



Plant Archives

Journal homepage: <http://www.plantarchives.org>DOI Url : <https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.170>

VARYING INTRA-ROW SPACING AND MULCHING EFFECT ON YIELD, QUALITY AND ECONOMICS OF PARTHENO-CARPIC CUCUMBER (*CUCUMIS SATIVUS* L.) UNDER PROTECTED CONDITION

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(Date of Receiving-12-06-2025; Date of Acceptance-26-08-2025)

ABSTRACT

The present experiment was conducted during two consecutive seasons 2023 and 2024 at the Horticultural Research Farm, Department of Horticulture, Naini Agricultural Institute, SHUATS, Prayagraj to assess the effect of different mulching materials and plant spacings on yield, quality and economics of cucumber under protected conditions. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications and 15 treatment combinations comprising 5 mulches- Double Shaded Mulch (M1), Transparent Mulch (M2), Black Mulch (M3), Straw Mulch (M4), and No Mulch (M5) and 3 spacings: 70 × 30 cm (S1), 70 × 45 cm (S2), and 70 × 60 cm (S3). The results revealed significant differences in all observed parameters. Among mulches, straw mulch (M4) showed superior performance in most of the traits, recording the highest fruit length (14.87 and 18.87 cm), fruit girth (12.49 and 14.47 cm), fruit weight (123.99 and 124.20 g), and yield per 1000 m² (15.8 and 16.923 q/1000 m²), TSS (2.68 and 2.96 °B), vitamin C (3.40 and 3.97 mg/100) and total chlorophyll (1.21 and 1.43 mg/g DW). In terms of spacing, 70 × 45 cm (S2) spacing significantly improved fruit length (16.76 and 21.14 cm), yield (16.740 and 17.863 q/1000 m²), TSS (3.02 and 3.21 °B), vitamin C (3.73 and 3.17 mg/100) and total chlorophyll (1.33 and 1.54 mg/g DW). The interaction of M4S2 (Straw Mulch + 70 × 45 cm) consistently produced the best results across both years, yield (18.00 and 19.123 q/1000 m²) TSS (3.20 and 2.93 °B), vitamin C (3.91 and 4.49 mg/100), total Chlorophyll (1.50 and 1.71 mg/g DW) and benefit cost ratio (2.37).

Key words: Black Mulch, Cucumber, Double shaded mulch, Vitamin C and TSS.

Introduction

The cultivated cucumber (*Cucumis sativus* L.) originates from India and possesses a diploid chromosome number of 2n = 14. Its likely wild ancestor is *Cucumis hardwickii*. Cucumber is an essential and commercially popular cucurbitaceous vegetable crop holding a coveted position in the vegetable market. They are the largest producer of biological water among the vegetables crops and are easily digestible and therefore are recommended even to patients suffering from weakness or other illnesses. It is a rich source of valuable nutrients and bioactive compounds used not only as food but also in therapeutic medicine and cosmetology. Cucumber is very popular vegetable throughout the world for its crispy taste and texture. The immature fruits of cucumber are used as

salad and for making pickles, raita and brined on commercial scale (Tewari *et al.*, 2024). Cucumber is used for different purpose like as salad, table purpose and pickling but mostly used as salad purpose. The fruit of cucumber is said to have cooling effect, prevents constipation and checks jaundice and indigestion. It contains (96.3g) water, (0.4g) protein, (0.1g) fat, (0.3g) minerals, (0.4g) fibre, (2.5g) carbohydrate, (13Kcal) energy, (10mg) calcium, (25mg) phosphorus, (1.5mg) iron, (0.33mg) thiamine, (0.2mg) niacin, (7mg) vitamin C per (100g) edible portion. Protected cultivation technology is the advance cultivation technique wherein the micro climate surrounding the crop is partially or fully controlled and modified as per the requirement of the crop (Tejaswini *et al.*, 2024). Protected cultivation technology is based

on the principle of greenhouse effect. Greenhouse effect is the phenomenon of increase in the ambient temperature, due to the production of excess greenhouse gas like carbon dioxide. The covering material of the greenhouse structure acts in a similar way, as it is transparent and permeable to shorter wave radiation but does not allow the longer wave radiation to escape outside. During the day time, solar radiations with the shorter wavelength enters and penetrate through the greenhouse covering material and gets reflected from the ground surface. The reflected radiation becomes long wave radiation and gets entrapped inside the greenhouse structure by the covering material. This causes the increase in the greenhouse temperature. A comparative study revealed that the protected cultivation of high value crop like cucumber is highly remunerative as compared to open field 3 cultivation. Even though the cost of cultivation is higher under protected cultivation, the higher yield of cucumber with high net return can be achieved under polyhouse condition as compared to open field condition (Kumar *et al.*, 2014). Protected cultivation of vegetable has emerged as an alternate production technology to overcome several biotic and abiotic stresses and to break the seasonal barrier to production. It gives a boost to the nutrient and irrigation use efficiency along with the proper utilization of natural resources. This technology is being employed popularly for the year round and off-season production of high value commercial crops like capsicum, tomato and cucumber. Increased yield with high photosynthetic efficiency and reduction in transpirational loss are some of the added advantages associated with this technology. The performance of cucumber grown inside the shade net was comparatively superior in comparison to open field condition and total fruit yield recorded from shade net with 35, 50 and 75 per cent shading were 238.4, 245.2 and 273.2 q/ha, respectively which were 8 to 10 times more than open field condition i.e. 36.3 q/ha (Kaur *et al.*, 2017). In addition to that, the infestation by pest and diseases under protected condition is scaled-down as compared to open field condition as it is covered and isolated structure from outside environment. Infestation of sucking pests like aphids and white fly was subsided considerably under the shade net house of 35% (Kaur *et al.*, 2021). Success in the cultivation of cucumber under polyhouse condition during the off season can be attained by the use of suitable cucumber hybrid like parthenocarpic variety or gynoecious hybrid along with adequate incorporation of nutrient which becomes indispensable for the growth and development. Cucumber gynoecious varieties are those which produce pistillate flowers predominantly and have the ability to set fruit without pollination and fertilization even under

lower temperature and in short day condition (Khadka *et al.*, 2017) making efficient utilization of the land, water, nutrient and other resources. These plants produce fruit that are mild in flavour, soft seeded to seedless in nature, and have a thin edible skin that requires little peeling. However, use of gynoecious hybrids for cultivation under tropical climatic condition is not recommended as they are highly unstable at high temperature condition. Sex modification is a major constraint associated with the cultivation of gynoecious hybrid under tropical climatic condition and will produce deformed and bitter fruit which will result in a reduced marketable value as it is not preferred by the consumer. Cucumber is well grown in warm, temperate and cool tropical regions of the world. The growth and development of crop are favoured by temperature above 20°C, however it can also survive at 32°C temperature. It grows well under high light intensity and humidity conditions but is susceptible to frost. Due to various biotic and abiotic factors the cucumber cultivation is more successful under protected conditions. The protected cultivation technology is utilized for the production of high quality and high yield. It increases the harvesting efficiency with greater yield of straight fruits exhibiting more plants per acre due to closer rows and adequate spacing (Singh and Aulakh 2018). Cucumber yield and quality is characterized by many factors including genetic, agronomic and environmental factors. There is very less information available on the production of cucumber under protected condition in India (Zurbano *et al.*, 2021). Both spacing and mulching greatly effects the cucumber production Mulching is one of the profitable agronomic measures of protecting crop from the vagaries of weather. It helps in conserving soil moisture, controlling weed infestations, regulate soil temperature and most importantly control soil borne diseases of crop. The use of plastic mulch is one of the measures of protecting vegetable crops from the attack root-knot nematode (*Meloidogyne* spp.), posited that beneficial yield of some vegetable crops to plastic mulches have traditional been attributed to altered soil temperatures, enhanced moisture conservation and weed control under the plastic mulch. Black plastic is often used in the spring to warm root zone temperatures (Torres-Olivar *et al.*, 2018). Management of proper density under polyhouse boost up the production per unit area by utilizing the available space and nutrients applied. The response of crops to mulch includes earlier production (Jha *et al.*, 2018), greater total yield and reduced insect and disease problems. Use of mulches provides suitable microclimatic conditions for producing superior branch characteristics, number of fruits per plant, fruit size, total yield and marketable yield of cucumber. The type of mulching material used and

color of plastic also effects the yield and quality parameters of cucumbers. In recent years a great deal of research work has been reported on the uses of mulching in vegetable crops. Plant density contributes to marketable yield in the various ways such as plant's ability to obtain the sun light needed for growth and adequate air movement around the plant to reduce risk of fungus and insect problems. And has been identified as key management practices for getting maximum marketable yields from greenhouse crops (Kishor *et al.*, 2010). The main objectives of mulching are weed control; conservation of soil moisture and modification of soil temperature Mulching is a non-chemical weed control crop production technique which is effective alternatives to herbicides

Method and Material

The field experiment was conducted during the two consecutive seasons at Horticultural Research Farm, Department of Horticulture, Naini Agricultural Institute, SHUATS, Prayagraj. The experiment was laid out into Randomized Complete Block Design (RCBD) with 3 replications with following treatments T1=M1 × S1, T2=M2 × S1, T3=M3 × S1, T4=M4 × S1, T5=M5 × S1, T6=M1 × S2, T7=M2 × S2, T8=M3 × S2, T9=M4 × S2, T10=M5 × S2 T11=M1 × S3 T12=M2 × S3, T13= M3 × S3, T14=M4 × S3 T15=M5 × S3. Standard culture practices recommended for cucumber were followed uniformly in all experimental plots, Where M1= Double Shaded Mulch, M2 = Transparent mulch, M3= Black Mulch, M4 = Straw Mulch M5= No Mulch, S1 = 70 cm × 30 cm, S2= 70cm × 45 cm and S3= 70 cm × 60 cm.

Parameters observed

Fruit length(cm), Fruit girth(cm), Fruit weight(g), Yield per hac(q/1000m²)., TSS (°B), Vitamin C (mg/100), Total chlorophyll content (mg /g DW⁻¹) and Economics.

Methodology

Fruit Length- Fruit length of 5 randomly selected plants was measured with the help of measuring scale in each treatment and their average value was used for further computation and it was expressed in cm.

Fruit girth(cm)- The girth of the fruit was recorded from selected plants with the help of Vernier callipers and average was worked out and it was expressed in cm.

Fruit weight(g)- Average weight of fruits was recorded based on five fruits in gram from five randomly selected plants individually of each genotype in each replication and then average fruit weight was calculated and it was expressed in gm.

Yield (q/1000m²)- Fruit yield per 1000 m² was calculated from the fruit yield per plot and expressed in quintals.

Vitamin C (mg/100)

Procedure

Take the sample of fruit juice (1ml). Add Meta phosphoric acid (5ml). From burette stand drop by drop of dye solution (blue Processor). Then write the titration value.

Preparation of Dye Solution

Sodium Bicarbonate – 0.042gm (42mg), 2,6–Dichlorophenol indophenol solution salt 0.050 gm (50 mg), Distilled Water – 150 ml were mixed well. Final volume maintained 200 ml with Distil water.

Preparation of Meta Phosphoric Acid

500 ml Distil water + 15 gm Meta Phosphoric acid

Formula to analyse:

$$\text{Vitamin C (mg/100gm)} = \frac{\text{Titration Value} \times \text{Dye Factor}}{\text{A liquat at extract} \times \text{Wt. of sample}} \times 100$$

Chlorophyll Estimation (mg /100gm)

Chlorophyll was analysed according to the method described by Hiscox and Isreaeltam (1979). The principle of this method is based on absorption of light by chlorophyll extract prepared by incubating the leaf tissue in DMSO (dimethyl sulfoxide). DMSO increase plasma membrane permeability thereby, causing the leaching out of the pigment (Hiscox and Isreaeltm). The absorbance of the known volume of solution containing known quantity of leaf tissue at two respective wavelength 663 and 645 nm was measured for chlorophyll content. Total chlorophyll content was estimated using the formula given by Arnon (1949). 50 mg fresh leaf ample was added to the test tube containing 10ml DMSO. Tubes were kept in Dark for 4 h at 65°C. Then the sample was taken out, cooled at room temperature and the absorbance was recorded at 663, 645 and 470 nm using DMSO as blank. The values thus obtained in µg/mL of extract (solvent). Values in mg/ g fresh weight was obtained by multiplying the above values with (V/W) X1000, Where V is volume of extract and W is dry weight of sample

$$\text{Total chlorophyll content (mg /g DW}^{-1}\text{)} = (20.2 \times A_{645}) + (8.02 \times A_{663}) \times V/W \times 1000$$

$$\text{Chlorophyll a content (mg /g DW}^{-1}\text{)} = (12.7 \times A_{663}) - (2.69 \times A_{645}) \times V/W \times 1000$$

$$\text{Chlorophyll b content (mg /g DW}^{-1}\text{)} = (22.9 \times A_{645}) - (4.68 \times A_{663}) \times V/W \times 1000$$

Economics

The B:C ratio was calculated by considering the cost

Table 1: Effect of spacing and mulching effect on yield, quality and economics.

Treat- ments	FL		FG		FW		YP		TS		VC		TC		BC	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	T	R
Mulching																
M1	14.13	18.00	11.33	13.31	114.99	115.71	14.83	15.95	2.51	2.67	3.05	3.62	1.12	1.33	M1S1	1.68
M2	13.52	17.89	10.66	12.64	105.66	109.96	14.56	15.68	2.42	2.61	3.05	3.62	1.09	1.30	M1S2	1.94
M3	14.38	18.85	11.39	13.37	119.99	122.57	15.23	16.35	2.56	2.74	3.33	3.90	1.17	1.38	M1S3	1.34
M4	14.87	18.87	12.49	14.47	123.99	124.20	15.80	16.92	2.68	2.96	3.40	3.97	1.21	1.43	M2S1	1.68
M5	13.10	17.08	10.66	12.64	100.66	102.64	14.33	15.45	2.35	2.57	2.86	3.57	1.07	1.28	M2S2	1.94
SE(m)	0.20	0.14	0.07	0.11	0.94	1.00	2.04	1.180	0.022	0.022	0.034	0.029	1.010	0.012	M2S3	1.34
C.D.	0.60	0.42	0.21	0.33	2.751	2.916	N/A	3.43	0.063	0.064	0.099	0.085	1.053	0.035	M3S1	1.71
Spacing															M3S2	1.70
S1	13.34	16.83	9.038	11.01	112.19	114.9	14.90	16.02	2.44	2.64	3.16	3.73	1.06	1.27	M3S3	1.41
S2	16.76	21.14	12.89	14.87	136.39	138.3	16.74	17.86	3.02	3.21	3.73	4.30	1.33	1.54	M4S1	1.92
S3	11.90	16.44	11.99	13.97	90.59	91.84	13.18	14.30	2.05	2.28	3.73	3.17	1.00	1.22	M4S2	2.37
SE(m)	0.234	0.114	0.057	0.09	0.73	0.77	0.914	0.91	2.056	0.017	0.026	0.023	1.010	0.009	M4S3	1.54
C.D.	0.600	0.331	0.167	0.26	2.13	2.25	2.662	2.66	0.049	0.050	0.077	0.066	1.017	0.027	M5S1	2.09
Interactions															M5S2	2.00
M ₁ × S ₁	10.99	16.98	10.99	12.97	53.00	114.28	15.00	16.12	2.45	2.56	2.45	2.56	3.067	3.63	M5S3	2.19
M ₂ × S ₁	10.00	15.84	10.00	11.98	54.66	113.13	14.70	15.82	2.34	2.60	2.34	2.60	2.967	3.53		
M ₃ × S ₁	7.19	17.96	7.197	9.177	52.00	119.88	15.20	16.32	2.5	2.70	2.5	2.70	3.447	4.02		
M ₄ × S ₁	8.00	18.83	8.00	9.98	50.66	120.19	15.50	16.62	2.68	2.93	2.68	2.93	3.473	4.04		
M ₅ × S ₁	8.99	14.54	8.99	10.98	54.66	107.05	14.30	15.42	2.23	2.43	2.23	2.43	2.890	3.45		
M ₁ × S ₂	14.99	21.26	14.99	16.97	53.33	136.18	16.50	17.62	3.00	2.56	3.00	2.56	3.763	4.33		
M ₂ × S ₂	13.99	20.43	13.99	15.98	49.00	135.16	16.20	17.32	2.95	2.60	2.95	2.60	3.683	4.25		
M ₃ × S ₂	11.99	21.64	11.99	13.97	47.66	146.44	17.00	18.12	3.10	2.70	3.10	2.70	3.76	4.33		
M ₄ × S ₂	13.50	22.25	13.50	15.47	45.66	149.54	18.00	19.12	3.20	2.93	3.20	2.93	3.91	4.49		
M ₅ × S ₂	10.00	20.13	10.00	11.98	49.33	124.21	16.00	17.12	2.87	2.43	2.87	2.43	3.55	4.12		
M ₁ × S ₃	8.00	21.26	8.00	9.98	57.00	96.60	13.00	14.12	2.09	2.28	2.09	2.28	2.32	4.33		
M ₂ × S ₃	7.99	20.43	7.99	9.973	58.00	81.59	12.79	13.92	1.97	2.19	1.97	2.19	2.50	4.25		
M ₃ × S ₃	14.99	21.64	14.99	16.97	56.00	101.39	13.50	14.62	2.10	2.31	2.10	2.31	2.78	4.33		
M ₄ × S ₃	15.99	22.25	15.99	17.97	54.66	102.8	13.90	15.02	2.17	2.46	2.17	2.46	2.82	4.49		
M ₅ × S ₃	12.99	20.13	12.99	14.97	58.33	76.67	12.69	13.82	1.95	2.15	1.95	2.15	2.16	4.12		
SE(m)	0.12	0.25	0.12	0.20	3.884	1.735	2.044	2.044	0.038	0.038	0.038	0.038	0.034	0.051		
C.D.	0.37	0.73	0.37	0.58	N/A	5.051	N/A		N/A	0.111	N/A	0.111	0.172	0.148		
T: Treatment; R: Ratio FL: Fruit Length(cm); FG: Fruit girth(cm); FW: Fruit weight(g); YP: Yield per 1000 m ² ; TS: TSS (°B); VC: Vitamin C (mg/100); TC: Total Chlorophyll a content (mg /g DW ⁻¹); BC: B:C Ratio																

T: Treatment; **R:** Ratio **FL:** Fruit Length(cm); **FG:** Fruit girth(cm); **FW:** Fruit weight(g); **YP:** Yield per 1000 m²; **TS:** TSS (°B); **VC:** Vitamin C (mg/100); **TC:** Total Chlorophyll a content (mg /g DW⁻¹); **BC:** B:C Ratio

of variable as well as fixed inputs and prevailing market rates along with the expenditure incurred on various inputs and operations. Simultaneously, gross returns were worked out for each treatment based on quality and market prices of the produce. The net returns were worked out by deducting the cost incurred from the gross returns of the particular treatment.

Result and Discussion

Fruit length (cm)

It is clear from the data that among the various mulches maximum fruit length (14.874 and 18.870 cm) was noticed in It was followed by M3 (14.387 and 18.857 cm) and minimum in M5 (13.101 and 17.087 cm) during both year of experiment. In case of spacings maximum fruit length was noticed in S2 (16.767 and 21.145 cm) followed by S1 (13.341 and 16.832 cm) whereas minimum

in S3 (11.905 cm) during both year of experiment. In case of Interaction maximum fruit length was recorded in M4S2 (17.927 and 22.250 cm) it was significantly at par with M1S2 (7.077 and 21.260 cm) and M3S2 (16.970 and 21.647cm) and minimum in M1S3 (11.847 and 5.760 cm) during both year of experiment. These results are accordance with Dhillon *et al.*, (2017).

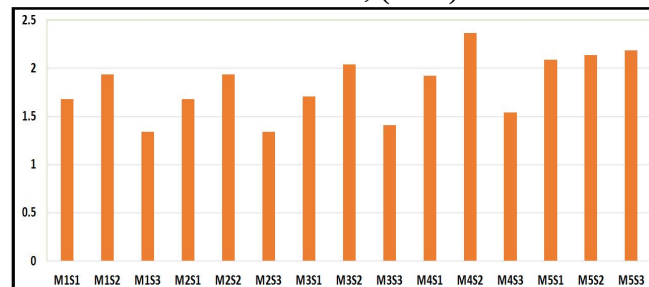


Fig. 1: Effect of intra-row spacing and mulching on Economics.

Fruit girth (cm)

It is clear from the data that among the various mulches maximum fruit girth was noticed in M4 (12.498 and 14.477 cm) It was followed by M3 (13.377 and 13.377 cm) and M1 (11.330 and 11.330) during both year of experiment. In case of spacings maximum fruit girth was noticed in S2 (12.898 and 14.878 cm) was followed by S3 and S1 (9.038 and 11.019 cm). In case of Interaction maximum fruit girth was noticed in treatment combination was found in M4S3 (15.993 and 17.973 cm) followed by M3S3 (14.997 and 14.997 cm) M5S3 (12.996 and 14.977cm) and whereas minimum in M3S1 (7.197 and 9.177 cm) during both year of experiment. Similar result were found in the findings of Prabhu *et al.*, (2006).

Fruit weight (gm)

It is clear from the data that among the various mulches maximum fruit weight was noticed in (123.998 and 124.206 gm). It was followed by M3 (119.998 and 122.571 gm) and M1 (114.997 and 115.717) both year of experiment. In case of spacings maximum fruit weight was found in (136.398 and 138.307 gm) followed by S1 (112.198 and 114.908 gm) and S3 (90.597 and 114.908gm) during both year of experiment. In case of Interaction maximum fruit girth was noticed was found in M4S2 (149.997 and 114.908) followed by M3S2 (144.00 and 119.880) and M3S2 (144.00 and 146.400gm) in treatment combination was followed by whereas maximum during both year of experiment. These results are similar with the Aiyelaagbe *et al.*, (2007).

Yield per 1000m² (q)

It is clear from the data that among the various mulches maximum yield per 1000 m² was noticed in combination M4 (15.800 and 16.923 q) It was followed by M3 (15.233 and 16.356) and M1 (14.833 and 15.956 q) whereas minimum in M5 (14.333 and 15.456) during both year of experiment. In case of spacings maximum yield per 1000 m² (16.74 and 17.863 q) was noticed in treatment S2 followed by S1 (14.900 and 16.023q) and S3 (13.180 and 14. 303 q). In case of Interaction maximum yield was noticed in M4S2 (18.00 and 19.123 q) followed by M3S2 (17.00 and 18.123 q) and M1S2 (16.500 and 18.123 q) treatment combination was followed by whereas it was minimum in M5S3 (12.699 and 13.822 q) during both year of experiment. Similar findings were reported by Narayanamma *et al.*, (2010).

Vitamin C (mg/100 gm)

Vitamin C content varied significantly among mulching treatments. In both years, M4 showed the highest values (3.40 mg/100 g in 2023; 3.97 mg/100 g in 2024), followed by M3, while M5 recorded the lowest values.

The enhancement in ascorbic acid under M4 might be attributed to the reduced fruit exposure to heat stress and better soil water status, which preserves Vitamin C integrity (Ghosh *et al.*, 2017) In 2023, S2 recorded the maximum Vitamin C content (3.73 mg/100 g), followed by S1 (3.16 mg/100 g). In 2024, the same trend was observed, with S2 (4.30 mg/100 g) outperforming the other spacings. Wider spacing possibly allowed better aeration and light penetration, improving metabolic processes responsible for ascorbic acid biosynthesis. The M4 × S2 combination yielded the highest Vitamin C content (3.91 mg/100 g in 2023; 4.49 mg/100 g in 2024), while M5 × S3 showed the lowest values. The data indicate that optimal mulching coupled with moderate plant density promotes better biochemical quality of the fruits.

Total Chlorophyll Content (mg/g DW)

Total chlorophyll a content was significantly influenced by mulching, with M4 recording the highest values (1.21 mg/g DW in 2023; 1.43 mg/g DW in 2024), followed by M3. The lowest content was found in M5. Improved leaf chlorophyll content under M4 could be due to reduced leaf temperature fluctuations and better nutrient uptake efficiency (Singh *et al.*, 2016). Wider spacing S2 showed higher chlorophyll a content (1.33 mg/g DW in 2023; 1.54 mg/g DW in 2024) compared to S1 and S3, possibly due to improved light interception and reduced mutual shading. The maximum chlorophyll a content was recorded in M4 × S2 (1.50 mg/g DW in 2023; 1.71 mg/g DW in 2024), while the lowest was observed in dense planting (S3) across most mulching treatments. The interaction was significant, indicating that proper spacing is crucial for maintaining photosynthetic capacity, which in turn influences yield and quality.

Economics

The B:C ratio varied widely across the treatment combinations, ranging from 1.34 to 2.37. The highest economic return was achieved with M4 × S2 (2.37), followed closely by M5 × S3 (2.19) and M5 × S2 (2.14). The lowest B:C ratio was observed in M1 × S3 (1.34). Higher economic efficiency under M4 × S2 could be attributed to the simultaneous improvement in yield and quality traits, which fetched higher market price.

Conclusion

The present study revealed that the application of mulching materials and plant spacing significantly influenced yield and quality traits of the crop across both years of experiment (2023 and 2024). Among mulching M4 (Straw Mulch) consistently performed the superior fruit traits such as length, girth, weight, yield per 1000 m², TSS, Vitamin C and chlorophyll content. Spacing S2

(70cm × 45) proved to be optimal, and superior yield, performance higher fruit quality, compared to S1 and S3. The interaction effects between mulch and spacing treatments further highlighted the synergistic impact on crop performance. The combination M4S2 emerged as the most effective treatment, significantly enhancing fruit size, weight, and overall yield per 1000 m², TSS, Vitamin C and chlorophyll content and benefit cost ratio. This was closely followed by M3S2 and M1S2 in most parameters. Conversely, the lowest performance in growth and yield traits was observed in combinations like M5S3 and M1S1.

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