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Effects of mulching on plant growth, viral diseases, earliness and fruit yield attributes of round gourd under variable sowing dates in North Indian plains

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Abstract

Round gourd is sensitive to low temperature (March), high temperature (May–June), high humidity (July–August), and whitefly-transmitted *begomovirus* diseases (July–September), thereby restricting its fruit availability period in North-Western Indian Plains. Mulches extend the growing season by modifying soil temperature and reducing the incidence of viral diseases. Therefore, the present study was conducted to investigate the effects of sowing time, mulching and their interaction on performance of round gourd crop so as to identify the best mulch at different sowing times. The field trials were conducted in a split-plot design during 2021 and 2022. The main plot consisted of six sowing dates, i.e., the first week of March (DS1), April (DS2), May (DS3), June (DS4), July (DS5) and August (DS6). The sub-plot comprised bare soil (BS) and three mulching treatments, viz., silver-black plastic mulch (SBPM), black plastic mulch (BPM) and paddy straw mulch (6 t/ha) (PSM). The BPM and SBPM increased the seasonal soil temperature over BS by 3.1–4.1°C and 2.1–3.1°C, respectively, whereas the PSM reduced the seasonal soil temperature by 2.3–3.5°C. The SBPM produced the best crop performance, followed by BPM and PSM in all sowing dates except DS5 in which the PSM outperformed BPM. The DS1 and DS2 were the best sowing times, and the crop performance gradually declined with each successive sowing time, except that the crop performed better in DS6 compared with DS5. The SBPM or BPM in DS2 and DS1 were the best treatment combinations for round gourd cultivation in the study area.

Introduction

Round gourd [*Praecitrullus fistulosus* (Stocks) Pangalo], also known as tinda, Indian squash, apple gourd, round melon or squash melon, is an important squash-like cucurbit primarily grown for its immature fruits. It is cultivated as a vegetable in the tropical South Asia (India and Pakistan), continental central Asia (Afghanistan), tropical East Africa (Kenya, Tanzania and Uganda), tropical West Africa (Ghana) and North America (USA) (Schippers, 2004; Chomicki *et al.*, 2020). The ideal temperature requirement for its seed germination is 21–35°C. It prefers warm, bright weather with temperatures ranging from 25 to 30°C during the day, and 18°C or more at night (Schippers, 2004).

One of the most crucial factors influencing the plant growth and fruit yield of this crop is the sowing time or season. In the plains of North-Western India, the crop is predominantly sown in spring–summer, viz., March–April. The slow germination combined with slow initial plant growth and development, due to low temperature in March, is one of the hurdles in obtaining high early fruit yield which generally fetch high market prices. On the contrary, the crop sown in May–June faces high temperature (>35°C) stress which leads to desiccation of flower buds, ultimately reducing fruit yield. The crop can also be sown in the rainy season (June–August); however, high weed infestation and incidence of *begomovirus* diseases, due to the high whitefly population, are the major hurdles in its successful cultivation in this season. Fruit availability period of round gourd is short in the plains of North-Western India, and there is a need to standardize its production technologies, and extend fruit availability period.

Mulches are known to extend the harvest duration of various vegetables, to control weeds, and to reduce the incidence of viral diseases. These are mainly of two types – organic (natural) and inorganic (synthetic). Organic mulch includes crop residues, hay, straw, hardwood, sawdust, dry leaves and compost (Ranjan *et al.*, 2017). Organic mulches have been reported to modify soil temperature, reduce evaporation losses, conserve soil moisture, promote drought tolerance, increase germination percentage, control weeds to some extent, add organic matter and other nutrients to the soil surface, reduce nitrate leaching and improve the soil physical and biological properties, thereby improving the plant growth attributes and yield of various crops, including tomato (Agele *et al.*, 1999, 2000), brinjal (Singh *et al.*, 2011), bell pepper

(Singh *et al.*, 2012), okra (Adekiya *et al.*, 2017) and squash melon (Birbal *et al.*, 2014, 2019). Among organic mulches, paddy straw mulch is readily available in Indian Punjab due to the extensive cultivation of paddy on about 3 million ha (Kaur *et al.*, 2020).

Inorganic mulches include plastic (polyethylene), aluminium-coated plastic, biodegradable plastic and photo-degradable plastic mulch. Plastic mulches are readily available and commercially used by many vegetable growers in Punjab and other parts of the world, owing to their multiple benefits (Gordon *et al.*, 2008; Mitchell *et al.*, 2013; El-Beltagi *et al.*, 2022). Plastic mulches are reported to control weeds (Johnson and Mullinix, 2008), conserve soil moisture, modify soil temperature (Moreno and Moreno, 2008; Dhatt *et al.*, 2017), enhance plant nutrient uptake from soil (Chen *et al.*, 2020), induce early fruit harvest (Dhatt *et al.*, 2016), improve plant growth (Zhang *et al.*, 2019; Lee and Park, 2020), yield attributes (Diaz-Perez, 2010) and reduce viral disease incidence (Stapleton and Summers, 2002) in many vegetable crops. These mulches are mainly made from low-density poly-ethylene and are available in various colours, each serving different function and purpose. However, black and silver-black coloured plastic mulches are easily available, and widely used in India. The influence of plastic mulch on soil temperature, plant growth, development and yield may vary with crop, bed width, season, location, soil type, climate and mulching material (Diaz-Perez and Batal, 2002; Mendonca *et al.*, 2021). Therefore, it becomes necessary to conduct studies on a particular vegetable in various seasons using different mulches at a particular location.

The literature on the effect of mulching in round gourd is scanty. The effects of straw and black plastic mulching on earliness, plant growth, fruit yield and yield components in round gourd in Bikaner, India have earlier been reported (Birbal *et al.*, 2014, 2019). Therefore, the present study was conducted to investigate the effects of sowing time, mulching and their interaction on plant growth attributes, viral disease incidence, earliness, fruit yield and yield components of round gourd so as to identify the best mulch for different sowing times.

Materials and methods

Experimental site description

The field trials were conducted for two consecutive years i.e. 2021 and 2022 (Fig. SI-1 in supplementary information file) at Punjab Agricultural University, Regional Research Station, Jodhpur Romana Farm, Bathinda, India (30°17 ′N, 74°58 ′E, 211 m a.s.l). The site lies in the South-Western zone of Punjab, which falls in the Indo-Gangetic plains and has a semi-arid climate, with an average annual rainfall of 400–450 mm, 70–80% of which occurs during the monsoon season (July to mid-September). The mean monthly agro-climatic observations during the crop season (Table SI-1) and the initial properties of the experimental soil (at 0–15 cm depth) (Table SI-2) were recorded for both years.

Plant materials, experimental design and treatments

The round gourd cultivar 'Punjab Tinda1' released by the Punjab Agricultural University, Ludhiana, for cultivation in the state of Punjab, India, was used in the present study (Garg, 2020). The field experiment was laid out in a split-plot design with three replications (Fig. SI-2 in supplementary information file). The main-plot treatment consisted of six sowing times, i.e., first week of March (DS1), April (DS2), May (DS3), June (DS4), July (DS5) and August (DS6). The sub-plot treatment comprised three mulching treatments (silver-black plastic mulch [SBPM; thickness 25 μm], black plastic mulch [BPM; thickness 25 μm] and paddy straw mulch [PSM; 6 t/ha] and a control [bare soil [BS]).

Field preparation and agronomic practices

After the application of pre-sowing irrigation, the experimental field was ploughed twice at field capacity with a disc harrow and cultivator, followed by planking to bring the soil to a fine tilth. After that, bed marks were made at a distance of 2.0 m. Mineral fertilizers, viz., urea (46% N), diammonium phosphate (DAP) (18% N and 46% P_2O_5), and muriate of potash (MOP) (60% K_2O) (Indian Farmers Fertilizer Cooperative, New Delhi, India), were used to supply 100 kg N, 50 kg P_2O_5 and 50 kg K_2O per hectare. Band placement of a full dose of all three fertilizers was carried out at 15 cm away on both sides of the bed mark. Fertilization was followed by the preparation of furrows (15 cm deep and 30 cm wide) in between two beds having 1.7 m wide base and 15 cm height above the ground. Plastic mulch of silver-black and black colours (2.1 m wide and 25 μm thick) was manually and tightly spread over the beds in the respective plots. Round holes of about 5 -cm diameter were made in the plastic mulch with a blade on top of the furrow on both sides of the bed at an intra-row spacing of 45 cm. Two seeds per hill were sown on pre-irrigated furrows at field capacity, and later on thinning was done to retain one plant per hill. Paddy straw mulch (6 t/ha) was applied immediately after sowing. Net plot size was 4.5 m × 2.0 m to accommodate 20 plants in two rows of ten each. Subsequent furrow irrigations were provided at weekly intervals during the summer, and on need-based in the rainy season.

Observations recorded

Soil temperature (°C)

One soil thermometer (Jain Scientific Glass Works, Ambala, India) per treatment was installed at 5-cm soil depth in-between two plants within a row (near the root zone of the plant). The soil temperature (°C) was recorded daily (0830 and 1400 h) in the mulching treatments along with bare soil. The weekly average soil temperatures for the entire crop season were calculated for both years.

Plant growth and disease attributes

Vine length (cm) of five randomly selected plants per plot was measured with a 1 m-long scale at 45 days after sowing (DAS) and at final harvest. The number of leaves per vine was recorded from five randomly selected plants per plot at peak harvest. The number of primary branches per vine was recorded from five randomly selected plants per plot at final harvest. Incidence of viral disease (%) was estimated as the proportion (%) of plants showing viral disease symptoms (interveinal chlorosis, chlorotic mottling and complete yellowing of leaves) in each plot at 60 DAS (Aguilar *et al.*, 2006).

Earliness, fruit yield and yield components

The first flush of fruits was borne early. These fruits remained small, unmarketable and for proper vegetative growth, fruits were removed as soon as they appeared. The fruits of the later flush attained marketable size and were harvested on alternate days, when they were green, immature, tender, and hairy. At each harvest, the number and weight of fruits from each plot was noted. The number of days from sowing to the day when 50% of the plants in each plot started fruit harvest was recorded as 'days to first picking'. The fruit yield obtained up to 55 DAS was considered as early yield (kg per plot), and was later on converted into tons per hectare. The number of fruits per vine was calculated by adding the number of fruits from each harvest, and dividing it by the number of plants per plot. To calculate fruit weight, the weight of fruits harvested from all pickings was added up and divided by the total number of fruits per plot. The duration in days from the first to last harvest was taken as harvest duration. The weight of fruits per plot from all pickings was added to estimate marketable yield (kg per plot), and was converted into tons per hectare.

Statistical analyses

The data collected during individual years were subjected to analysis of variance (ANOVA) procedure laid out for split-plot design (Gomez and Gomez, 1984). The individual year data were also subjected to pooled ANOVA using mixed-model so as to study the effects of sowing date, mulching and their interaction (sowing date × mulching) on various traits. The mean values were compared using Fisher's least significant difference (LSD) test ($P = 0.05$). All the data were analysed employing R-studio software version 1.4.1106 using 'doebioresearch' package.

Results

Effect of mulching on the morning and afternoon soil temperatures (°C) at 5 cm depth

The SBPM and BPM increased the morning and afternoon soil temperatures over BS throughout the crop season during both years (Figs 1 and 2). However, the increase in soil temperature was higher with BPM compared with SBPM. Secondly, the increment in soil temperature with plastic mulching over BS was higher in the afternoon than in the morning hours. The SBPM enhanced the morning soil temperature over BS by 0.4–1.9°C (average 1.2°C) during 2021, 1.0–2.8°C (average 1.6°C) during 2022, whereas the increment in the afternoon soil temperature varied from 1.0 to 3.6°C (average 2.1°C) during 2021 and 1.8–4.3°C (average 3.1°C) during 2022. The BPM increased the morning soil temperature over BS by 0.6–2.5°C (average 1.5°C) during 2021, 1.3–3.4°C (average 2.1°C) during 2022 whereas the enhancement in afternoon soil temperature varied from 1.4 to 4.7°C (average 3.1°C) during 2021 and 2.3–5.6°C (average 4.1°C) during 2022.

On the contrary, the PSM decreased the morning and afternoon soil temperatures over BS throughout the crop season during both years (Figs 1 and 2). However, the decreased temperature was more pronounced in the afternoon than in the morning. The PSM reduced the morning soil temperature over BS by 0.8–1.4°C (average 1.1°C) during 2021, 0.5–1.8°C (average 0.9°C) during 2022, whereas the decrease in afternoon soil temperature varied from 1.5 to 3.5°C (average 2.3°C) during 2021, and 1.3–5.5°C (average 3.5°C) during 2022.

Plant growth parameters

Irrespective of sowing time, mulching significantly ($P < 0.001$) influenced the plant growth attributes, viz., vine length (at 45 DAS and at final harvest), number of leaves, and number of primary branches during both years (Tables 1 and 2). The highest values of these growth attributes were obtained for SBPM, which was significantly better than BPM, PSM and BS. On the basis of data pooled over the years (Table 3), the SBPM increased the vine length (at 45 DAS) over BS by 45.0%, vine length (at final harvest) by 20.8%, number of leaves by 67.4%, and number of primary branches by 18.9%. The BPM ranked second to SBPM, and it enhanced the vine length (at 45 DAS) over BS by 30.7%, vine length (at final harvest) by 11.6%, number of leaves by 46.4%, and number of primary branches by 13.6%. However, the SBPM and BPM registered similar values of the number of primary branches during 2021 (Table 1) and for pooled data (Table 3). Compared with plastic mulches, the magnitude of increase in growth attributes with PSM was lower, and it recorded values at par with BS in respect of vine length (at final harvest) during 2021 (Table 1), and the number of primary branches during both years. Based on data pooled over the years (Table 3), the PSM improved the vine length (at 45 DAS) over BS by 16.5%, and the number of leaves by 16.6%.

Irrespective of mulch, the plant growth attributes were significantly ($P < 0.001$) affected by sowing time during both years (Tables 1 and 2). The maximum vine length (at 45 DAS) was observed in DS3, and it was statistically at par with DS2 whereas the minimum value was recorded in DS1 (Table 3). The maximum vine length (at the final harvest) was recorded in DS1 during 2021 (Table 1), and DS2 during 2022 (Table 2), whereas for pooled data, both sowing dates registered at par values (Table 3). Vine length (at final harvest) exhibited a decreasing trend with each successive sowing date, and the minimum vine length was recorded with DS6. The maximum number of leaves and number of primary branches were recorded with DS2. The lowest number of leaves was manifested in DS6 during both years. The DS5 and DS6 registered the minimum and at par values of the number of primary branches (Table 3).

The interaction effects (sowing time × mulch) for pooled data revealed that the maximum vine length (at 45 DAS) was exhibited by DS3 + SBPM, whereas the highest vine length (at final harvest) was registered by DS1 + SBPM (Table 4). The maximum number of leaves was exhibited by DS2 + SBPM, which was at par with DS1 + SBPM. The number of primary branches was the maximum in DS2 + BPM, DS3 + BPM and DS3 + SBPM. The lowest vine length (at 45 DAS) was exhibited by DS1 + BS, which was at par with DS1 + PSM. The minimum vine length (at final harvest), number of leaves and number of primary branches were manifested by DS6 + BS.

Incidence of viral diseases (%)

Irrespective of sowing time, mulching significantly ($P < 0.001$) reduced the incidence of viral diseases during both years (Tables 1 and 2). The minimum incidence was recorded using SBPM followed by BPM, PSM and BS during both years. On the basis of data pooled over the years (Table 3), the SBPM, BPM and PSM decreased the incidence of viral diseases over BS by 73.8, 68.4, and 53.4%, respectively.

Irrespective of mulch, the incidence of viral diseases was significantly ($P < 0.001$) affected by the sowing time during both years (Tables 1 and 2). The lowest incidence was recorded in DS1 during both years and it exhibited an increasing trend with each successive sowing date. However, the highest incidence was observed in DS5 during both years.

The interaction effects (sowing time × mulch) were significant ($P < 0.001$) for the incidence of viral diseases during both years

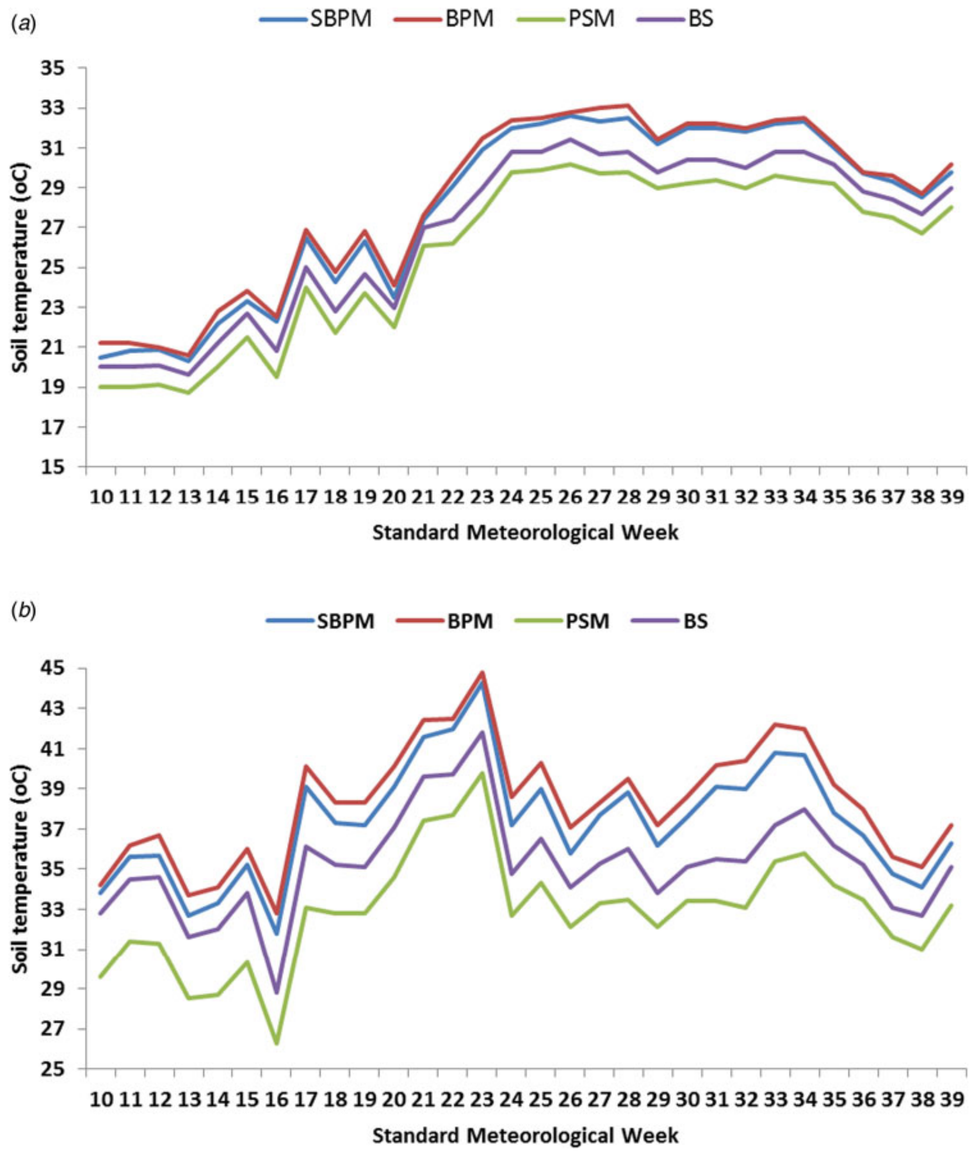

Figure 1. Effects of mulching on weekly soil temperature (°C) (at 5 cm depth) recorded in the morning (08.30 h) (a); and in the afternoon (14.00 h) (b) during the crop season (March to early-October 2021) at Punjab Agricultural University, Regional Research Station, Jodhpur Romana Farm, Bathinda, India. SBPM, BPM, PSM and BS stand for silver-black plastic mulch (25 μm thick), black plastic mulch (25 μm thick), paddy straw mulch (6 t/ha) and bare soil, respectively.

(Tables 1 and 2). On the basis of pooled data (Table 4), the minimum incidence was recorded in DS1 + SBPM, which was at par with DS1 + BPM, DS2 + SBPM, DS2 + BPM and DS3 + SBPM. The maximum viral disease incidence was observed in DS5 + BS.

Earliness

Irrespective of sowing time, the application of different mulches induced significant differences ($P < 0.001$) in the early yield of round gourd during both years (Tables 1 and 2). The highest early yield was produced with SBPM, followed by BPM, PSM and BS. On the basis of pooled data (Table 3), the SBPM, BPM and PSM enhanced the early yield over BS by 192.8, 134.6 and 26.5%, respectively.

Irrespective of mulching, the sowing date resulted in significant differences ($P < 0.001$) in early yield during both years (Tables 1 and 2). The highest early yield was observed in DS2 during both years. It was significantly higher compared with DS3 and DS1 during 2021 (Table 1), but was at par with DS1 during 2022 (Table 2). The lowest early yield was recorded in DS5 during both years.

The interaction effects (sowing time × mulch) were significant ($P < 0.001$) for early yield during both years (Tables 1 and 2). On the basis of pooled data (Table 4), the highest early yield was observed in DS2 + SBPM, which was at par with DS1 + SBPM. On the other hand, the lowest early yield was recorded in DS5 + BPM, which was at par with DS6 + BS, DS5 + BS, DS5 + PSM, DS4 + BS, DS5 + SBPM, DS6 + PSM and DS4 + PSM.

Fruit yield and yield components

Irrespective of the sowing time, mulching significantly ($P < 0.001$) affected the fruit yield and yield components of round gourd during both years (Tables 1 and 2). The maximum fruit yield and yield components (fruit number, fruit weight and harvest duration) were recorded using SBPM, which was superior to BPM, PSM and BS during both years. However, the SBPM performed

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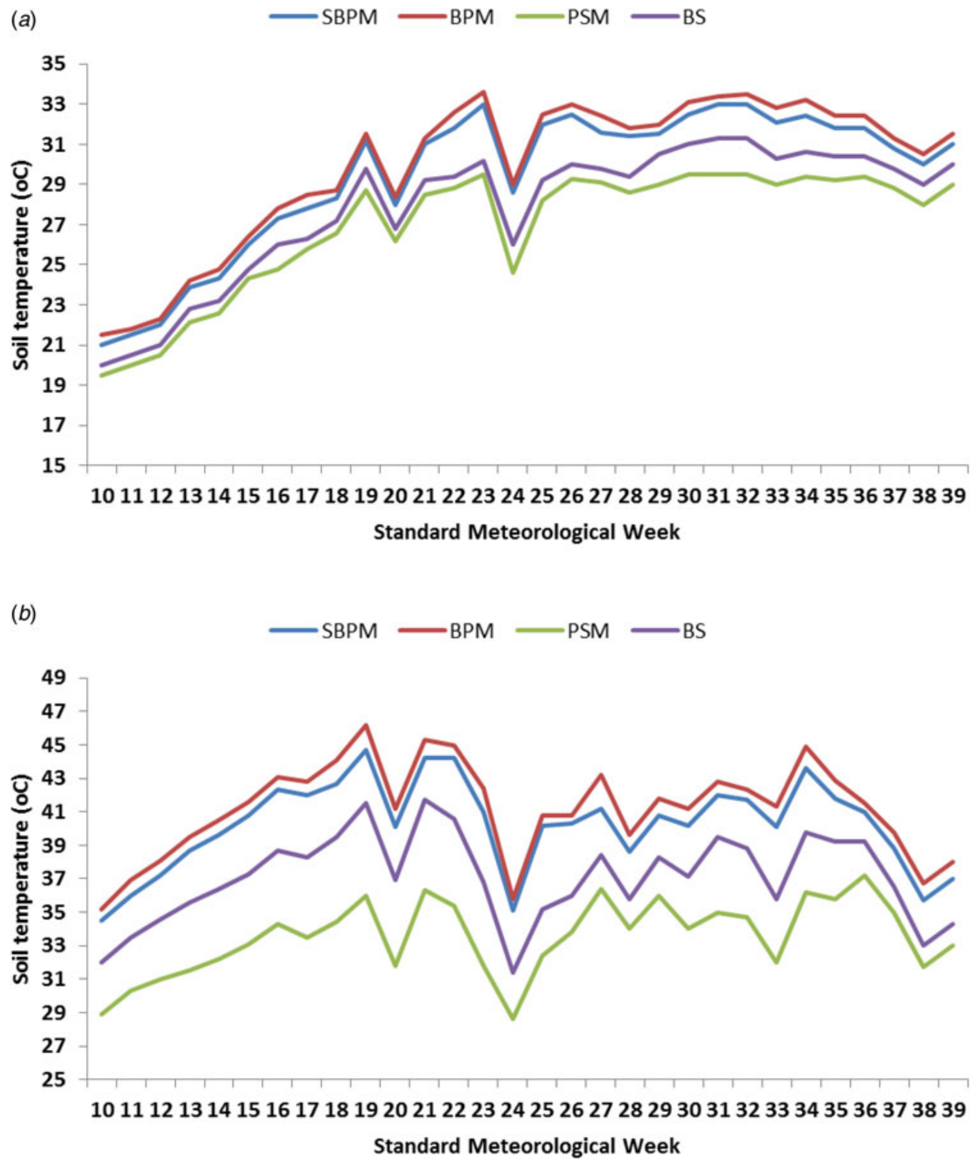

Figure 2. Effects of mulching on weekly soil temperature (°C) (at 5 cm depth) recorded in the morning (08.30 h) (a); and in the afternoon (14 00 h) (b) during the crop season (March to early-October 2022) at Punjab Agricultural University, Regional Research Station, Jodhpur Romana Farm, Bathinda, India. SBPM, BPM, PSM and BS stand for silver-black plastic mulch (25 μm thick), black plastic mulch (25 μm thick), paddy straw mulch (6 t/ha) and bare soil, respectively.

at par with BPM in respect of fruit weight during 2021 (Table 1), and fruit number and harvest duration during 2022 (Table 2). On the basis of pooled data (Table 3), the SBPM increased the fruit number over BS by 74.4%, fruit weight by 12.8%, harvest duration by 26.7% and fruit yield by 88.6%. The BPM ranked second to SBPM, and it improved the fruit number over BS by 59.5%, harvest duration by 21.9%, and fruit yield by 63.2%. However, the BPM registered fruit weight at par with BS in 2022 (Table 2), but it increased the same by 11.9% over BS in 2021 (Table 1). The PSM ranked third in performance after SBPM and BPM. But it was at par with BS in respect of fruit weight during both years, and with respect to fruit number, harvest duration and fruit yield during 2021 (Table 1). However, the PSM increased the fruit number over BS by 18.9%, harvest duration by 12.7% and fruit yield by 26.1% during 2022 (Table 2).

Irrespective of mulch, the sowing time exhibited significant differences ($P < 0.001$) in fruit yield and yield components (fruit number, fruit weight and harvest duration) of round gourd during both years (Tables 1 and 2). The highest values of these four traits were observed in DS1 during 2021 and in DS2 during 2022. However, DS1 recorded fruit weight at par with DS2 during 2022 (Table 2) and for pooled data (Table 3). The minimum fruit number, harvest duration and fruit yield were recorded in DS5 during both years, and the values were significantly lower compared with other sowing dates. However, the fruit yield in DS6 was at par with DS5 during 2022 (Table 2). The lowest fruit weight was manifested in DS6, whereas the fruit weight in DS3 and DS4 was statistically at par during both years. Besides, the fruit number in DS4 and DS6 was statistically at par during both years.

The interaction effects (sowing time × mulch) for pooled data (Table 4) revealed that the highest fruit number, and yield were recorded in DS2 + SBPM, which was at par with DS1 + SBPM. The harvest duration was the maximum in DS1 + SBPM,

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Table 1. Effects of sowing date and mulching on plant growth, earliness, viral diseases, fruit yield and yield components of round gourd in 2021

Sowing date (DS)	Vine length at 45 DAS[3] (cm)	Vine length at final harvest (cm)	Number of leaves per plant	Number of primary branches	Incidence of viral diseases (%)	Early yield (t/ha)	Fruit number per vine	Fruit weight (g)	Harvest duration (days)	Yield (t/ha)
DS1[1]	69.8 c	304.6 a	429.6 b	3.93 a	4.6 f	2.54 c	9.08 a	71.3 a	47.4 a	13.88 a
DS2	125.8 a	263.0 b	352.5 d	4.13 a	6.7 e	3.48 a	8.25 b	65.1 b	33.8 b	11.36 b
DS3	129.1 a	183.3 c	367.3 c	3.87 a	10.4 d	3.09 b	5.07 c	46.6 c	32.8 b	5.05 c
DS4	123.8 a	156.6 d	441.1 a	4.08 a	16.7 c	1.29 d	3.04 d	45.2 c	24.9 c	2.94 d
DS5	127.1 a	134.8 e	208.5 e	2.83 b	37.5 a	0.44 f	1.30 e	34.5 d	12.9 e	0.94 f
DS6	115.6 b	129.4 e	158.2 f	2.59 b	31.3 b	0.93 e	2.77 d	28.3 e	21.7 d	1.73 e
Mulching (M)										
SBPM[2]	137.4 d	215.0 f	407.6 g	3.90 c	8.9 j	2.99 g	6.39 f	52.5 f	32.2 f	8.09 g
BPM	122.1 e	200.9 g	365.4 h	3.84 c	10.8 i	2.48 h	5.57 g	50.6 f	30.9 g	6.94 h
PSM	108.3 f	183.3 h	284.1 i	3.17 d	15.8 h	1.31 i	4.03 h	45.7 g	26.8 h	4.55 i
BS	93.0 g	181.9 h	247.7 j	3.37 d	35.8 g	1.06 j	3.68 h	45.2 g	25.8 h	4.35 i
P values										
DS	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
M	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
DS × M	<0.001	<0.001	<0.001	0.011	<0.001	<0.001	<0.001	0.055	<0.001	<0.001

[1]DS1, DS2, DS3, DS4, DS5 and DS6 stand for first week of March, April, May, June, July and August, respectively. [2] SBPM, BPM, PSM and BS stand for silver-black plastic mulch (25 µm thick), black plastic mulch (25 µm thick), paddy straw mulch (6 t/ha) and bare soil, respectively. [3]DAS stand for days after sowing. Means in a column with no letter in common are significantly different by Fisher's LSD test.

Table 2. Effects of sowing date and mulching on plant growth, earliness, viral diseases, fruit yield and yield components of round gourd in 2022

Sowing date (DS)	Vine length at 45 DAS[3] (cm)	Vine length at final harvest (cm)	Number of leaves per plant	Number of primary branches	Incidence of viral diseases (%)	Early yield (t/ha)	Fruit number per vine	Fruit weight (g)	Harvest duration (days)	Yield (t/ha)
DS1[1]	91.8 c	231.4 b	350.3 b	3.00 c	7.1 f	2.65 a	9.70 b	58.8 a	36.8 b	12.01 b
DS2	130.6 a	263.8 a	486.7 a	3.53 a	9.2 e	2.78 a	12.29 a	58.9 a	44.3 a	15.23 a
DS3	134.1 a	189.5 c	303.4 c	3.21 b	13.8 d	2.44 b	3.90 c	51.8 b	25.9 c	4.12 c
DS4	114.0 b	130.1 d	340.1 b	2.84 d	20.0 c	1.11 c	2.39 d	50.6 b	20.5 d	2.60 d
DS5	114.2 b	123.7 d	153.7 d	2.36 f	41.7 a	0.25 e	0.81 e	37.1 c	9.6 f	0.68 e
DS6	92.9 c	101.1 e	103.2 e	2.53 e	35.0 b	0.58 d	2.09 d	28.5 d	16.3 e	1.28 e
Mulching (M)										
SBPM[2]	131.4 d	191.2 f	369.2 f	3.21 g	11.1 j	2.58 f	6.49 f	50.3 e	28.3 g	7.84 f
BPM	120.3 e	174.6 g	315.1 g	3.02 h	13.3 i	2.00 g	6.15 f	45.8 f	27.3 g	6.84 g
PSM	107.6 f	172.4 g	257.0 h	2.76 i	19.7 h	1.10 h	4.42 g	48.3 ef	24.8 h	5.17 h
BS	92.4 g	154.9 h	216.9 i	2.64 i	40.3 g	0.85 i	3.72 h	46.0 f	22.0 i	4.10 i
P values										
DS	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
M	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.001	<0.001
DS × M	0.001	0.003	<0.001	0.016	<0.001	<0.001	<0.001	0.001	<0.001	<0.001

[1]DS1, DS2, DS3, DS4, DS5 and DS6 stand for first week of March, April, May, June, July and August, respectively. [2] SBPM, BPM, PSM and BS stand for silver-black plastic mulch (25 µm thick), black plastic mulch (25 µm thick), paddy straw mulch (6 t/ha) and bare soil, respectively. [3]DAS stand for days after sowing. Means in a column with no letter in common are significantly different by Fisher's LSD test.

which was at par with DS1 + BPM, and DS2 + SBPM. On the contrary, the lowest fruit number, and yield were observed in DS5 + BS.

The interaction effects also revealed that various mulches improved the fruit yield and yield components of round gourd by a variable degree in different sowing times. Based on pooled

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Table 3. Effects of sowing date and mulching on plant growth, earliness, viral diseases, fruit yield and yield components of round gourd for data pooled over 2021 and 2022

Sowing date (DS)	Vine length at 45 DAS[3] (cm)	Vine length at final harvest (cm)	Number of leaves per plant	Number of primary branches	Incidence of viral diseases (%)	Early yield (t/ha)	Fruit number per vine	Fruit weight (g)	Harvest duration (days)	Yield (t/ha)
DS1[1]	80.8 d	268.0 a	390.0 b	3.46 b	5.8 f	2.60 c	9.39 b	65.0 a	42.1 a	12.95 b
DS2	128.2 a	263.4 a	419.6 a	3.83 a	7.9 e	3.13 a	10.27 a	62.0 a	39.1 b	13.30 a
DS3	131.6 a	186.4 b	335.3 c	3.54 b	12.1 d	2.77 b	4.49 c	49.2 b	29.4 c	4.58 c
DS4	118.9 b	143.3 c	390.6 b	3.46 b	18.3 c	1.20 d	2.72 d	47.9 b	22.7 d	2.77 d
DS5	120.7 b	129.3 d	181.1 d	2.59 c	39.6 a	0.34 f	1.06 e	35.8 c	11.3 f	0.81 f
DS6	104.2 c	115.2 e	130.7 e	2.56 c	33.1 b	0.75 e	2.43 d	28.4 d	19.0 e	1.50 e
Mulching (M)										
SBPM[2]	134.4 e	203.1 f	388.4 f	3.56 d	10.0 j	2.79 g	6.44 f	51.4 e	30.3 g	7.96 g
BPM	121.2 f	187.7 g	340.3 g	3.43 d	12.1 i	2.24 h	5.86 f	48.2 f	29.1 g	6.89 h
PSM	107.9 g	177.9 gh	270.6 h	2.97 e	17.8 h	1.20 i	4.23 g	47.0 f	25.8 h	4.86 i
BS	92.7 h	168.4 h	232.3 i	3.01 e	38.1 g	0.96 j	3.70 g	45.6 f	23.9 h	4.22 j
P values										
DS	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
M	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001
DS × M	0.001	0.847	<0.001	0.568	<0.001	<0.001	0.002	0.120	0.753	<0.001

[1]DS1, DS2, DS3, DS4, DS5 and DS6 stand for first week of March, April, May, June, July and August, respectively. [2] SBPM, BPM, PSM and BS stand for silver-black plastic mulch (25 μm thick), black plastic mulch (25 μm thick), paddy straw mulch (6 t/ha) and bare soil, respectively. [3]DAS stand for days after sowing. Means in a column with no letter in common are significantly different by Fisher's LSD test.

data (Table 4), the SBPM enhanced the fruit yield over BS by 324.1% in DS6, 161.5% in DS5, 155.8% in DS3, 97.8% in DS4, 78.1% in DS2 and 63.5% in DS1. Similarly, the BPM increased the fruit yield over BS by 313.0% in DS6, 114.0% in DS3, 72.9% in DS4, 57.1% in DS2 and 43.4% in DS1. Likewise, the PSM improved the fruit yield of round gourd over BS by 77.8% in DS6, 51.9% in DS5, 40.7% in DS3, 27.6% in DS4 and 15.4% in DS2.

Discussion

The plastic mulches increased the morning and afternoon soil temperatures over bare soil. The BPM caused more remarkable changes in the morning (1.5–2.1°C) and afternoon (3.1–4.1°C) soil temperatures compared with SBPM (1.2–1.6°C in the morning and 2.1–3.1°C in the afternoon). This difference in temperature modification was observed as the degree of soil warming is considered to be inversely correlated with the light reflected by the coloured plastic mulches. The BPM is reported to have the lowest light reflectance (10% photosynthetically active radiation [PAR]) (Diaz-Perez and Batal, 2002). In other words, it absorbs most of the incident solar radiation and transmits to the earth's surface by conductance (Kumar and Dey, 2011). On the other hand, SBPM is reported to reflect a considerable portion (about 55% PAR) of the solar radiation, primarily infrared radiation, thereby raising the soil temperature by a lower magnitude than BPM. Also, the broader differences in soil temperatures of these two plastic mulches during the afternoon compared with the morning hours were due to greater incident solar radiation at 1400 h than at 0830 h or, in other words, were positively correlated with air temperature. Mendonca *et al.* (2021) have also reported a higher increase in soil temperature (at 5 cm depth) with BPM (2.16 and 2.37°C) compared with silver plastic mulch (1.95 and 1.37°C) over BS at 0700 and 1400 h, respectively, in tomato grown in the fall-winter season in Brazil.

On the contrary, the PSM decreased the morning (0.9–1.1°C) and afternoon (2.3–3.5°C) soil temperature (at 5 cm depth) over BS. The PSM did not allow the solar radiation to reach the earth's surface, thereby reducing the soil temperature compared with BS, which was warmed by the incident solar radiation. Here also, the differences were wider in the afternoon compared with the morning hours, as these differences were directly proportional to incident solar radiation. Mendonca *et al.* (2021) have reported 3.06°C and 3.40°C reduction in soil temperature (at 5 cm depth) at 1400 h with rice straw mulch over BS in tomato grown in fall–winter and spring–summer seasons, respectively, in Brazil.

Among mulches, SBPM showed the best plant growth attributes of round gourd, followed by BPM and PSM in all sowing dates. Irrespective of sowing time, among four plant growth traits studied, the per cent improvement over BS was the highest in number of leaves (16.5–67.2%), followed by vine length (at 45 DAS) (16.4–44.9%), vine length (at final harvest) (5.6–20.6%) and number of primary branches (3.0–3.6%). The increase (%) in vine length with plastic mulching was higher at 45 DAS than that at final harvest. This differential increment suggested the role of plastic mulching in giving a high initial impetus to plant growth and development. The improvement in plant growth attributes of round gourd with plastic mulching could be primarily due to an increase in soil temperature, which influences various physiological processes in roots, such as water and nutrient uptake (Diaz-Perez and Batal, 2002; Diaz-Perez, 2009). The other reasons could be weed control, soil moisture conservation, improved soil microbial activity and reduced nitrate leaching with plastic

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Table 4. Interaction effects (sowing date × mulching) on plant growth, earliness, viral diseases, fruit yield and yield components of round gourd for data pooled over 2021 and 2022

Treatment (sowing date + mulching)	Vine length at 45 DAS[3] (cm)	Vine length at final harvest (cm)	Number of leaves per plant	Number of primary branches	Incidence of viral diseases (%)	Early yield (t/ha)	Fruit number per vine	Fruit weight (g)	Harvest duration (days)	Yield (t/ha)
DS1[1] + SBPM[2]	102.6 fgh	293.9 a	527.8 ab	3.80 abc	2.5 m	4.43 a	11.96 a	66.7 a	46.8 a	16.68 ab
DS1 + BPM	94.5 gh	264.5 b	424.9 cd	3.55 abcde	4.2 lm	3.48 cd	10.40 b	67.5 a	45.0 ab	14.63 c
DS1 + PSM	65.2 jk	262.4 b	315.5 fg	3.27 cdef	6.7 jkl	1.28 hij	7.76 c	61.6 ab	38.5 cd	10.27 d
DS1 + BS	61.0 k	251.1 b	291.6 fg	3.22 cdefg	10.0 hij	1.20 ij	7.45 cd	64.4 ab	38.2 cd	10.20 d
DS2 + SBPM	143.2 b	273.9 ab	541.3 a	3.86 ab	4.2 lm	4.66 a	12.28 a	67.4 a	41.7 abc	17.20 a
DS2 + BPM	131.5 bc	263.0 b	471.2 bc	3.97 a	5.8 klm	3.92 b	11.82 ab	62.9 ab	40.8 bcd	15.18 bc
DS2 + PSM	122.5 cde	270.7 ab	357.8 ef	3.77 abcd	8.3 ijk	2.06 ef	8.75 c	60.3 abc	37.5 cd	11.15 d
DS2 + BS	115.6 def	246.1 b	308.1 fg	3.74 abcd	13.3 gh	1.88 fg	8.25 c	57.4 bcd	36.3 de	9.66 d
DS3 + SBPM	158.2 a	210.2 c	438.4 c	3.97 a	5.8 klm	3.86 bc	6.08 de	51.8 defg	32.0 ef	6.60 e
DS3 + BPM	136.3 bc	198.9 cd	420.7 cde	3.98 a	7.5 jkl	3.20 d	5.88 e	44.6 ghi	31.0 fg	5.52 e
DS3 + PSM	124.2 cd	164.3 e	284.5 gh	3.18 defg	11.7 hi	2.39 e	3.40 f	52.0 def	29.2 fgh	3.63 f
DS3 + BS	107.7 efg	172.2 de	197.7 ij	3.02 efgh	23.3 e	1.62 gh	2.60 fghi	48.2 efgh	25.3 hij	2.58 fgh
DS4 + SBPM	146.0 ab	161.4 ef	427.3 cd	3.87 a	10.0 hij	2.17 ef	3.20 fgh	53.6 cde	25.8 ghi	3.66 f
DS4 + BPM	135.4 bc	151.5 efgh	414.7 cde	3.59 abcde	11.7 hi	1.55 ghi	3.05 fgh	48.1 efgh	25.2 hij	3.20 fg
DS4 + PSM	115.4 def	134.9 fghi	371.2 def	3.08 efgh	16.7 fg	0.60 k	2.63 fghi	43.9 hij	20.5 jkl	2.36 fghi
DS4 + BS	78.9 ij	125.5 hij	349.0 fg	3.27 bcdef	35.0 c	0.48 k	1.98 fghij	46.0 fgh	19.3 klm	1.85 ghijk
DS5 + SBPM	144.6 ab	153.5 efg	226.1 hi	2.78 fghi	20.0 ef	0.49 k	1.73 hij	37.3 jk	13.3 nop	1.36 hijk
DS5 + BPM	124.2 cd	130.2 ghi	161.9 ijk	2.59 hij	23.3 e	0.24 k	0.78 j	32.6 kl	9.8 op	0.57 k
DS5 + PSM	111.5 def	119.2 ij	176.7 ijk	2.35 ij	34.2 c	0.33 k	1.00 j	38.2 ijk	12.5 nop	0.79 jk
DS5 + BS	102.3 fgh	114.2 ij	159.6 jk	2.65 ghij	80.8 a	0.29 k	0.73 j	35.1 k	9.3 p	0.52 k
DS6 + SBPM	112.1 def	125.7 ghij	169.4 ijk	3.02 efgh	17.5 f	1.11 j	3.40 f	31.8 kl	21.8 ijk	2.29 fghij
DS6 + BPM	105.3 fgh	118.2 ij	148.1 jkl	2.90 fghi	20.0 ef	1.06 j	3.27 fg	33.4 k	22.7 ijk	2.23 fghij
DS6 + PSM	108.8 efg	115.7 ij	117.6 kl	2.17 j	29.2 d	0.55 k	1.85 ghij	26.1 lm	16.5 lmn	0.96 ijk
DS6 + BS	90.7 hi	101.4 j	87.8 l	2.13 j	65.8 b	0.28 k	1.22 ij	22.3 m	15.0 mno	0.54 k

[1]DS1, DS2, DS3, DS4, DS5 and DS6 stand for first week of March, April, May, June, July and August, respectively. [2] SBPM, BPM, PSM and BS stand for silver-black plastic mulch (25 µm thick), black plastic mulch (25 µm thick), paddy straw mulch (6 t/ha) and bare soil, respectively. [3]DAS stand for days after sowing. Means in a column with no letter in common are significantly different by Fisher's LSD test.

mulching. The better performance of SBPM over BPM may be attributed to the increased photosynthetic activity of plants with the former, as the radiations reflected by the SBPM fall in PAR, thereby improving plant growth and morphogenesis (Diaz-Perez and Batal, 2002). While working on squash melon in Rajasthan, India, Birbal *et al.* (2019) have also recorded 56.0 and 33.5% increase in vine length with PSM and BPM, respectively, over BS. Mulches have also been reported to increase the number of leaves in sponge gourd (Khan *et al.*, 2015), and cucumber (Soleymani *et al.*, 2015).

The improvement in plant growth attributes of round gourd with PSM was lower compared with plastic mulching in all sowing dates. It could be due to the lowering of soil temperature with PSM over BS. Although PSM helped in controlling weeds and conserving soil moisture, but it appeared that an increase in soil temperature and the radiations reflected by plastic mulches played a more critical role in improving the plant growth attributes of round gourd. While working on okra in Nigeria, Adekiya *et al.* (2017) have reported significant increases in plant height (117.6 and 73.7%) and number of leaves (53.3 and 50.0%) over BS, with the use of grass mulches in dry and wet seasons, respectively.

All three mulches significantly reduced the incidence of viral diseases over BS in all six sowing dates. The maximum decrease in disease incidence was exhibited by SBPM, followed by BPM and PSM. The reduction in viral disease incidence could be due to the reason that plastic mulches act as a repellent for the vector (whitefly) due to modification of the light environment around the plant. However, as PSM also reduced the incidence of viral diseases over BS, modification in soil temperature, which in turn affected the plant's response to viral disease, may be the other reason for the reduction in disease incidence (Diaz-Perez *et al.*, 2007). While working on late-season cantaloupe, Stapleton and Summers (2002) have reported that the number of aphids on leaves of plants on plastic film mulch was consistently lower than on plants growing over BS. Furthermore, the start of appearance of viral disease symptoms was delayed by 3–6 weeks in mulched plants, which was crucial for normal flowering and fruiting.

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All three mulches significantly enhanced the early yield of round gourd over BS. Irrespective of sowing time and based on pooled data, the highest increment (192.8%) was registered by SBPM, followed by BPM (134.6%), while PSM recorded the lowest increase over BS (26.5%). The increase in early yield with mulching could be attributed to an increase in the rate of plant growth and development (faster vegetative growth, early flowering and early fruit set) due to modification in soil temperature. Ibarra *et al.* (2001) have observed 266% higher early yield of muskmelon grown in Mexico with BPM compared with the control and attributed it to soil-accumulated heat. Wortman *et al.* (2016) have also observed early fruit set in cucumber with SBPM, and attributed it to higher uptake and better absorption of nutrients.

Both the plastic mulches significantly increased the fruit yield and yield contributing traits (fruit number, fruit weight and harvest duration) of round gourd over BS during both years except for BPM with respect to fruit weight during 2022. On the contrary, PSM caused a significant increase in fruit yield, fruit number and harvest duration over BS only during 2022, which was a comparatively hot year compared with 2021. It implied that the soil temperature-lowering effect of PSM proved useful in the second year as it protected the round gourd plants from high-temperature stress. During these two years, the maximum improvement in fruit yield and yield components was exhibited by SBPM, followed by BPM and PSM, in all six sowing times except in DS5, in which PSM proved superior to BPM. Irrespective of sowing time, among these four yield related traits, the maximum per cent improvement over BS was recorded in fruit yield (15.2–88.6%) followed by fruit number (13.5–73.0%) and harvest duration (8.0–26.8%), whereas fruit weight exhibited the lowest increment (3.1–12.7%). Extension in harvest duration with mulching may be the reason behind the increased fruit number. Whereas the improvement in fruit yield of round gourd with mulching was considered to be due to increased fruit number, fruit weight and early yield as these three traits have been reported to be positively correlated with the fruit yield of round gourd (Garg, 2019). Birbal *et al.* (2019) have also observed increases in fruit yield (26.4 and 48.8%), fruit number (17.6 and 37.0%) and fruit weight (7.9 and 13.9%) of round gourd grown at Bikaner, India, with BPM and straw mulching, respectively, over BS. Singh *et al.* (2017) have reported that the harvest duration of tomato was maximum with double-shaded plastic mulch (85.6 days) that was statistically at par with BPM (83.8 days), but significantly higher than with straw mulch (79.8 days) and BS (78.2 days).

In DS5, the fruit yield and its contributing traits with BPM were similar to those of the control and inferior to those with PSM. It revealed that plants faced high-temperature stress in DS5 due to an increase in soil temperature with BPM, leading to less-than-expected fruit yield. However, the cooling effect of PSM saved plants from heat stress in DS5, thereby improving yield and its contributing traits.

Among the six sowing times, DS1 (first fortnight of March) in 2021, and DS2 (first fortnight of April) in 2022 proved to be the best sowing times of round gourd because of superior crop performance with respect to most of the traits. The crop performance declined with each successive sowing date. However, crops sown in the first fortnight of August (DS6) performed better than that sown in the first fortnight of July (DS5) during both years. The probable reason was that round gourd is a short-duration (80–90 days) crop, which performs best in hot and dry weather (March–June), but its performance declines in hot and humid weather (July–August). In the first two sowing dates (DS1 and DS2), crop growth phases were completed before the onset of humid weather (monsoon rains). However in the other sowing dates (DS3–DS6), crop growth phases occurred in July and August, leading to their comparatively poor performance.

The round gourd crop sown at the optimum time (DS1 and DS2) showed improved growth attributes because it provided the plants with a longer growing period before the onset of adverse environmental conditions, such as high-temperature stress or disease pressure. This extended growth phase helped the plants establish a more robust root system, which enhanced their water and nutrient uptake, leading to vigorous plant growth and development. The increased leaf area captured more sunlight and converted it into energy, leading to better plant growth, and potentially high fruit yield. On the contrary, late-sown round gourd crop faced comparatively less favourable growing conditions, which hampered leaf development. Insufficient leaf area limited the plant's ability to photosynthesize and produce energy, potentially affecting plant growth and yield (Aniekwe and Anike, 2015). Khan *et al.* (2001) also studied the effect of six sowing dates (28 February, 10 March, 20 March, 30 March, 9 April and 19 April) on plant growth and fruit yield of round gourd at Dera Ismail Khan, Pakistan, and reported that early sowing (28 February) yielded higher than late sowing (19 April). The maximum fruit yield was recorded in 30 March sowing, which was at par with 10 March and 20 March sowings.

The DS1 recorded the lowest vine length (at 45 DAS) during both years due to below-optimum air temperatures up to mid-April. Whereas DS3 and DS2 manifested the highest vine length (at 45 DAS) which DS5 and DS4, closely followed. The probable reason for the increase in vine length during late-season sowings was high air temperature as reported by Papadopoulos and Hao (2000) in cucurbits.

During both years, the viral disease incidence was the lowest in DS1, but it progressed with each successive sowing date, except that it was significantly lower in DS6 compared with DS5. Whitefly, a vector of *begomovirus* diseases in cucurbits, has a high infestation in South-Western Punjab, India, during July to September, due to a considerable area under *Bt*-cotton hybrids, coupled with warm and humid weather. Therefore, viral disease incidence was high in late-sown crop of round gourd compared with early-sown crop. Secondly, late-sown crop often faces adverse climatic conditions such as high air temperature, which increase the rate of systemic movement, and decrease the time for the first appearance of viral disease symptoms (Diaz-Perez *et al.*, 2007). Early-planting of tomato in spring season lead to a comparatively lower incidence of tomato spotted wilt virus compared with late-season planting (Riley and Pappu, 2000).

The interaction effects revealed that the best plant growth attributes, earliness, fruit yield, and yield components of round gourd, along with low viral disease incidence were achieved with DS2 + SBPM, DS1 + SBPM, DS2 + BPM and DS1 + BPM. In other words, utilization of SBPM or BPM in the cultivation of round gourd in DS1 or DS2 improved earliness, growth, fruit yield and reduced the incidence of viral diseases. However, the improvement in various traits with these mulches (over BS) was enhanced in challenging environments or in late-season sowings (DS3 through DS6) than in more favourable environments (DS1 and DS2). However, in DS4 through DS6, the absolute values of fruit yield and yield components were too low to be adopted by the growers, even with mulching. Nevertheless, sowing of round gourd in DS3 (first week of May) along with utilization of

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SBPM may also be recommended for the farmers of South-Western Indian Punjab, in which 70–80 days gap exists between the harvesting of wheat (mid-April), and the transplanting of paddy (mid-July). Round gourd may become a profitable option even with a moderate fruit yield as high prices in late sowings may compensate for the low fruit yield. Additionally, round gourd cultivation may provide a new crop in the lean period.

Conclusion

In North Indian plains, it is advised to sow round gourd in early-March to early-April using silver-black or black plastic mulch for improving earliness, growth and fruit yield attributes, and lowering viral disease incidence. Moreover, the silver-black plastic mulch proved beneficial in extending the crop sowing time to first week of May so as to exploit the 70–80 days gap between wheat harvesting and paddy transplanting.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0021859624000406

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