was followed to perform the experiment. Given as follows:

■ RESULTS AND DISCUSSION

The effect of different protected structures on crop growth parameters have also studied. The date of transplanting is same in all treatment, standard irrigation treatment and silver on black mulch was used in the experiment. Only raise bed cultivation along with silver on black plastic mulch and drip irrigation followed for control. The detailed result are shown in following figures and tables.

Effect of structures on microclimate:

The maximum temperature rise inside the structure was caused by UVS polythene sheet during the entire cropping season *i.e.* from October to March. During the month of January, the minimum temperature outside the structure varied from 2-10°C, while minimum temperature inside non-woven sheet varied from 3.1-10.9°C, for Thin plastic film it's varied from 5.4 -14.2°C and for UVS sheet it ranged from 7.8 - 16.1°C. A similar type of pattern was observed for the entire cropping period *i.e.* for the month of February and March. Regarding the maximum temperature in the month of January, maximum temperature varied from 14 - 23°C. In case of non-woven cladding material, maximum temperature inside the structure varied from 18.4-27.6°C. For Thin plastic sheet and UVS sheet it ranged

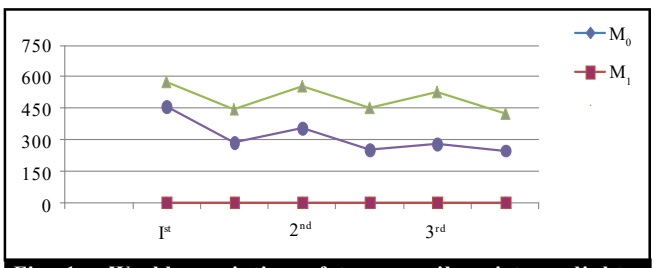

Fig. 1a: Weekly variation of temp., soil moisture, light intensity under non-woven tunnel structure

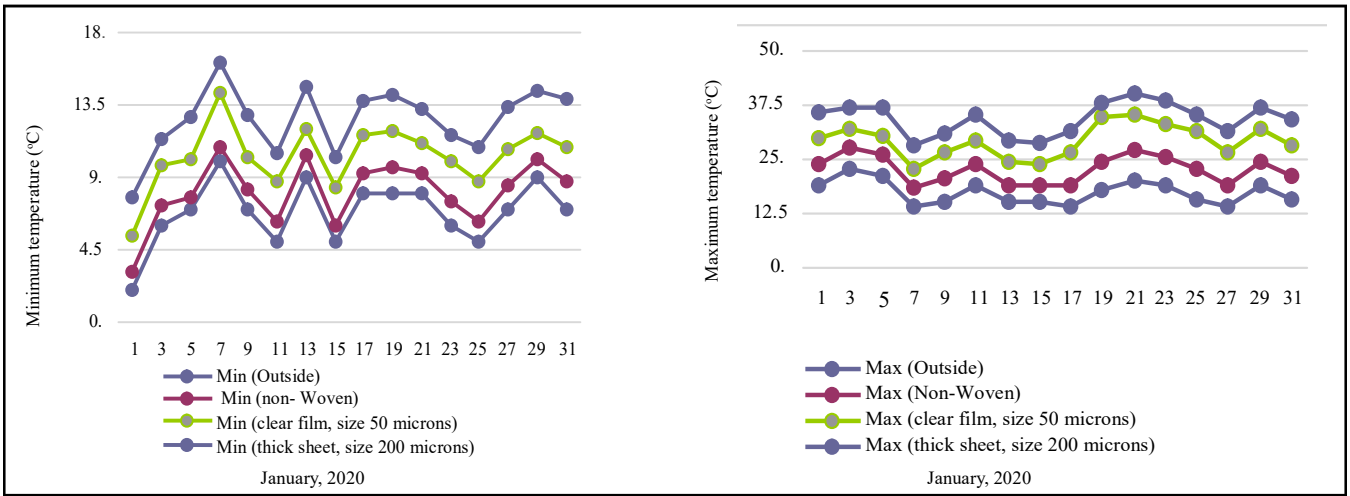

Fig. 1b: Variation in microclimate parameters for month of January 2020

from 22.8 - 31.8°C and 28 - 40.1°C, respectively. The fig shows the variation in microclimate parameters for month of January, an identical type of pattern was recorded for the month of February and March. The soil moisture and light intensity was found in the range of 58-71 per cent and 342- 546 lux, respectively inside tunnels and all the installed structures followed same trend (Fig. 3a and b).

Number of flowers and fruits :

Data regarding number of flowers per plant has shown significant difference. From Table 1, the highest number of flowers were found in H_1M_1 treatment (12.5), followed by H_1M_3 (7.5) while the lowest number were observed in H_3M_2 (1.5) and H_3M_3 (1.5). The number of fruits per plant ranged from 5.5 (H_3M_3) to 45.5 (H_1M_1). From Table 1, it can be observed that the number of fruits per plant were low under low tunnel height of 75 cm irrespective of the covering material. Also, the control (6.5) fruit number is close to the value obtained by H_3M_3 (5.5). During winter season covered tunnels have higher temperature than in open, which may have caused the increase in fruit number. Davies *et al.* (2002) reported similar effects of temperature on flower and fruit numbers.

Size of fruit: (length, width) and weight :

From Table 1, the fruit length is maximum (4.65 cm) in H_1M_1 treatment, immediately followed by H_1M_2 (4.60 cm) and H_2M_2 (4.45 cm). The minimum length was recorded in the treatment with H_3M_2 (2.85 cm) which is close with the result seen in control (2.95 cm).

Table 1: Result of varying height of low tunnel with different cladding materials on the quality parameters (Avg values) of strawberry winter dawn

Treatments	No. of flowers	Fruits	Fruit length (cm)	Width (cm)	Weight (g)	TSS (% Brix)	Frost damage
H_2M_2	3.00	14.0	4.45	3.45	22.00	5.50	5%
H_2M_3	6.50	11.5	3.35	3.10	17.50	5.20	4%
H_3M_1	5.00	9.0	4.35	3.00	15.50	5.75	8%
H_3M_3	1.50	5.5	3.10	2.95	13.00	5.40	4%
H_1M_1	12.50	45.50	4.65	3.45	28.00	6.10	5%
H_3M_2	1.50	9.5	2.85	2.70	13.00	5.35	5%
H_1M_2	5.00	35.0	4.60	3.70	15.00	6.00	6%
H_1M_3	7.50	31.00	3.85	3.20	21.00	6.00	5%
H_2M_1	3.00	15.0	3.70	3.15	16.00	5.75	7%
Control	4.50	6.50	2.95	3.10	14.00	5.0	25%

Data related to fruit width revealed that the maximum fruit width was seen in the treatment H_1M_2 (3.70 cm) while the minimum was observed in H_3M_2 treatment (2.7 cm) while in control, it was recorded 3.1 cm.The fruit weight shows the significant variation in terms of height given and material used for low tunnel. By the data from the Table 1, the maximum value recorded was in the treatment H_1M_1 (28 g) while the minimum was seen in H_3M_2 and H_3M_3 (13 g) immediately followed by the control (14 g). Singh *et al.* (2012) has reported similar trends regarding size of the fruit.

Fig. 2 : Fruits under different tunnels in uncovered condition

Total soluble solids (TSS):

As per the Table 1, the value of TSS varies from 5.00 % Brix (controlled) to maximum of 6.10 % Brix in H_1M_1. TSS of strawberry grown inside tunnels exhibit decide TSS value than control condition.

ANOVA:

The cognizance about the contribution of the individual parameter on the process is vital in deciding about the nature of control to be entrenched. ANOVA is statistical tool used to study the percentage contribution of the individual input parameter on the output response. ANOVA table helps in analysing the factor that needs notable attention. To grasp the significance about the regression model between the input parameters and response variables P test and F test are performed. These P (contribution of parameter) and F values are used to study the level of significance of regression model under consideration. The F value calculated is compared with the standard F value for a given level of significance. If the value of calculated F is found to be greater than the standard F value, then it can be established that the regression model is significant in representing the correlation between the input parameters and the responses. Analysis of variance (ANOVA) was applied to check the variability and how much significant were the values was observed. For this, two most significant output values *i.e.* number of fruits and TSS were taken and ANOVA was performed in minitab software.

ANOVA (No. of fruits):

From the table we observe that the high F-value graph shows a case where the variability of group means is large relative to the within group variability. The P-Value is less than 0.005, which implies that the null hypothesis is rejected and ANOVA model is highly significant with a significance level higher than 95 per cent.

Model summary:

From the table, we can observe that the value of R-sq is about 98 per cent which represents the optimal correlation between input and output parameters. Higher

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	2	1441.1	91.83%	1441.1	720.53	33.73	0.001
Linear	2	1441.1	91.83%	1441.1	720.53	33.73	0.001
Height of structure	2	1441.1	91.83%	1441.1	720.53	33.73	0.001
Error	6	128.2	8.17%	128.2	21.36		
Total	8	1569.2	100.00%				

ANOVA(No. of fruits)

Model summary						
S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
2.71987	98.06%	96.12%	149.804	90.18%	90.25	49.44

the value of R-sq, more variation is explained by the input variables and hence better is the model. The value of R-sq (adj) is about 96 per cent which signifies that the correlation between the input and output parameters represented by the R-sq value is highly reliable.

Regression equation:

No. of fruits = 19.56+ 17.61 height of structure(45)- 6.06 height of structure(60)-11.56 height of structure (75)

Fig. 3 and 4 displays the 2-d and the 3-d plot of No. of fruits vs cladding material and height of structure. It reveals that the no. of fruits decreases with increase in height of structure and with increase in mesh size of cladding material.

From this table we observe that the high F-value graph shows a case where the variability of group means is large relative to the within group variability. The P-Value is less than 0.005, which implies that the Null hypothesis is rejected and ANOVA model is highly significant with a significance level higher than 95 per cent.

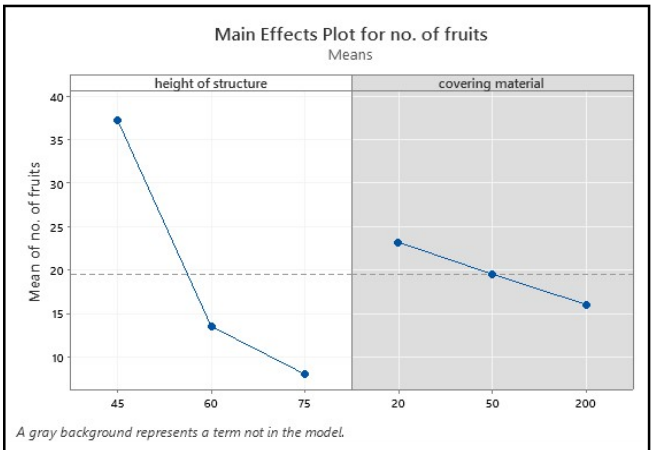

Fig. 3 : Effects plot for no. of fruits due to height of structure and cladding material

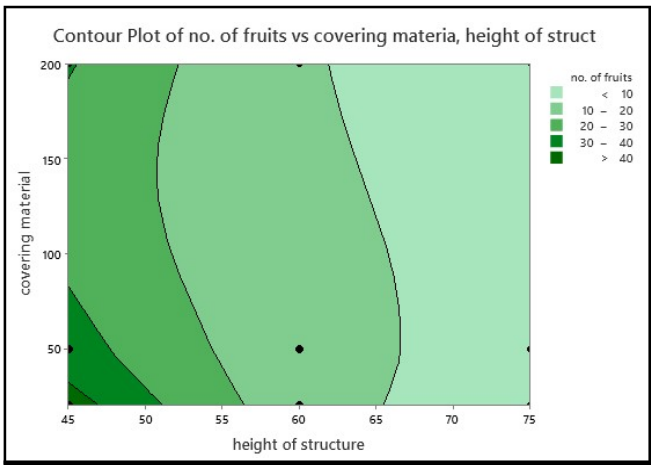

Fig. 4 : 2-d plot for no. of fruits vs cladding material and height of structure

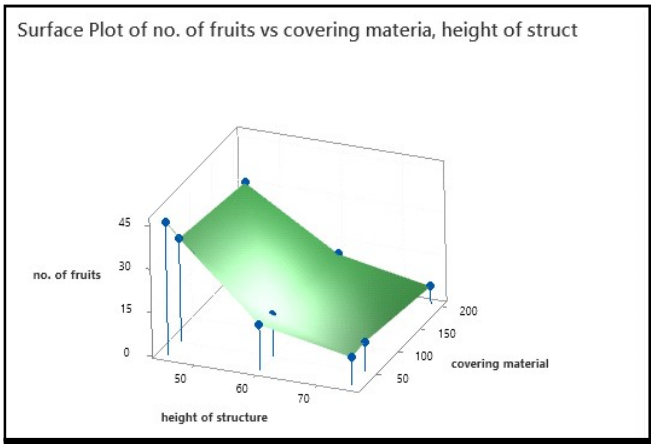

Fig. 5 : 3-d plot for no. of fruits vs cladding material and height of structure

Model summary :

From the table, we can observe that the value of R-sq is about 100 per cent which represents the perfect correlation between input and output parameters. Higher the value of R-sq, more variation is explained by the input variables and hence, better is the model. The value

Analysis of variance (TSS)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	4	4.33278	99.59%	4.33278	1.08319	243.72	0.000050
Linear	4	4.33278	99.59%	4.33278	1.08319	243.72	0.000050
Height of structure	2	4.03722	92.80%	4.03722	2.01861	454.19	0.000019
Covering material	2	0.29556	6.79%	0.29556	0.14778	33.25	0.003219
Error	4	0.01778	0.41%	0.01778	0.00444		
Total	8	4.35056	100.00%				

Model summary						
S	R-sq	R-sq (adj)	PRESS	R-sq (pred)	AICc	BIC
0.0666667	99.59%	99.18%	0.09	97.93%	23.50	-17.32

of R-sq (adj) is about 99 per cent which signifies that the correlation between the input and output parameters represented by the R-sq value is highly reliable.

Regression equation :

TSS= 5.2778 + 0.8889 height of structure (45)- 0.1611 height of structure (60)- 0.7278 height of structure (75)+0.2556 covering material (20)- 0.1111 covering material (50)- 0.1444 covering material (200)

Fig. 6 and 7 displays the 2-d and the 3-d plot of TSS vs cladding material and height of structure. It reveals that the TSS decreases with increase in height of structure and with increase in mesh size of cladding material.

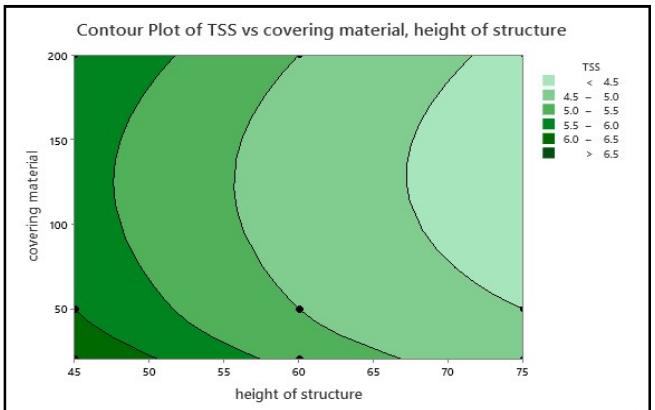

Fig. 7 : 2-d plot for TSS vs cladding material and height of structure

Plant height :

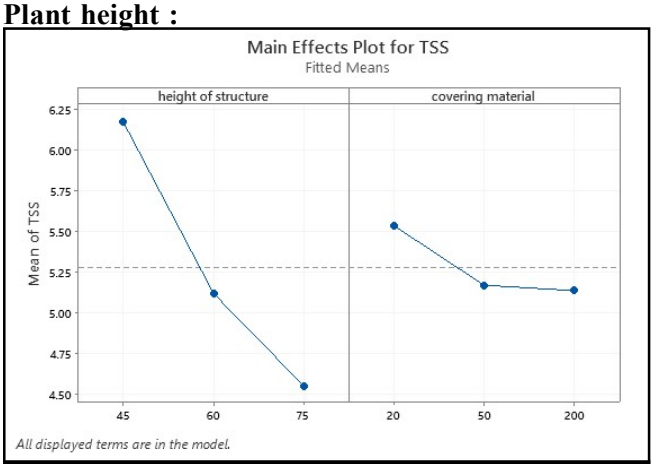

Fig. 6 : Effects plot for TSS due to height of structure and cladding material

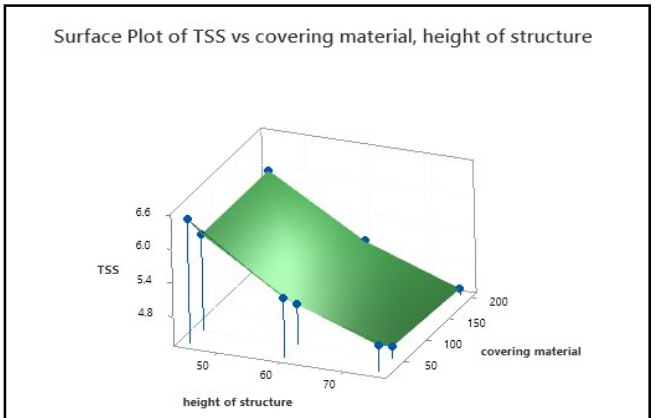

Fig. 8 : 3-d plot for TSS vs cladding material and height of structure

Table 2: Result of varying height of low tunnel with different materials on the vegetative growth of (avg. values) strawberry winter dawn

Treatments	Plant height	No. of leaves	Plant width	Plant length
H_2M_2	13.80	36.00	27.20	30.67
H_2M_3	14.76	54.23	26.55	30.10
H_3M_1	17.27	51.67	29.97	32.40
H_3M_3	17.93	53.33	35.70	30.37
H_1M_1	18.70	70.00	24.00	24.30
H_3M_2	15.47	59.67	30.73	30.60
H_1M_2	17.83	75.67	29.13	30.63
H_1M_3	18.00	60.33	33.67	29.67
H_2M_1	14.87	42.00	29.00	28.73
Control	14.37	36.00	28.83	29.90

Table 3 : Sensory evaluation

Parameters	Colour	Taste	Sweetness	Smell	Appearance	Texture	Size
Tunnels	9	8	8	6	8	9	9
Control	7	7	8	6	8	7	7

Where, 1 – Dislike extremely, 2 – Dislike very much, 3 – Dislike moderately, 4 – Dislike slightly, 5 –Neither like or dislike, 6 – Like slightly, 7 – Like moderately, 8 – Like very much and 9 – Like extremely. The sensory analysis was done after picking and revealed that strawberry grown inside tunnels have better post harvest quality than grown without tunnels.

From Table 2, the maximum plant height (18.7 cm) was recorded in the treatment with non-woven low tunnel of 45 cm height closely followed by H_1M_3 (18.00) and the minimum (13.8) was observed in the one with clear film of height 60 cm and in control (14.37). The minimum plant height was found in under the low tunnel at 60 cm of height irrespective of the material used for low tunnel.

Number of leaves:

The maximum number of leaves (75) was recorded in the treatment with clear film of height 45 cm and the minimum (36) was observed in the control treatment and one with clear film of height 60 cm (Table 3). Overall, the numbers of leaves were maximum under the low tunnel at 45 cm of height irrespective of the material used for low tunnel.

Plant spread :

As depicted in Table 2, plant spread in terms of plant length and width varies significantly. The treatment with H_3M_3 has shown maximum plant width (35.70 cm) which is closely followed by H_1M_3 treatment (33.67 cm). The minimum plant length was seen in the treatment H_1M_1 (24 cm).

Conclusion:

The application of low tunnels or frost management structures provided better microclimate conditions which resulted in early and more vigorous crop growth for winter strawberry cultivation in North India. The maximum yield of crop, number of fruits (45), maximum weight (28g) was observed in the tunnel of size 45 cm with non-woven 20 GSM protective sheet followed by UV 200 micron of 60 cm and minimum values were observed in open cultivation. Maximum yield was obtained under non woven tunnel because structures covered with non woven material offered desired microclimate for the strawberry. All the tunnels maintained favourable soil and canopy temperature for the growth of crop and it was observed that crop grown inside tunnels were protected from any kind of frost injury and exhibited better post-harvest quality than the strawberry grown in open. Hence, organic winter production of strawberry in non-woven plastic covered low tunnel is one of the best options to attain early production as well as to extend cropping season in North Indian conditions.

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