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Seed production potential of bell pepper (*Capsicum annuum*) under protected and open conditions in Indo-Gangetic plains of northern India

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ABSTRACT

Bell pepper (*Capsicum annuum* L. var. *Grossum* Sendt.) crop is sensitive to frost and high temperature. High temperature above 35°C during April-May in northern plains of India causes poor fruit and seed set under open conditions. The present study was carried out during winter (*rabi*) seasons of 2019–20 and 2020–21 at Punjab Agricultural University, Ludhiana, Punjab to analyze the seed production potential of the bell pepper variety PSM-1 under protected and open conditions. The investigation was laid out in a split-plot design (SPD) with main plot of two environments [polyhouse (E_1) and low tunnel (E_2)] and subplots of three different transplanting dates [the second week of November (D_1), December (D_2) and February (D_3)]. Being thermosensitive in nature, protected cultivation resulted in the production of significantly larger bell pepper fruits with concomitant enhancement in seed quality. Despite the initial high monetary investment, polyhouses proved to be more conducive for bell pepper growth, fruit, and seed production among protected structures, resulting in a higher yield and improved quality of fruits and seeds. November transplanted crop in the polyhouse took the highest number of days to flower initiation and fruit harvest consuming the highest heat units, resulting in the better plant growth, seed quality and yield contributing traits, viz. number of fruits/plant, fruit yield/ plant, average fruit weight, seed weight/fruit, 1000-seed weight, seed yield, germination and SVI-I providing maximum net returns to the farmers. For low tunnel cultivation setting, December transplanted plants recorded the best performance in terms of plant growth, seed yield and seed quality traits.

Keywords: Bell pepper, Pollen viability, Stigma receptivity, Vigour index

Bell pepper (*Capsicum annuum* L. var. *Grossum* Sendt.) is a widely commercialized high-value horticultural crop cultivated across the world for its high levels of anti-diabetic, immunostimulant and cancer-fighting antioxidants like lycopene, carotenoids, vitamin A, C, B_6, E and K_1, and essential minerals like iron, calcium, magnesium, potassium and phosphorous (USDA 2019). Its production has gradually risen over the years with a production of 563 thousand metric tonnes over an area of 38,000 ha during the years 2021–22 (Anonymous 2023).

Bell pepper is a thermosensitive winter crop highly susceptible to frost and high temperature with a narrow optimum temperature pre-requisite of 20–25°C for successful cultivation. Temperature fluctuations, below 15°C or above 32°C, can lead to growth retardation, premature flower and fruit drop resulting in significant decline in seed yield and quality (Pinero *et al.* 2022). Thereby, bell-pepper production in open field conditions may cause significant reduction in fruit and seed yields as well. Contemporary agricultural practices, such as protected cultivation, facilitate the extension of favourable climatic conditions during essential growth periods, enhance fruit and seed production, and integrate fragmented and marginal areas into farming within urban and peri-urban settings (Wani *et al.* 2011). Protected cultivations are increasingly being employed to extend harvest spans, maximize productivity/unit area, resource-use efficiency and economic profitability for the production of high-value cash crops including bell-pepper (Choudary 2016). Another technique rapidly gaining attraction is low tunnel technology as an easier, cheaper alternative of polyhouse to meet high food demands on limited areas.

Growing degree days (GDD) and photothermal units (PTU) are agro-meteorological indices used to predict flowering and harvest time in field and vegetable crops. PSM-1 is a heat tolerant early maturing bell pepper variety producing uniform, tri-lobed, non-pungent, deep red coloured fruits on maturity (Anonymous 2021). Thus, being an economically important crop, this study was designed to optimize and assess the effect of polyhouse, low tunnels and open conditions on seed yield and quality in bell pepper.

MATERIALS AND METHODS

The present study was carried out during winter (*rabi*) seasons of 2019–20 and 2020–21 at Punjab Agricultural

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University, Ludhiana, Punjab. The experiment was laid out in a split plot design (SPD) with main plot, viz. Polyhouse (E_1) and low tunnels (E_2) and sub-plot of three different transplanting dates, i.e. second week of November (D_1), second week of December (D_2) and second week of February (D_3). The plants transplanted in February were treated as open conditions (control) in a low tunnel environment (E_2D_3).

The nursery of the bell pepper variety 'PSM-1' was raised as per the recommended cultural practices (Anonymous 2021). The seeds were sown at three different times, first week of October, third week of October and first week of November. The seedlings of equivalent size and vigour were transplanted in the main field when the seedlings achieved transplantable height of 15–20 cm. The transplanting beds were prepared by adding 62.5 tonnes of well-decomposed farmyard manure/ha, alongside 125 kg/ha, 62.5 kg/ ha and 30 kg/ha doses of inorganic fertilizers, viz. N, P_2O_5 and K_2O, respectively, as per the recommended specifications by Punjab Agricultural University (Anonymous 2021). The seedlings were transplanted at 90 cm row to row and 30 cm plant to plant spacing in each plot. Data on meteorological observations were collected from the Punjab Agricultural University, Ludhiana, Punjab.

Two crop phenophases, viz. flower initiation and the red ripe stage for seed harvest were chosen for recording observations on growth and development parameters. Growing degree days (GDD) were determined as number of temperature degrees above a base temperature, taken as 7°C for bell pepper crop. GDD were calculated using the following formula as per De Beurs and Henebry (2008):

$$\text{GDD (°C Day)} = \frac{\text{T max} + \text{T min}}{2} - \text{T base}$$

Where T_{max}, Daily maximum temperature (ºC); T_{min}, Daily minimum temperature (ºC) and T_{base}, Base temperature (ºC).

Photothermal units (PTU) were calculated by multiplying the growing degree days to the day length (Kaur *et al.* 2019).

Pollen viability was determined using acetocarmine as per the method suggested by Singh (2017) by spreading the extracted pollen grains on slides with drops of 1% acetocarmine. Stained and unstained or shrivelled pollens were counted and the average of the three counts was expressed as pollen viability (%). Stigma receptivity was determined by totalling the number of bubbles emerging from the stigma within a minute of applying 6% hydrogen peroxide on the stigma of the mature buds (Makwana and Akarsh 2017).

Ten plants per replication were selected randomly at the final harvest to measure plant height and the total number of fruits/plant. The total weight of fruits harvested/plant was expressed as the fruit yield/plant. The fruit yield/plant was divided by the total number of fruits/plant to get the average fruit weight. The polar diameter of five randomly selected mature fruits was measured at the harvest stage to obtain fruit length in bell pepper. The total seed weight of each replication was divided by the number of fruits in that replication to obtain seed weight/fruit. Thousand seeds were counted in each replication and the weight of the seeds was measured on a weighing balance to record 1000-seed weight. The seeds extracted were sun dried for 24 h and collected. Seed yield/plant was obtained by dividing the total seed weight by the total number of plants. Seed yield/ha was calculated using the seed yield obtained per m^2. Heat use efficiency (HUE) for seed harvested was calculated using the following formula described by Singh and Khushu (2012):

$$\text{HUE (g/m}^2\text{/°C day)} = \frac{\text{Dry matter yield (g/m}^2\text{)}}{\Sigma \text{ GDD (°C Day)}}$$

The standard germination test was carried out using the rolling paper method. The germinated seedlings were evaluated on the 14^{th} day and the germination was calculated as:

$$\text{Germination (\%)} = \frac{\text{No. of seeds germinated}}{\text{Total no. of seeds}} \times 100$$

For seedling vigour index I (SVI-I), the germination percentage was multiplied by the average seedling length (Abdul-Baki and Anderson 1973).

The data of both the years 2019–20 and 2020–21 was pooled for the comparison of treatments. Pearson's correlation and biplot analysis were conducted using Minitab version 17.

RESULTS AND DISCUSSION

Crop phenology of bell pepper: The phenology of bell pepper was significantly influenced by varying growing environments and transplanting dates. The number of days taken to flower initiation (114.1 days) and, consequently, the number of days to fruit harvest (197.4 days) were significantly the highest in the crop transplanted in November under polyhouse (E_1D_1). November transplanted crop took the highest number of days to harvest which could be attributed to the low temperature experienced by the crop during the early crop growth stages, which were not congenial for flowering, forcing the plants to remain in the vegetative stage and bear flowers when frost was over, i.e. February to early March (Long and Ort 2010, Pramanik *et al.* 2020). Statistically, fewer days were taken for the flower initiation and the fruit harvest in the crop transplanted in other treatments (Table 1). The least number of days were required to attain flower initiation (52.0 days) and fruit harvest (99.8 days) when the crop was transplanted in the month of February under both polyhouse (E_1D_3) and low tunnel (E_2D_3) due to optimum weather conditions for flowering in February-March and for fruiting in early April, triggering the plants to start their vegetative and reproductive growth at the same time.

Growing degree days and photothermal units: Agrometeorological indices of bell pepper such as

Table 1 Effect of different growing environments and transplanting dates on agrometeorological indices, seed yield and yield contributing traits in bell pepper

Parameters	Polyhouse (E_1)			Low tunnel (E_2)		
	D_1	D_2	D_3	D_1	D_2	D_3*
Number of days to flower initiation	114.1^{a}	89.3^{c}	49.4^{f}	108.5^{b}	85.5^{d}	52.0^{e}
GDD (flower initiation)	826.0^{a}	574.9^{c}	597.9^{c}	756.9^{ab}	533.6^{c}	636.1^{bc}
PTU (flower initiation)	8681.5^{a}	6141.0^{cd}	6913.5^{bcd}	7900.1^{ab}	5671.1^{d}	7382.4^{abc}
Number of days to fruit harvest for seed extraction	197.4^{a}	163.4^{bc}	100.7^{d}	169.7^{b}	153.3^{c}	99.8^{d}
GDD (fruit harvest)	2305.6^{a}	1894.5^{b}	1607.2^{c}	1726.2^{bc}	1674.9^{bc}	1584.2^{c}
PTU (fruit harvest)	27546.9^{a}	22922.6^{b}	20025.0^{b}	19814.8^{b}	19991.1^{b}	19714.7^{b}
Plant height (cm)	85.9^{a}	84.1^{a}	68.4^{b}	32.9^{d}	37.8^{c}	34.3^{cd}
Number of fruits/plant	11.4^{a}	10.1^{b}	8.4^{c}	6.3^{d}	7.9^{c}	5.1^{e}
Fruit yield/plant (g)	799.20^{a}	643.72^{b}	453.85^{c}	202.39^{e}	347.15^{d}	171.86^{e}
Average fruit weight (g)	69.8^{a}	64.2^{b}	53.9^{c}	32.2^{e}	43.6^{d}	33.8^{e}
Fruit length (cm)	8.4^{a}	7.7^{b}	7.6^{b}	5.2^{c}	5.7^{c}	5.6^{c}
Seed weight/fruit (g)	0.31^{a}	0.28^{b}	0.23^{c}	0.18^{d}	0.24^{c}	0.13^{e}
1000-seed weight (g)	6.0^{a}	5.3^{b}	4.5^{d}	4.2^{e}	4.9^{c}	3.6^{f}
Seed yield (g/plant)	3.6^{a}	2.9^{b}	1.9^{c}	1.2^{d}	2.0^{c}	0.6^{e}
Seed yield (q/ha)	2.2^{a}	1.7^{b}	1.2^{c}	0.6^{e}	1.0^{d}	0.3^{f}
HUE for seed production (g/m^2/°C Day)	0.00160^{a}	0.00158^{a}	0.00124^{bc}	0.00070^{d}	0.00120^{bc}	0.00043^{e}

DDG, Growing degree days; PTU, Photo-thermal units; D_1, D_2 and D_3, Three different transplanting dates, i.e. second week of November, second week of December and second week of February, respectively. Least square means with different superscript letters are significantly different. *February transplanted crop in low tunnels (E_2D_3) was treated as open conditions.

accumulated growing degree days (GDD) and photo-thermal units (PTU) were calculated to predict the heat units consumed to attain flower initiation and fruit harvest (Table 1). The crop transplanted in the month of November accumulated higher GDD (826.0 °C day, 756.9°C day) and PTU (8681.5°C days h, 7900.1°C days h) to attain days to flower initiation under both polyhouse and low tunnel cultivation, respectively. This was followed by a gradual decline in GDD and PTU thereafter for the crop transplanted in the month of December. This trend witnessed an upward trend in the GDD and PTU accumulated for the crop transplanted in the month of February, possibly due to the early availability of congenial temperature for flower initiation, stimulating the plants to start their vegetative and reproductive growth at the same time (Long and Ort 2010, Pramanik *et al.* 2020). Data revealed that significantly higher heat units were consumed in the form of GDD (2305.6°C day) and PTU (27546.9°C days h) to attain physiological maturity for the crop transplanted in the month of November under polyhouse, followed by a progressive decrease for later months. Statistically similar heat units were consumed by the crop transplanted in the months of November and December under low tunnel conditions to attain maturity.

Pollen viability and stigma receptivity in bell pepper: Pollen viability and stigma receptivity are two chief pre-requisites indicating the reproductive success and subsequently, successful seed set in the crop. Data revealed statistically at par pollen viability and stigma receptivity levels in the crop transplanted in the months of November and December (Fig. 1a). Plants transplanted in the month of February under both environments recorded significantly lower stigma receptivity. Stigma receptivity and viability of the pollen were recorded to be statistically the lowest in the plants transplanted in the open conditions (E_2D_3) i.e. 72.3% and 79.1%, respectively. This could be attributed to the presence of high temperature, beyond 35°C, apparently increasing the instances of stigma degeneration, affecting pollen grain adhesion, stigma receptivity, pollen tube penetration into the transmitting tissue and finally pollen germination (Hedhly *et al.* 2005).

Fruit yield and yield contributing characters: Significant differences were observed in the fruit characteristics in the crop grown under polyhouse and low tunnel with polyhouse recording significantly better yield and fruit quality (Table 1). In polyhouse, higher plant height and HUE for seed production was recorded in November and December transplanted crop than in February transplanted crop (Table 1). Significantly the highest number of fruits/plant (11.4) and fruit yield/plant (799.2 g) were recorded in the November transplanted crop (E_1D_1) along with significantly the highest average fruit length along the polar diameter of the fruit (8.4 cm) and average fruit weight (69.8 g) in comparison to other treatments. These differences could be attributed to favourable environmental conditions experienced by the crop when grown under polyhouse as compared to low tunnels and open conditions (Pramanik *et al.* 2020).

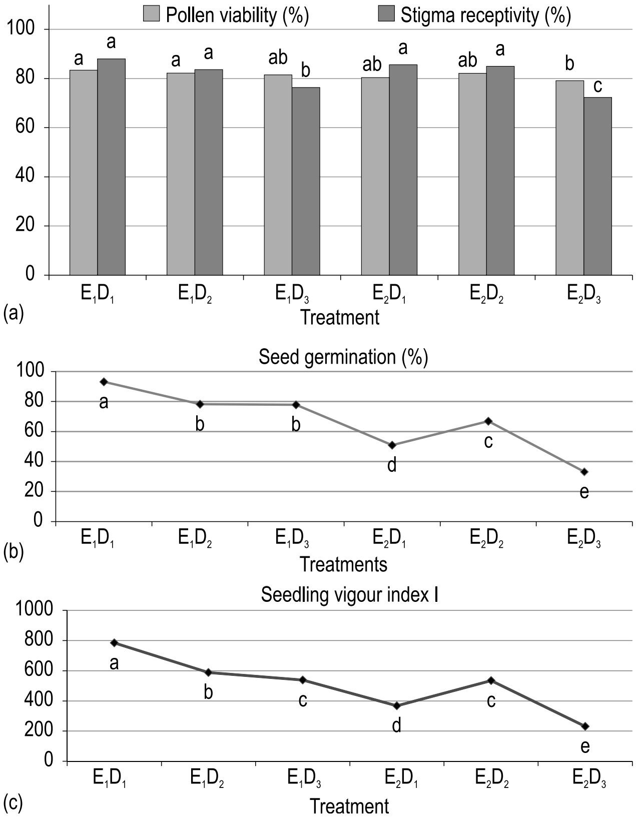

Fig. 1 Effect of different growing environments and transplanting dates on the (a) pollen viability and stigma receptivity and the seed quality parameters (b) germination (%) (c) SVI-I of harvested seeds in bell pepper. Least square means with different superscript letters are significantly different. *February transplanted crop in low tunnels (E_2D_2) was treated as open conditions.

Crop cultivation under polyhouses has been reported to stimulate cell division and enlargement in the crop's apical regions resulting in higher vegetative growth with plants attaining more plant height and improved metabolic activities, high intake of nutrients and the accumulation of sufficient photosynthates which may aid in the expansion of fruit size, resulting in higher fruit weight. However, in open conditions, sharp increase in temperature following the frost conditions creates sudden warmer microclimatic conditions for fruit development, due to which fruits quickly start ripening as a stress avoidance response, forcing the plants to enter reproductive growth earlier leading to flower and fruit drop especially in temperature-sensitive crops such as bell pepper (Dhaliwal *et al.* 2017). Higher temperature of around 35–40°C in the months of April–May faced by the plants on late transplantation was reported not to be congenial for fruit development and thus adversely affected the growth and reproductive cycle by accelerating the flowering and maturity, thereby reducing yield and fruit quality (Long and Ort 2010).

Seed yield and yield contributing characters: The seed yield differed significantly amongst the crop grown under polyhouse, low tunnel and open field conditions with polyhouse recording the significantly higher seed yield as similarly reported by Pramanik *et al.* (2020). Significantly the highest 1000-seed weight, seed weight/fruit and seed yield/plant was recorded in November transplanted crop (E_1D_1) than in other treatments (Table 1). Likewise, the highest HUE for seed production was documented in the crop transplanted in November (0.00160 g/m^2/°C Day) followed closely by the crop transplanted in December (0.00158 g/m^2/°C Day) in polyhouse with the other treatments recording significantly lower HUE. On the contrary in open conditions (E_2D_3), February transplanted plants had significantly the lowest HUE (0.00043 g/m^2/°C Day) resulting in lesser seed yield (0.6 g/plant; 0.3 q/ha), seed weight/fruit (0.13 g) and 1000-seed weight (3.6 g) due to high temperature experienced by the crop at seed development and seed filling stages. High temperature leads to forced maturity and reduced numbers of days to attain seed physiological maturity resulting in lesser seed weight. Higher temperature in the months of April–May also leads to a multiple fold decrease in the activities of phloem loading and unloading enzymes resulting in the reduced translocation of assimilates to developing seeds (Duke and Doehlert 1996). This low seed weight/fruit was directly correlated with the reduction in seed number and lesser pollen viability and stigma receptivity recorded in the open conditions. Additionally, failure of proper cell division and reduction in the number of cotyledonary cells and their expansion under heat stress were linked with reduced seed size which were negatively linked to seed weight/fruit and consequently lower seed yield (Prasad *et al.* 2011).

Seed germination and vigour: Fig. 1 (b and c) reveals that November transplanted plants of polyhouse recorded the highest germination (93.2%) and SVI-I (784.3) whereas February transplanted plants of low tunnel recorded the least germination (33.2%) and SVI-I (231.2) which failed to meet the minimum seed germination standards for bell pepper (i.e. 60%) permissible for sale as per the directives of Indian Minimum Seed Certification Standards (Anonymous 2013). Heat stress experienced by the crop in low tunnel/open conditions also factored in lesser seed germination and vigour potential as per the reports of Pagmas and Nawata (2007), with over 20% of seeds being flat, dark brown, and not germinating due to the reduced accumulation of storage products especially carbohydrates and lipids during chief seed developmental stages. Additionally, a linear relationship was observed between the heat units GDD and PTU consumed to obtain physiological maturity and the quality of the bell pepper seed obtained highlighting the importance of early transplantation in the month of November to provide adequate time period and weather conditions for both vegetative and then reproductive growth of the plant, resulting in production of the highest quality seed.

Correlation analysis: Correlation studies were conducted to find the interdependence of fruit, seed characteristics to the agrometeorological indices recorded during various crop phenophases. Days to flower initiation was correlated at $P \leq 0.05$ level to the seed characteristics like seed yield, seed weight/plant and 1000-seed weight. Seed

Table 2 Correlation analysis of the seed characteristics in bell pepper with the phenophases and agrometeorological indices

Parameters	Seed weight/ plant (g)	1000 seed weight (g)	Seed yield (g/plant)	Seed yield (q/ha)	HUE for seed production (g/m^2/°C Day)
Days to flower initiation	0.541*	0.598**	0.524*	0.476*	0.381^{NS}
GDD (flower initiation)	0.148^{NS}	0.243^{NS}	0.249^{NS}	0.265^{NS}	-0.001^{NS}
PTU (flower initiation)	-0.011^{NS}	0.084^{NS}	0.118^{NS}	0.154^{NS}	-0.130^{NS}
Days to fruit harvest	0.680**	0.735***	0.668**	0.622**	0.536*
GDD (fruit harvest)	0.781***	0.859***	0.859***	0.856***	0.677**
PTU (fruit harvest)	0.784***	0.860***	0.880***	0.888***	0.706***

GDD, Growing degree days; PTU, Photo thermal units; HUE, Heat use efficiency. Significant at *P≤0.05 level; **P≤0.01 level; ***P≤ 0.001 level; NS, Non-significant.

parameters were found to have a non-significant correlation with the GDD, PTU consumed till flower initiation but were rather strongly correlated at P≤0.001 level with days to attaining physiological maturity and heat indices like GDD and PTU (Table 2). Significant relationships were revealed between the crop phenology, highlighting the importance of optimizing phenophases and thermal conditions during flower and fruit harvest initiation to maximize seed quality and yield in bell pepper cultivation. The loading plot in the biplot analysis of the given data also corroborates our results with very high correlation witnessed amongst the fruit and seed characteristic vectors, positively correlated with the days taken to fruit harvest and the associated GDD and PTU heat units consumed (Fig. 2). Similarly, the score plot analysis in the biplot constructed highlights and co-signs the projected merit of the November transplantation in polyhouse condition.

Economic analysis: The cost of crop cultivation was recorded to be especially high under polyhouse owing to the higher establishment costs roughly amounting to 66% of the total cost of cultivation (Table 3). Additionally, literature perusal revealed the recurring maintenance cost in polyhouses of the structural frame, polyhouse sheet, shade glazing material which have an estimated shelf life of 10, 2 and 3–5 years, respectively (Murthy *et al.* 2009) and similarly, the life of materials used in galvanized pipes and plastic sheets in low tunnel cultivation have been reported to have a shelf life of 1–2 years (Sebade 2018). However, only the one-time structural cost of building the polyhouse and low tunnel was included in the total variable cost and the asset depreciation cost was not incurred in the total variable cost calculated in this study. The elevated variable costs, though, should be compensated by the increased returns derived from superior seed quality and higher yields associated with early transplanting in November and December, as compared to open conditions, as deduced by their exceptionally high benefit-to-cost ratio.

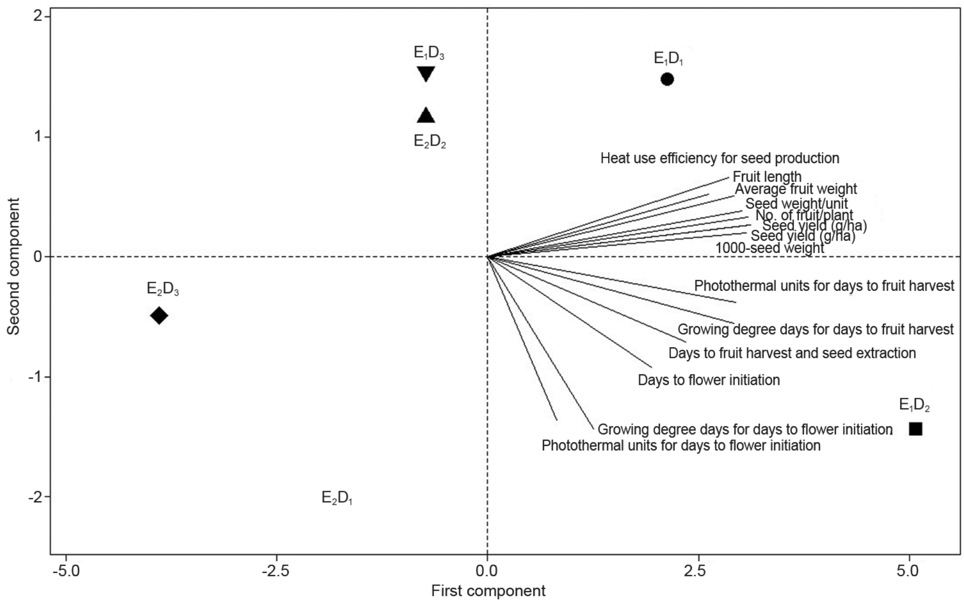

Fig. 2 Principal component analysis of the agrometeorological indices, fruit and seed characteristics at different growing environments and transplanting time
D_1, Second week of November; D_2, Second week of December and D_3, Second week of February, respectively. *February transplanted crop in low tunnels (E_2D_3) was treated as open conditions.

Polyhouse with the transplantation in the month of November (E_1D_1) had maximum net profits (₹15,38,688) as compared to other treatments with a high benefit to cost ratio of 7.37 making the seed production highly feasible and profitable. Pramanik *et al.* (2011) also similarly reported higher economic remuneration to growers, endorsing the adoption of protected cultivation despite the high initial investment and technical knowledge requisite. However, bell pepper cultivation in low tunnel with the transplantation in the month of December (E_2D_2) obtained the highest benefit to cost ratio of 9.58 amongst all treatments (Table 3). Seed production under polyhouse with the crop

Table 3 Benefit-to-Cost ratio for different treatments

Environment	Quantity	Polyhouse (E_1)			Low tunnel (E_2)		
Transplanting date		D_1	D_2	D_3	D_1	D_2	D_3^*
Structure cost		1,60,000	1,60,000	1,60,000	20,000	20,000	-
Seed (g)	200	4000	4000	4000	4000	4000	4000
Manure and Fertilizers							
Urea (kg)	110	649	649	649	649	649	649
Single super phosphate (kg)	175	1313	1313	1313	1313	1313	1313
Muriate of potash (kg)	20	360	360	360	360	360	360
FYM (t)	25	17875	17875	17875	17875	17875	17875
Irrigation (No.)	16	1328	1328	1328	1328	1328	1328
Labour (h)	750	33750	33750	33750	33750	33750	33750
Tractor (h)	10	5220	5220	5220	5220	5220	5220
Mulching (Black)		16,817	16,817	16,817	-	-	-
Total costs (₹)		2,41,312	2,41,312	2,41,312	84,495	84,495	64,495
Seed yield (kg/acre)		89	68.7	48.5	23.8	40.5	13.7
Seed price (₹/kg)		20,000	20,000	20,000	20,000	20,000	20,000
Cost of cultivation (₹/acre)		2,41,312	2,41,312	2,41,312	84,495	84,495	64,495
Gross returns (₹/acre)		17,80,000	13,74,000	9,70,000	4,76,000	8,10,000	2,74,000
Net profit (₹/acre)		15,38,688	11,32,688	7,28,688	3,91,505	7,25,505	2,09,505
B: C Ratio		7.37	5.69	4.01	5.63	9.58	4.24

D_1, Second week of November; D_2, Second week of December and D_3, Second week of February, respectively. *February transplanted crop in low tunnels (E_2D_3) was treated as open conditions.

transplanted in the month of November was still concluded as most profitable owing to the significantly superior performance of the harvested bell pepper fruit and seed characteristics of the produce harvested from the polyhouse with November transplanting date on all indices as compared to other treatments of polyhouse and low tunnel.

From the current investigation, it can be inferred that bell pepper crop grown under polyhouse with November transplanting outperformed other treatments in terms of plant growth, seed yield and seed quality contributing traits, along with the maximum benefit-to-cost ratio. However, December transplanting recorded better plant growth, seed yield and seed quality contributing traits as compared to other transplanting dates under low tunnel cultivation.

REFERENCES

Anonymous. 2013. *Indian Minimum Seed Certification Standards*, pp. 202–03. The Central Seed Certification Board, Department of Agriculture and Co-operation, Ministry of Agriculture, Government of India, New Delhi.

Anonymous. 2021. *Package of Practices for Cultivation of Vegetables*, pp. 54–55. Punjab Agricultural University, Ludhiana, Punjab.

Anonymous. 2023. Second advance estimates (2021–22) of area and production of Horticulture crops released. Ministry of Agriculture and Family Welfare. :https://pib.gov.in/PressReleasePage.aspx?PRID=1841480 (accessed on 13 May 2024).

Choudary A K. 2016. Scaling-up of protected cultivation in Himachal Pradesh, India. *Current Science* **111**: 272–77. https://doi.org/10.18520/cs/v111/i2/272-277

De-Beurs K M and Henebry G M. 2008. War, drought, and phenology: Changes in the land surface phenology of Afghanistan since 1982. *Journal of Land Use Science* **3**: 95–111. https://doi.org/10.1080/17474230701786109

Dhaliwal M S, Sharma S P, Jindal S K, Dhaliwal L K and Gaikwad A K. 2017. Growth and yield of bell pepper as influenced by growing environment, mulch, and planting date. *Journal of Crop Improvement* **31**: 830–46. https://doi.org/10.1080/15427528.2017.1391146

Duke E R and Doehlert D C. 1996. Effects of heat stress on enzyme activities and transcript levels in developing maize kernels grown in culture. *Environmental and Experimental Botany* **36**: 199–208. https://doi.org/10.1016/0098-8472(96)01004-0

Hedhly A, Hormaza J I and Herrero M. 2005. The effect of temperature on pollen germination, pollen tube growth, and stigmatic receptivity in peach. *Plant Biology* **7**: 476–83. https://doi.org/10.1055/s-2005-865850

Kaur H, Kingra P K and Singh S. 2019. Effect of sowing date, irrigation and mulch on thermal time requirement and heat use efficiency of maize (*Zea mays* L.). *Journal of Agrometeorology* **21**: 46–50. https://doi.org/10.54386/jam.v21i1.204

Long S P and Ort D. 2010. More than taking the heat: Crops and global change. *Current Opinion in Plant Biology* **13**: 241–48. https://doi.org/10.1016/j.pbi.2010.04.008

Makwana M A and Akarsh P. 2017. Stigma receptivity test in diverse species of tomato. *International Journal of Agricultural Science and Research* **7**: 1–8. http://dx.doi.org/10.24247/ijasroct20171

Murthy D S, Prabhakar B S, Hebbar S S, Srinivas V and Prabhakar

M. 2009. Economic feasibility of vegetable production under polyhouse: A case study of capsicum and tomato. *Journal of Horticultural Sciences* **4**: 148–52. https://doi.org/10.24154/jhs.v4i2.533

Pagmas P and Nawata E. 2007. Effect of high temperature during the seed development on quality and chemical composition of chilli pepper seeds. *Japanese Journal of Tropical Agriculture* **51**: 22–29.

Pinero M C, Lorenzo P, Sanchez-Guerrero M C, Medrano E, Lopez-Marin J and Del Amor F M. 2022. Tailored physicochemical properties and bioactive value of sweet pepper fruits from controlled high temperature. *Horticulturae* **8**: 582. https://doi.org/10.3390/horticulturae8070582

Pramanik K, Mohapatra P P, Pradhan J, Acharya L K and Jena C. 2020. Factors influencing performance of capsicum under protected cultivation: A review. *International Journal of Environment and Climate Change* **10**: 572–88. https://doi.org/10.9734/IJECC/2020/v10i1230339

Prasad P V V, Pisipati S R, Momcilovic I and Ristic Z. 2011. Independent and combined effects of high temperature and drought stress during grain filling on plant yield and chloroplast protein synthesis elongation factor expression in spring wheat. *Journal of Agronomy and Crop Science* **197**: 430–41. https://doi.org/10.1111/j.1439-037X.2011.00477.x

Sebade B. 2018. Simple, low-cost low tunnel can add weeks to growing season. *Barnyards and Backyards*, pp. 13–15. University of Wyoming, USA. https://www.uwyo.edu/barnbackyard/_files/documents/magazine/2018/spring/0418lowtunnel.pdf

Singh M and Khushu M K. 2012. Growth and yield prediction of wheat in relation to agroclimatic indices under irrigated and rainfed condition. *Journal of Agrometeorology* **14**: 63–66. https://doi.org/10.54386/jam.v14i1.1386

Singh R J. 2017. *Practical Manual on Plant Cytogenetics*. 1st edn. CRC Press, Boca Raton, Florida, USA. https://doi.org/10.4324/9781351228268

USDA. 2019. *Peppers, Sweet, Red, Raw (SR Legacy, 1700108)*. Agricultural Research Service. US Department of Agriculture. https://fdc.nal.usda.gov/fdc-app.html#/food-details/170108/nutrients (accessed on 13 May 2024).

Wani K P, Singh P K, Amin A, Mushtaq F and Zahoor A D. 2011. Protected cultivation of tomato, capsicum and cucumber under Kashmir valley conditions. *Asian Journal of Science and Technology* **1**: 56–61.