

Effect of different growing environments on growth, yield and quality of bell pepper (*Capsicum annuum* L. var. *grossum* Sendt.) genotypes under terai region of West Bengal

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Abstract

Bell pepper is commonly produced in protected conditions with constraints. To study alternatives to shaded structures, this experiment was conducted at the Instructional Farm, Uttar Banga Krishi Viswavidyalaya, during the rabi season of 2022-23 with two growing environments, *i.e.*, arecanut shade (G1) and open field (G2) (as factor A), while five varieties—California Wonder (V1), Pusa Capsicum - 1 (KTPC -1) (V2), VLCP 2016-57 (V3), KTOC -1 (V4), and KTYC - 17 (V5)—were taken as factor B, laid out in a factorial randomized block design with three replications. Following comparable agronomic techniques in G1 and G2, growth, yield, and quality metrics were measured for the five varieties. The results substantiated that shade had a positive influence on bell pepper, as most parameters—such as plant height (26.32 cm, 36.96 cm, and 63.17 cm at 30, 60, and 90 DAT, respectively); internode length (2.72 cm, 4.61 cm, and 6.58 cm at 30, 60, and 90 DAT, respectively); days to first flowering (53.78 DAT); number of flowers per plant (18.28); number of fruits per plant (10.37); fruit length (6.57 cm); fruit width (5.74 cm); pericarp thickness (4.75 mm); average fruit. Regarding the varieties, California Wonder (V1) reported better results for a few parameters: days to first flowering (52.30 DAT), number of flowers per plant (19.75), and number of fruits per plant (10.55). However, for most yield-attributing parameters—such as fruit length (7.17 cm), pericarp thickness (4.68 mm), average fruit weight (98.00 g), and fruit yield per plant (0.81 g)—the variety KTOC- 1 (V4) outperformed. The efficient utilization of natural resources under arecanut shade may have favored bell pepper productivity. However, the variety KTOC-1 as an intercrop would be the most appropriate choice for the Terai region of West Bengal.

Key words: Bell pepper, capsicum, growing environment, arecanut shade, open field

Introduction

Bell pepper (*Capsicum annuum* L. var. *grossum* Sendt.) is a popular solanaceous vegetable crop cherished worldwide for its culinary flexibility and nutritional potency. It is a diploid with chromosome no. of $2n=2x=24$. Originating primarily from Mexico and Guatemala as the secondary centre (Thakur *et al.*, 2020). Its fruits are consumed either raw, as a salad, or as vegetables in curries. In the human diet, it is considered a balanced nutrition, as it contains 1.29 mg protein, 11 mg calcium, 870 I.U. vitamin A, 17.5 mg ascorbic acid, 0.6 mg thiamine, 0.03 mg riboflavin, and 0.55 mg niacin per 100 g edible fruit (Ashrafunnesa *et al.*, 2018).

Bell pepper is a cool-season tropical crop mainly cultivated during the cool season for its fully developed immature fruit (Brahma *et al.*, 2010). The optimal temperature for growth and fruit set is 25°C during the day and 18°C at night (Samanta and Hazra, 2019). However, during the cooler months, heat and direct sunlight can severely impair their overall quality, yield and marketability (Padron *et al.*, 2015). Despite its widespread popularity, its cultivation encounters challenges, particularly when cultivated in open field conditions due to erratic weather behaviour. Therefore, protected structures such as; polyhouse, net-house, walk-in-tunnels, low tunnels, *etc.*, are mostly used

for the majority of bell pepper production nationwide. However, among the various protected structures, polyhouse production has been proven to be the most profitable cultivation technique (Gill, 2018). Research works by, Ansary *et al.* (2020); Samanta and Hazra (2019); Chatterjee *et al.* (2018) and Dhaliwal *et al.* (2017) also reported that the performance of bell peppers under protected structures is better as compared to the open field. Although, protected cultivation is remunerative but high initial investment, lack of technical guidance, non-availability of genuine building material, natural disasters, *etc.* are major constraints and setbacks that often restrict small and marginal farmers for its adoption and commercialization (Pramanik *et al.*, 2020).

Inarguably, cultivation of crops in open field conditions is considerably much easier and less expensive but the sensitivity of bell peppers to abiotic stresses (fluctuating temperature, humidity, light intensity, wind flow, *etc.*) in open field conditions is comparatively high (Bijalwan *et al.*, 2022; Prasanth *et al.*, 2024). Therefore, refinement in the open field cultivation of bell pepper by bringing it under the natural shade of arecanut (*Areca catechu* L.) plantation may help to reduce some of the environmental stresses on the growth, yield and quality of bell pepper. Besides this, it will solve the major problem of vegetable production *i.e.*, limited land availability for cultivation.

The majority of rural households in North Bengal have an arecanut garden in their backyard (Mula *et al.*, 2015), but arecanut as a sole crop does not fully utilize natural resources such as soil, space and light (Bhat *et al.*, 2016). Researchers have explored intercropping arecanut with various vegetables like spinach, brinjal, tomato, cowpea, and french bean, among others, with promising results (Mula *et al.*, 2015). Introducing a high-value low volume crop like bell pepper as an intercrop might achieve better outcomes (Kabir *et al.*, 2020; Hamdani *et al.*, 2018; Jakhar *et al.*, 2017; Ilahy *et al.*, 2013) have reported improved performance of bell pepper upon shade growing. However, scanty information is available on the influence of arecanut shade condition on bell pepper. Additionally, the performance of crops depends on their genetic makeup and their adaptability to growing conditions hence, selecting an appropriate variety becomes crucial. Therefore, based on the aforementioned facts, a field experiment was undertaken to examine the performance of different bell pepper genotypes under open field conditions and arecanut shade, specific to this region.

Materials and methods

An experiment was carried out during the Rabi (winter) season of 2022–23 at the Instructional Farm of the Department of Vegetable and Spice Crops, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar. The experimental site was located in a sub-tropical humid climate. Under arecanut shade, average maximum temperatures ranged from 2°C to 28°C and minimum temperatures from 15°C to 25°C (Fig. 1), with light intensity between 30,000 and 34,000 lux (Fig. 2). In open conditions, maximum temperatures reached 29°C and minimum temperatures varied between 17°C and 26°C (Fig. 1), with light intensity from 52,000 to 75,000 lux (Fig. 2). The area receives about 1400 mm of annual rainfall, with average relative humidity levels of 78 % at its maximum and 53 % at its minimum. The experiment was laid out in a Randomized Block Design (Factorial) with three replications. Factor A included two growing environments *viz.*, arecanut shade and open field, while Factor B comprised five genotypes *viz.*, California Wonder, Pusa Capsicum – 1 (KTPC-1), VLCP 2016-57, KTOC-1 and KTYC-17.

Determination of growth parameters: The parameters like plant height and internode length (cm) were recorded from randomly selected five plants at intervals of 30, 60 and 90 days after transplanting. Days to first flowering, number of flowers per plant, number of fruits per plant, fruit length (cm), fruit width (cm), and pericarp thickness (mm) were recorded from the five randomly tagged plants.

Determination of yield parameters: The yield parameters were recorded from all the harvests involving five plants selected randomly and divided by the total count of marketable fruits collected from these specific plants. The weight of five fruits was measured individually and recorded separately. Following this, the average weight of the fruits was calculated.

Determination of quality parameters: The ascorbic acid (mg) of freshly harvested fruits was measured as per the methodology outlined by Ranganna (2001). The leaf chlorophyll (mg) was determined using the method by Sadasivam and Manickam (1996) and total soluble solids (TSS °Brix) of fully matured fruits were determined using an “ERMA hand refractometer” with a range of 0° to 32° Brix.

Meteorological observations: Temperature and light intensity were monitored in both growing environments. Maximum and minimum temperatures were recorded daily using a hand-held infrared thermometer at 9.00 am for the minimum and 1.00 pm for the maximum, with multiple readings taken to determine an average (Owen *et al.*, 2017). Similarly, the light intensity was recorded with a digital lux meter (LX-1332A) positioned 1.00 m above the plant’s canopy.

Statistical analysis: The collected data underwent analysis using the OPSTAT software from Hisar Agricultural University, as detailed by Sheoran *et al.* (1998).

Results and discussion

Growth parameters: The data presented in Table 1 revealed that various growth parameters of bell peppers were notably influenced by the factors *viz.*, growing environments and different varieties. The maximum plant height at 30, 60, and 90 DAT was recorded under G₁ (arecanut shade) *i.e.*, 26.32 cm, 36.96 cm and 63.17 cm respectively, whereas, the minimum plant height (20.03 cm, 31.75 cm and 46.30 cm) at 30, 60, and 90 DAT were recorded in G₂ (open field condition). However, the lowest plant height (53 cm) was recorded in bell peppers grown under open field conditions. The increase in plant height could be due to the deflected low light intensity of 30,000 lux to 34,000 lux (Fig. 2) under arecanut shade. A similar finding was also reported by Dhaliwal *et al.*, 2017; Chatterjee *et al.*, 2018; Kabir *et al.*, 2020) where the plant height of bell pepper was recorded as maximum under the shade condition.

Alike, plant height under the experiment, the maximum internode length of 2.72 cm, 4.61 cm, and 6.58 cm at 30, 60, and 90 DAT respectively in bell pepper was also observed in plants grown under G₁ (arecanut shade). On the contrary, a minimum internode length of 2.54 cm, 3.21 cm, and 3.24 cm at 30, 60, and 90 DAT was recorded in G₂ (open field). The findings of Ilahy *et al.* (2013) supported that with a shade level of 50 %, the internode length in pepper was increased up to 31 %.

Early flowering is one of the most desirable characteristics that enable the crop plant for fruit yield (Jung, 2017). Under the experiment, early flower initiation (53.78 days) was recorded in the plants grown under G₁ (arecanut shade). On the other hand, flowering was delayed (55.86 days) in crops grown under the G₂ (open field). Early flowering under arecanut shade is likely due to increased photosynthesis, which accelerates growth and development, leading to the rapid completion of the vegetative stage and earlier flowering. Similarly, Pramanik *et al.* (2021) reported that shade conditions facilitate hormonal action for flower initiation and emergence.

The highest number of flowers (18.28) was obtained under G₁ (arecanut shade), and the minimum flower (16.8) was obtained in G₂ (open field). This might be the positive impact of shade conditions on plant growth and development by lowering solar radiation and altering microclimatic factors (Mahmood *et al.*, 2018).

Concerning the results on different varieties depleted in Table 1, the highest plant height (24.48 cm) was recorded in V₂ (Pusa Capsicum-1-KTPC-1) at 30 DAT and 36.52 cm and 60.42 cm in V₃ (VLCP-2016-57) at 60 and 90 DAT respectively. However, the lowest height at 30 and 60 DAT was found in V₁ (California

Wonder) *i.e.*, 21.28 cm and 31.14 cm, and the lowest plant height (51.61 cm) at 90 DAT was recorded in V₅ (KTOC-1). Among the different varieties, the maximum internode length at 30, 60, and 90 DAT (2.87 cm, 4.27 cm, and 5.34 cm respectively) was found in V₁ (California Wonder). On the other hand, the minimum internode length at 30 and 60 DAT (2.47 cm and 3.57 cm respectively) was noticed in V₅ (KTYC-17) and at 90 DAT it was reported in V₄ (KTOC-1) with 4.17 cm. Concerning the early flower initiation, the minimum days *i.e.*, 52.30 days were recorded in V₁ (California Wonder). In contrast, the flowering was delayed *i.e.*, 56.70 days in V₄ (KTOC-1). Similarly, the maximum number of flowers (19.75) was recorded in V₁ (California Wonder). However, the minimum number of flowers (14.75) was recorded in V₄ (KTOC-1).

Considering the interaction effect (Table 1), the maximum plant height at 30 and 60 DAT (30.27 cm and 41.51 cm respectively) was recorded in the interaction G₂V₂ *i.e.*, open field + Pusa Capsicum-1-KTPC-1. However, the maximum plant height (71.42 cm) at 90 DAT was recorded in G₁V₃ (arecanut shade + VLCP 2016-57). While, the lowest plant height at 30 and 60 DAT *i.e.*, 17.42 cm and 29.49 cm respectively were recorded in G₁V₅ (arecanut shade + KTYC-17), and at 90 DAT (40.35 cm) was recorded in G₂V₁ (open field + California Wonder). The interaction effects between growing environments and varieties have been found significant at 30 and 90 days after transplanting and non-significant at 60 DAT. The maximum internode length *i.e.*, 3.15 cm at 30 DAT and 5.27 cm at 60 DAT respectively was recorded in G₁V₁ (arecanut shade + California wonder). Furthermore, the maximum internode length (7.73 cm at 90 DAT) was recorded in G₁V₂ (arecanut shade + Pusa Capsicum-1-KTPC-1). The interaction G₂V₄ (open field + KOTC-1) showed the minimum internode length (2.70 cm at 60 DAT) followed by 2.87 cm at 90 DAT in G₂V₅ (open field + KTYC-17). The interaction effect of the growing environment and variety showed a non-significant difference in internode length at 30 days of transplanting. A significant difference was found among treatment combinations for early flower initiation. The early flower initiation (51.2 days) was observed in interaction G₁V₁

Table 1. Effect of growing environments on growth parameters of bell pepper genotypes

Treatments	Plant height (cm)			Internode length (cm)			Days to first flowering	No. of flower plant ⁻¹
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT		
Growing environment								
G ₁	26.32	36.96	63.17	2.72	4.61	6.58	53.78	18.28
G ₂	20.03	31.75	46.30	2.54	3.21	3.24	55.86	16.80
SEm±	0.98	1.20	1.68	0.10	0.12	0.09	0.08	0.06
CD (P=0.05)	2.06	2.53	3.53	NS	0.25	0.18	0.18	0.13
Varieties								
V ₁	21.28	31.14	54.00	2.87	4.27	5.34	52.30	19.75
V ₂	24.48	36.20	54.78	2.74	4.01	5.69	54.15	18.80
V ₃	23.87	36.52	60.42	2.49	4.09	4.94	56.55	18.60
V ₄	24.03	35.13	51.61	2.55	3.61	4.17	56.70	14.75
V ₅	22.21	32.78	52.86	2.48	3.57	4.40	54.40	15.80
SEm±	1.55	1.90	2.66	0.16	0.18	0.14	0.13	0.10
CD (P=0.05)	NS	4.00	5.58	NS	0.39	0.28	0.28	0.21
Interaction								
G ₁ V ₁	21.48	31.33	67.66	3.15	5.27	7.25	51.20	20.00
G ₁ V ₂	18.70	30.90	60.52	2.77	4.74	7.73	53.80	21.30
G ₁ V ₃	21.40	35.36	71.42	2.62	4.73	6.56	55.60	19.90
G ₁ V ₄	21.13	31.67	57.22	2.43	4.51	5.41	54.80	14.60
G ₁ V ₅	17.42	29.49	59.03	2.60	3.78	5.93	53.50	15.60
G ₂ V ₁	21.07	30.95	40.35	2.58	3.26	3.43	53.40	19.50
G ₂ V ₂	30.27	41.51	49.03	2.71	3.27	3.65	54.50	16.30
G ₂ V ₃	26.33	37.69	49.42	2.37	3.45	3.33	57.50	17.30
G ₂ V ₄	26.93	38.59	46.00	2.66	2.7	2.93	58.60	14.90
G ₂ V ₅	27.00	36.07	46.69	2.36	3.36	2.87	55.30	16.00
S E m±	2.19	2.69	3.76	0.22	0.26	0.19	0.19	0.14
CD (P=0.05)	4.61	NS	7.90	NS	0.55	0.40	0.40	0.29

(arecanut shade + California Wonder). On the contrary, late flower initiation (58.6 days) was recorded in G₂V₄ (open field + KTOC-1). Salunkhe *et al.* (2017) also reported that the minimum period (33.39 days) was required for the first flower initiation inside the polyhouse, while in the open field condition; the maximum period of 52.44 days was required for flower initiation. The highest number of flowers (21.30/plant) was obtained in interaction G₁V₂ (arecanut shade + Pusa Capsicum-1-KTPC-1), followed by G₁V₃ (arecanut shade + VLCP 2016-57) *i.e.*, 19.90/plant. However, the minimum number of flowers (14.60/plant) was recorded in G₁V₄ (arecanut shade + KTOC-1). This is due to the positive impact of shade on plants by altering

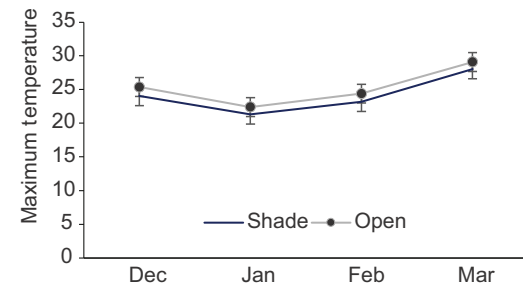
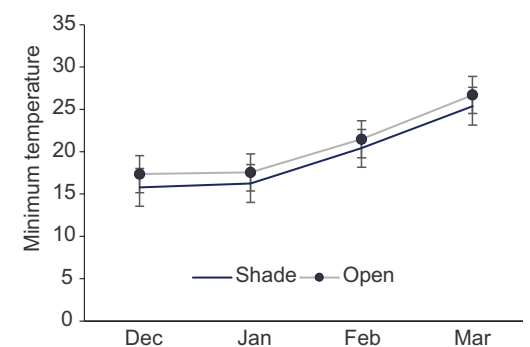


Fig. 1. Monthly average minimum (A) and maximum (B) temperature °C, where, Shade= Arecanut shade & Open= open field

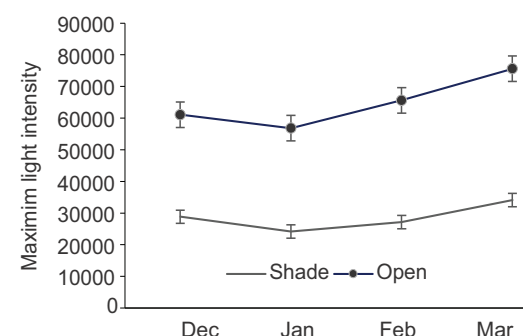
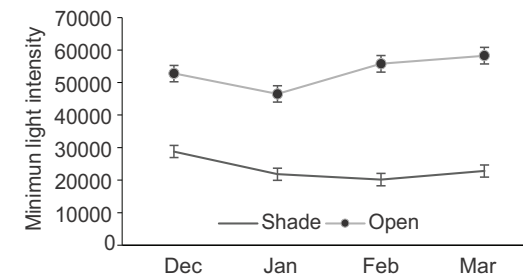


Fig. 2. Monthly average minimum (A) and Maximum (B) light intensity (Lux), where, Shade= arecanut shade & Open= open field

microclimatic factors (Mahmood *et al.*, 2018; Diaz-Perez, 2019). A similar finding was reported by Nkansah *et al.* (2017) where the number of flowers per plant was higher under shade conditions.

Yield parameters: The data illustrated in Table 2 reveals that yield parameters *viz.*, number of fruits (10.37/plant), fruit length (6.57 cm), fruit width (5.74 cm), pericarp thickness (4.75 mm), average fruit (76.65 g), fruit yield (770 g/plant), fruit yield (35.97 kg plot⁻¹), and fruit yield (20.80 t ha⁻¹) was recorded maximum under G₁ (arecanut shade). In contrast, the number of fruits (8.27/plant), fruit length (5.95 cm), fruit width (4.19 cm), pericarp thickness (3.59 mm), average fruit (67.42 g), fruit yield (540 g/plant), fruit yield (25.20 kg plot⁻¹), and fruit yield (14.57 t ha⁻¹) were found minimum under G₂ (open field). The high yield observed under arecanut shade might be the result of the reduced light intensity of 30,000 lux to 34,000 lux (Fig. 2) coupled with a temperature range of 21-28°C (max.) and 15-25°C (min.) (Fig. 1) which created a favorable micro-climatic condition for growth and development contributing to higher yield establishment. Conversely, the high light intensity of 52,000 lux to 75,000 (Fig. 2) lux and a temperature range of 22-29°C (max.) and 17-26°C (min.) (Fig. 1) during the vegetative and reproductive stages (december-march) in open field conditions were not favorable for fruiting and resulted in poor yield (Samanta and Hazra, 2019).

Considering the varietal performance, varieties varied significantly, where, the highest number of fruits (10.55/plant) was recorded in V₁ (California Wonder), and the lowest number of fruits (8.10/plant) was recorded in V₅ (KTYC-17). The maximum fruit length (7.17 cm) was obtained in V₄ (KTOC-1). In contrast, the minimum fruit length (5.65 cm) was obtained in V₁ (California Wonder). The highest fruit width (5.55 cm) was obtained in V₅ (KTYC-17), whereas, the lowest fruit width (4.49 cm) was obtained in V₁ (California Wonder). The maximum pericarp thickness (4.68 mm) was recorded in V₄ (KTOC-1); however, the thinner pericarp (3.67 mm) was reported in V₅ (KTYC-17). The highest (98.00 g) fruit weight was in V₄ (KTOC-1). In contrast, the lowest (53.82 g) average fruit weight was obtained in V₂ (Pusa Capsicum-1-KTPC-1). These results could be due to favourable climatic conditions under shade which favour optimal timing of flowering and the subsequent transformation to fruit (Chatterjee *et al.*, 2018). The varieties V₄ (KTOC-1) had

the highest fruits (810 g/plant). Whereas, V₃ (VLCP 2016-57) yielded the lowest fruit (520 g/plant). Similarly, V₄ (KTOC-1) was found with a maximum fruit yield (36.91 kg plot⁻¹). On the other hand, the minimum fruit yield of 24.09 kg plot⁻¹ was obtained in V₃ (VLCP 2016-57).

Considering the interaction arecanut shade x variety, the highest number of fruits (12.47) was noted in G₁V₂ (arecanut shade + Pusa Capsicum-1-KTPC-1). Contrastingly, in the interaction open field + variety, the maximum number of fruits (9.30) was recorded in G₂V₃ (open field + VLCP 2016-57). Comparing both the interactions the highest number of the fruits (12.47) was found in G₁V₂ (arecanut shade + Pusa Capsicum-1-KTPC-1). Likewise, in the interaction, arecanut shade x variety, the maximum yield (42.59 kg plot⁻¹) was recorded in G₁V₄ (arecanut shade + KTOC-1). However, in the interaction open field + variety, the highest yield (31.23 kg plot⁻¹) was obtained in G₂V₄ (open field + KTOC-1). Considering both the interaction the G₁V₄ (arecanut shade + KTOC-1) is revealed with the highest fruit yield (41.59 kg plot⁻¹). The higher yield of bell peppers under arecanut shade suggests that the 30,000 to 34,000 lux light intensity offered by the arecanut shade is sufficient to enhance the yield (Samanta and Hazra, 2019).

Quality parameters: The levels of ascorbic acid were notably affected by both factors as shown in Table 3. The G₁ (arecanut shade) showed the maximum (154.54 mg/100 g) ascorbic content, whereas G₂ (open field) showed the minimum (141.42 mg/100 g). The G₂ (open field) produced the highest (5.69 °Brix) TSS, while the G₁ (arecanut shade) produced the lowest (4.83 °Brix) TSS. The maximum leaf chlorophyll a, b, and total chlorophyll *i.e.*, 3.22, 1.30, and 4.52 mg/100 g were recorded under G₁ (arecanut shade). In contrast, the minimum (2.74, 0.69, and 3.43 mg/100 g respectively) was recorded in G₂ (open field). Concerning the varieties, maximum (154.14 mg/100 g) ascorbic acid was obtained in V₄ (KTOC-1). Contrastingly, the lowest (144.04 mg/100 g) was reported in V₅ (KTYC-17). V₁ (California Wonder) was found with a maximum (6.16 °Brix) TSS content, followed by 5.16 °Brix in V₃ (VLCP 2016-57). However, the lowest (4.92 °Brix) TSS content was observed in V₅ (KTYC-17). To different bell pepper varieties, the chlorophyll a content was maximum (3.12 mg/100 g) in V₂ (Pusa capsicum-1-KTPC-1), followed by V₁ (California Wonder) *i.e.*, 3.06 mg/100 mg and 2.97 mg/100 g in V₃ (VLCP 2016-57). On the other hand, the lowest (2.88 mg/100 g) chlorophyll a content was obtained in V₄ (KTOC-1). The chlorophyll b was recorded maximum (1.11 mg/100 g) in variety

Table 2. Effect of growing environments on yield parameters of bell pepper genotypes

Treatments	No. of fruits plant ⁻¹	Fruit length (cm)	Fruit width (cm)	Pericarp thickness (mm)	Average fruit weight (g)	Fruit yield plant ⁻¹ (g)	Fruit yield (kg plot ⁻¹)	Projected yield (t ha ⁻¹)
Growing environments								
G ₁	10.37	6.57	5.74	4.75	76.65	0.770	35.97	20.80
G ₂	8.27	5.95	4.19	3.59	67.42	0.540	25.20	14.57
SEm±	0.29	0.07	0.02	0.10	0.60	0.03	1.06	0.62
CD (P=0.05)	0.61	0.15	0.05	0.20	1.27	0.04	2.24	1.29
Varieties								
V ₁	10.55	5.65	4.49	4.18	57.22	0.610	29.25	16.91
V ₂	10.33	6.03	4.77	4.33	53.82	0.560	26.38	15.26
V ₃	9.38	5.69	5.25	3.99	55.74	0.520	24.09	13.93
V ₄	8.23	7.17	4.76	4.68	98.00	0.810	36.91	21.34
V ₅	8.10	6.75	5.55	3.67	95.39	0.770	36.29	20.98
SEm±	0.46	0.11	0.04	0.15	0.95	0.04	1.68	0.97
CD (P=0.05)	0.97	0.23	0.08	0.32	2.00	0.07	3.54	2.05
Interaction								
G ₁ V ₁	11.97	6.43	5.72	4.42	64.31	0.770	36.99	21.39
G ₁ V ₂	12.47	5.81	5.47	5.38	56.22	0.700	32.77	18.95
G ₁ V ₃	9.47	6.17	5.84	4.63	60.85	0.570	25.90	14.98
G ₁ V ₄	9.13	7.38	5.28	5.13	101.41	0.920	42.59	24.63
G ₁ V ₅	8.80	7.06	6.38	4.21	100.47	0.880	41.59	24.05
G ₂ V ₁	9.13	4.87	3.27	3.93	50.13	0.450	21.51	12.44
G ₂ V ₂	8.20	6.26	4.06	3.27	51.41	0.420	19.99	11.56
G ₂ V ₃	9.30	5.21	4.66	3.35	50.64	0.470	22.27	12.88
G ₂ V ₄	7.33	6.96	4.24	4.23	94.60	0.690	31.23	18.06
G ₂ V ₅	7.40	6.45	4.72	3.13	90.31	0.660	30.99	17.92
SEm±	0.65	0.16	0.05	0.21	1.35	0.06	2.38	1.38
CD (P=0.05)	1.37	0.33	0.11	0.45	2.83	0.10	5.00	2.89

Table 3. Effect of growing environments on quality parameters of bell pepper genotypes

Growing environments	Ascorbic acid (mg/100 g)	TSS (°Brix)	Chlorophyll a (mg/100 g)	Chlorophyll b (mg/100g)	Total Chlorophyll (mg/100 g)
G ₁	154.54	4.83	3.22	1.30	4.52
G ₂	141.42	5.69	2.74	0.69	3.43
SEm±	1.40	0.02	0.01	0.01	0.01
CD (P=0.05)	2.95	0.07	0.04	0.04	0.03
Varieties					
V ₁	147.23	6.16	3.06	1.11	4.17
V ₂	144.35	4.94	3.12	0.96	4.08
V ₃	150.15	5.16	2.97	0.89	3.86
V ₄	154.14	5.12	2.85	1.01	3.87
V ₅	144.04	4.92	2.90	0.99	3.89
SEm±	2.22	0.04	0.02	0.02	0.02
CD (P=0.05)	4.66	0.11	0.06	0.07	0.05
Interaction					
G ₁ V ₁	154.46	5.71	3.37	1.39	4.76
G ₁ V ₂	150.92	4.58	3.29	1.24	4.53
G ₁ V ₃	158.08	4.82	3.15	1.17	4.33
G ₁ V ₄	161.16	4.95	3.06	1.48	4.54
G ₁ V ₅	148.08	4.07	3.20	1.21	4.42
G ₂ V ₁	140.00	6.61	2.74	0.83	3.57
G ₂ V ₂	137.78	5.29	2.95	0.68	3.62
G ₂ V ₃	142.22	5.51	2.78	0.61	3.39
G ₂ V ₄	147.11	5.29	2.65	0.54	3.19
G ₂ V ₅	154.46	5.76	2.59	0.77	3.36
S E m±	3.14	0.05	0.03	0.03	0.02
CD (P=0.05)	6.59	0.15	0.09	0.09	0.07

V₁ (California Wonder), followed by 1.01 mg/100 g in V₄ (KTOC-1), where the lowest (0.89 mg/100 g) chlorophyll b was recorded in V₃ (VLCP V₄ (KTOC-1), where the lowest (0.89 mg/100 g) chlorophyll b was recorded in V₃ (VLCP 2016-57).

The interaction effect varied significantly, under arecanut shade x variety, maximum ascorbic (161.16 mg/100 g) content was obtained in G₁V₄ (arecanut shade + KTOC-1). However, under open field x variety, the maximum ascorbic acid (154.46 mg/100 g) was recorded in G₂V₅ (open field + KTYC-15). The findings of Sinkovic *et al.*, 2017 were similar, the ascorbic acid content was highest (165.9 mg/100 g) under polypropylene shade. Likewise, the interaction effect of arecanut shade x variety on TSS (°Brix), the maximum TSS (5.71 °Brix) content was noted in G₁V₁ (arecanut shade + California Wonder). Whereas, under the interaction open field x variety, the maximum TSS (6.61 °Brix) was obtained in G₂V₁ (open field + California Wonder). Angmo *et al.* (2022) suggested a similar result, the TSS content was less in peppers grown in the shade than in open conditions. With the interaction of arecanut shade x variety, the highest chlorophyll (4.76 mg/100 g) was obtained in G₁V₁ (arecanut shade + California Wonder). Chatterjee *et al.*, 2018; Diaz-Perez (2020), reported that shade condition favors higher chlorophyll (chlorophyll a and b) concentrations over open field.

The study revealed that arecanut shade (G₁) performed better over the open field (G₂) for bell pepper cultivation, with the combination of G₁V₄ (arecanut shade + KTOC-1) showing optimal performance. This interaction resulted in superior yield and quality characteristics, including fruit length (7.38 cm), fruit weight (98.00 g/fruit), fruit yield (36.91 kg plot⁻¹), projected yield per hectare (21.34 t ha⁻¹), and the highest ascorbic acid content (161.16 mg/100 g). The arecanut shade provides an optimal micro-climate for bell peppers, suggesting it can serve as a cost-effective alternative to shade houses, enabling marginal farmers in the Terai zones of West Bengal to produce high-

quality bell peppers with minimal investment. Consequently, there is significant potential for future research to explore this approach with other genotypes and to investigate the effects of biotic and abiotic stress on bell peppers in different growing environments, as well as the impact of varied nutrient doses on their growth, yield, and quality.

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