Varying intra-row spacing and mulching effect on growth and yield of parthenocarpic cucumber (*Cucumis sativus* L.) under protected condition

**Abstract**

A field 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 growth, flowering, and yield of cucumber. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications and fifteen treatment combinations comprising five mulches- Double Shaded Mulch (M1), Transparent Mulch (M2), Black Mulch (M3), Straw Mulch (M4), and No Mulch (M5)-and three 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 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 (15.80 and 16.92 q/1000 m²). In terms of spacing, 70 × 45 cm (S2) spacing significantly improved vegetative and yield traits, yielding the highest vine length (3.64 and 4.87 m), fruit length (16.76 and 21.14 cm), and yield (16.74 and 17.86 q/1000 m²). The interaction of M4S2 (Straw Mulch + 70 × 45 cm) consistently produced the best results across both years, with maximum vine length, fruit size, and yield (18.00 and 19.12 q/1000 m²).

**Keywords:** Black Mulch, Cucumber, Double shaded mulch, Mulching and Transparent Mulch.

**Introduction**

Cultivated cucumber is botanically known as *Cucumis sativus* L. and is native to India. It has the diploid chromosome number of 2n=14 and *Cucumis hardwickii* is the probable progenitor of cultivated cucumber. Cucumber is one of the important monoecious annual vegetable crops in the Cucurbitaceae family that has been cultivated by man for over 3000 years. 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 green house 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 temperatureMulching is a non-chemical weed control crop production technique which is effective alternatives to herbicides

**Method & Material**

The field experiment was conducted during thetwo 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 X S1, T2=M2 X S1, T3=M3 X S1, T4=M4 X S1, T5 =M5 X S1, T6=M1 X S2,T7 =M2 X S2, T8 =M3 X S2, T9=M4 X S2, T10=M5 X S2 T11=M1 X S3 T12=M2 X S3, T13= M3 X S3, T14=M4 X S3 T15=M5 X 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 X 30 cm, S2= 70cm X 45 cm and S3= 70 cm X 60 cm.

**Parameters observed**: Vine length (m), Days to 50 % flowering, Internodal length, Days to first fruit harvest, Fruit Length, Fruit girth, Fruit weight, Yield per hac.

**Result and Discussion**

**Vine Length**

As data presented in table 1. It is clear from the data that among the various mulches maximum vine length was noticed in M5 (4.05 and 5.29m). It was followed by M4 (4.04 and 5.27 m) both year of experiment. Whereas minimum vine length was reported in M1 (3.188 m). In case of spacings maximum vine length was noticed in S3 (3.64 and 4.87 m) followed by S2 (3.61 m 4.840) and S1 (3.57 m and 4.803m). In case of Interaction maximum vine length was noticed M5S1 (4.4143m 5.378m) followed by M4S1 (4.130 and 5.365 m) and M5S3(4.123 and 5.358m) whereas minimum in M1S1 and M3S3(3.000m and 4.235m) during both year of experiment.

**4.2 Days to 50% flowering**

It is clear from the data that among the various mulches minimum Days to 50% flowering was noticed in M4 (40.66 and 43.65) It was followed by M1 (42.00 and 44.63) and M3 (42.33 and 46.241) whereas maximum (43. 889 and 47.780) during both year of experiment. In case of spacings minimum Days to 50% flowering was noticed in S2 (39.33 and 43.40) followed by (42.86 and 45.99) whereas maximum during both year of experiment (46.06 and 48.04). In case of Interaction minimum Days to 50% flowering was found in treatment combination (37.66 and 39.75) M3S2 was followed by 39.33 and 42.25 (M2S2) whereas maximum M2S1 (48.33 and 50.23) during both year 2023 and 2024 respectively. These findings are accordance with Singh *et al.,* (2007**)**.

**Table 1: Effect of spacing and mulching effect on growth and yield**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Vine length (m)** | | **Days to 50 % flowering** | | **Internodal length** | | **Days to first fruit harvest** | |
| **Mulching** | **2023** | **2024** | **2023** | **2024** | **2023** | **2024** | **2023** | **2024** |
| M1 | 3.18 | 4.42 | 42.00 | 44.63 | 9.72 | 14.06 | 57.77 | 58.97 |
| M2 | 3.40 | 4.64 | 43.88 | 47.78 | 9.92 | 14.20 | 53.88 | 55.08 |
| M3 | 3.33 | 4.56 | 42.33 | 46.24 | 9.44 | 13.50 | 51.88 | 53.08 |
| M4 | 4.04 | 5.27 | 40.66 | 43.65 | 9.30 | 13.48 | 50.33 | 51.53 |
| M5 | 4.05 | 5.29 | 43.88 | 46.76 | 10.07 | 14.47 | 54.11 | 55.31 |
| **SE(m)** | 0.49 | 1.11 | 0.38 | **0.38** | 0.09 | 0.12 | 2.24 | 0.431 |
| C.D. | 1.43 | 3.23 | 1.12 | **1.12** | 0.28 | 0.35 | N/A | 1.255 |
| **Spacing** |  |  |  |  |  |  |  |  |
| S1 | 3.57 | 4.80 | 42.86 | 45.99 | 9.68 | 13.93 | 53.00 | 54.20 |
| S2 | 3.61 | 4.84 | 39.33 | 43.40 | 9.87 | 13.34 | 45.00 | 46.20 |
| S3 | 3.64 | 4.87 | 46.06 | 48.04 | 10.52 | 14.55 | 56.80 | 58.00 |
| **SE(m)** | 0.38 | 0.85 | 0.38 | 0.07 | 0.07 | 0.095 | 1.73 | 0.33 |
| **C.D.** | 2.4 | 0.85 | 1.120 | 0.21 | 0.21 | 0.277 | 5.05 | 0.97 |
| **Spacing** |  |  |  |  |  |  |  |  |
| M1 X S1 | 3.00 | 4.23 | 43.33 | 44.43 | 9.76 | 14.07 | 53.00 | 54.20 |
| M2 X S1 | 3.11 | 4.34 | 48.33 | 50.23 | 9.80 | 14.24 | 54.66 | 55.86 |
| M3 X S1 | 3.45 | 4.69 | 42.33 | 43.77 | 9.50 | 13.56 | 52.00 | 53.20 |
| M4 X S1 | 4.13 | 5.36 | 40.66 | 42.75 | 9.40 | 13.30 | 50.66 | 51.86 |
| M5 X S1 | 4.14 | 5.37 | 43.66 | 46.77 | 9.98 | 14.47 | 54.66 | 55.86 |
| M1 X S2 | 3.13 | 4.36 | 39.30 | 44.69 | 9.90 | 13.62 | 53.33 | 54.53 |
| M2 X S2 | 3.44 | 4.67 | 39.33 | 42.25 | 9.60 | 13.11 | 49.00 | 50.20 |
| M3 X S2 | 3.543 | 4.77 | 39.33 | 46.21 | 9.70 | 12.95 | 47.66 | 48.86 |
| M4 X S2 | 4.00 | 5.23 | 37.66 | 39.75 | 9.50 | 13.13 | 45.66 | 46.86 |
| M5 X S2 | 3.91 | 5.14 | 40.66 | 44.12 | 9.850 | 13.81 | 49.33 | 50.53 |
| M1 X S3 | 3.43 | 4.66 | 46.33 | 49.71 | 10.50 | 14.480 | 57.00 | 58.20 |
| M2 X S3 | 3.66 | 4.90 | 47.66 | 50.85 | 10.98 | 15.3 | 58.00 | 59.20 |
| M3 X S3 | 3.00 | 4.23 | 45.33 | 48.73 | 10.12 | 14.07 | 56.00 | 57.20 |
| M4 X S3 | 3.99 | 5.22 | 43.66 | 41.53 | 10.00 | 14.00 | 54.67 | 55.86 |
| M5 X S3 | 4.12 | 5.35 | 47.33 | 49.38 | 11.00 | 15.062 | 58.33 | 59.533 |
| **SE(m)** | **0.493** | 1.922 | 0.385 | 0.666 | 0.167 | 0.212 | 3.884 | 2.173 |
| **C.D.** | **2.485** | 5.596 | 1.120 | 1.939 | N/A | N/A | N/A | 0.746 |

**Continued…..**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Fruit Length** | | **Fruit girth** | | **Fruit weight** | | **Yield per hac.** | |
| **Mulching** | **2023** | **2024** | **2023** | **2024** | **2023** | **2024** | **2023** | **2024** |
| M1 | 14.13 | 18.00 | 11.33 | 13.31 | 114.99 | 115.71 | 14.83 | 15.95 |
| M2 | 13.52 | 17.89 | 10.66 | 12.64 | 105.66 | 109.96 | 14.56 | 15.68 |
| M3 | 14.38 | 18.85 | 11.39 | 13.37 | 119.99 | 122.57 | 15.23 | 16.35 |
| M4 | 14.87 | 18.87 | 12.49 | 14.47 | 123.99 | 124.20 | 15.80 | 16.92 |
| M5 | 13.10 | 17.08 | 10.66 | 12.64 | 100.66 | 102.64 | 14.33 | 15.45 |
| **SE(m)** | 0.20 | 0.14 | 0.07 | 0.11 | 0.94 | 1.00 | 2.04 | 1.180 |
| C.D. | 0.60 | 0.42 | 0.21 | 0.33 | 2.751 | 2.916 | N/A | 3.43 |
| **Spacing** |  |  |  |  |  |  |  |  |
| S1 | 13.34 | 16.83 | 9.038 | 11.01 | 112.19 | 114.9 | 14.90 | 16.02 |
| S2 | 16.76 | 21.14 | 12.89 | 14.87 | 136.39 | 138.3 | 16.74 | 17.86 |
| S3 | 11.90 | 16.44 | 11.99 | 13.97 | 90.59 | 91.84 | 13.18 | 14.30 |
| **SE(m)** | 0.234 | 0.114 | 0.057 | 0.09 | 0.73 | **0.77** | 0.914 | 0.91 |
| **C.D.** | 0.600 | 0.331 | 0.167 | 0.26 | 2.13 | 2.25 | 2.662 | 2.66 |
| **Spacing** |  |  |  |  |  |  |  |  |
| M1 X S1 | 10.99 | 16.98 | 10.99 | 12.97 | 53.00 | 114.28 | 15.00 | 16.12 |
| M2 X S1 | 10.00 | 15.84 | 10.00 | 11.98 | 54.66 | 113.13 | 14.70 | 15.82 |
| M3 X S1 | 7.19 | 17.96 | 7.197 | 9.177 | 52.00 | 119.88 | 15.20 | 16.32 |
| M4 X S1 | 8.00 | 18.83 | 8.00 | 9.98 | 50.66 | 120.19 | 15.50 | 16.62 |
| M5 X S1 | 8.99 | 14.54 | 8.99 | 10.98 | 54.66 | 107.05 | 14.30 | 15.42 |
| M1 X S2 | 14.99 | 21.26 | 14.99 | 16.97 | 53.33 | 136.18 | 16.50 | 17.62 |
| M2 X S2 | 13.99 | 20.43 | 13.99 | 15.98 | 49.00 | 135.16 | 16.20 | 17.32 |
| M3 X S2 | 11.99 | 21.64 | 11.99 | 13.97 | 47.66 | 146.44 | 17.00 | 18.12 |
| M4 X S2 | 13.50 | 22.25 | 13.50 | 15.47 | 45.66 | 149.54 | 18.00 | 19.12 |
| M5 X S2 | 10.00 | 20.13 | 10.00 | 11.98 | 49.33 | 124.21 | 16.00 | 17.12 |
| M1 X S3 | 8.00 | 21.26 | 8.00 | 9.98 | 57.00 | 96.6 | 13.00 | 14.12 |
| M2 X S3 | 7.993 | 20.43 | 7.99 | 9.973 | 58.00 | 81.59 | 12.799 | 13.92 |
| M3 X S3 | 14.99 | 21.64 | 14.99 | 16.97 | 56.00 | 101.39 | 13.500 | 14.62 |
| M4 X S3 | 15.99 | 22.25 | 15.99 | 17.97 | 54.66 | 102.8 | 13.900 | 15.02 |
| M5 X S3 | 12.99 | 20.13 | 12.99 | 14.97 | 58.33 | 76.67 | 12.699 | 13.82 |
| **SE(m)** | 0.12 | 0.25 | 0.12 | 0.20 | 3.884 | 1.735 | 2.044 | 2.044 |
| **C.D.** | 0.37 | 0.73 | 0.37 | 0.58 | N/A | 5.051 | N/A |  |

**Internodal length (cm)**

It is clear from the data that among the various mulches minimum Internodal length (9.30 and13.48 cm) was noticed in M4. It was followed by M3 (9.44 and 13.50 cm) and M1 (9.72 and 13.50 cm) whereas maximum internodal length (10.07 and 14.47 cm) was noticed in M5. In case of Spacings minimum Internodal lengthwas noticed in S2 8.87 and 13.34 cm) treatment combination was followed S1 (9.68 and 13.93 cm) and S3 (10.52 and 14.5 cm). In case of Interaction minimum Internodal length was noticed in M4S1 (9.40 and 13.30) followed by M3S1 (9.50 and 13.30 cm) whereas maximum in M5S3 (11.00 and 15.06) during both year of trail 2023 and 2024 respectively. These results are accordance with Arshad *et al.,* (2014) and Kumar (2014).

**Days to first fruit Harvest (Days after Sowing)**

It is clear from the data that among the various mulches minimum days to first fruit harvest was noticed in M4 (50.33 and 51.53) followed by M3 (51.88 and 53.08) and M2 (53.88 and ab53.089) whereas maximum in M1 (57.778 and 58.978) during both year of experiment. In case of spacings minimum days to first fruit Harvest was noticed in S2 (45.00 and 46.200) followed by S1 (53.00 and 54.200) and S3 (56.800 and 58.00) in both trail. In case of Interaction minimum Days to first fruit Harvest was noticed in M5S2 (45.00 and 46.86) followed by M04S2 (45.667 and 46.86) and M3S2 (47.667 and 48.86) and maximum in M4S3(58.333 and 59.533) during both year of experiment.

**Fuit length (cm)**

It is clear from the data that among the various mulches maximum fruit length (14.87 and 18.87 cm) was noticed in It was followed by M3 (14.38 and 18.85 cm) and minimum in M5 (13.10 and 17.08 cm) during both year of experiment. In case of spacings maximum fruit length was noticed in S2 (16.76 and 21.14 cm) followed by S1 (13.34 and 16.83 cm) whereas minimum in S3 (11.90 cm) during both year of experiment. In case of Interaction maximum fruit length was recorded in M4S3 (15.99 and 22.25 cm) it was significantly at par with M3S3 (14.99 and 21.64 cm) and M1S2 (14.99 and 21.26 cm) and minimum in M3S1 (7.19 and 7.960 cm) during both year of experiment. These results are accordance with Dhillon *et al.,* (2017).

**Fruit girth (cm)**

It is clear from the data that among the various mulches maximum fruit girth was noticed in M4 (12.49 and 14.47 cm) It was followed by M3 (11.39 and 13.37 cm) and M1 (11.33 and 13.31) during both year of experiment. In case of spacings maximum fruit girth was noticed in S2 (12.89 and 14.87 cm) was followed by S3 and S1 (11.99 and 13.97) and (9.038 and 11.01 cm) respectively . In case of Interaction maximum fruit girth was noticed in treatment combination was found in M4S3 (15.99 and 17.97 cm) followed by M3S3 (14.99 and 16.97 cm) M2S2 (13.99 and 15.98 cm) and whereas minimum in M3S1 (7.19 and 9.17cm) during both year of experiment. Similar result were found in the findings of Prabhu *et al.,* (2006).

**Fruit weight**

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 (119.99 and 122.57 gm) and M1 (114.99 and115.71) 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 (149.99 and 114.90) 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**

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 (15.23 and 16.35) and M1 (14.83 and 15.9 q) whereas minimum in M5 (14.33 and 15.45) during both year of experiment. In case of spacings maximum yield per 1000 m2 (16.74 and 17.86 q) was noticed in treatment S2 followed by S1 (14.90 and 16.02q) and S3 (13.180 and 14. 303q). In case of Interaction maximum yield was noticed in M4S2 (18.00 and 19.12 q) followed by M3S2 (17.00 and 18.123 q) and M1S2 (16.50 and 18.123 q) treatment combination was followed by whereas it was minimum in M5S3 (12.699 and 13.82 q) during both year of experiment. Similar findings were reported by Narayanamma *et al.,*(2010).

**Conclusion**

The findings of the present study clearly demonstrate that both mulching materials and plant spacing exerted a significant influence on vine growth, phenological development, and yield-related attributes of the crop during the two consecutive years (2023 and 2024). Among the mulching treatments, M4 consistently outperformed all others, promoting the most vigorous vine growth, earliest flowering, shortest internodal length, earlier fruit maturity, and superior fruit characteristics—including increased length, girth, weight, and overall yield per 1000 m².

In terms of plant spacing, S2 (medium spacing) emerged as the most favorable, striking an optimal balance between vegetative growth and reproductive output. Plants under S2 showed improved canopy architecture, earlier phenological events, enhanced fruit quality, and higher yields when compared to both narrower (S1) and wider (S3) spacing treatments.

The interaction between mulching and spacing further revealed a synergistic effect on crop performance. The combination M4S2 stood out as the most effective treatment, significantly enhancing vine length, flowering and fruiting earliness, and yield-contributing traits such as fruit size, weight, and total productivity per 1000 m². This was closely followed by M3S2 and M1S2, which also showed considerable promise across most parameters. In contrast, M5S3 and M1S1 recorded the poorest performance, underscoring the importance of strategic integration of mulching and spacing for maximizing crop potential.

These results underscore the critical role of optimized cultural practices in improving pumpkin productivity and can inform future recommendations for sustainable and efficient cultivation techniques.

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