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Research Article

Impact of In-Situ Moisture Conservation Techniques on Yield in a Pomegranate Orchard

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ABSTRACT

In-situ soil moisture conservation involves capturing rain and retaining it in soil for plant utilization which can result in better growth ultimately leading to enhanced biomass yields. Soil and Water Conservation Research Institute in Chakwal, conducted this research spread over the span of three years (2019-2021) with a focus on evaluating the effectiveness of in-situ moisture conservation techniques in a pomegranate orchard. The experiment was designed using a Randomized Complete Block Design and aimed at assessing the impact of various treatments on soil moisture content and fruit yield. The study revealed significant improvements in mean soil moisture content, with the maximum increase observed in the treatment involving the application of black sheet combined with gypsum (55% higher than the control). Additionally, the use of grass mulch with gypsum application showed a notable increase of 43% over the control. Fruit yield, a crucial parameter in orchard productivity, showed highest values in the treatment utilizing black sheet with gypsum application, resulting in a remarkable 50% increase compared to the control. Similarly, the control treatment revealed the lowest fruit yield at 16 fruits per plant. The in-situ soil moisture conservation technologies were considered suitable for Barani area conditions. The experimental findings reveal the potential of in-situ moisture conservation techniques in optimizing soil moisture levels and enhancing pomegranate fruit yield. The study provides valuable insights into sustainable agricultural practices, demonstrating the practical benefits of incorporating moisture conservation strategies for improved orchard management, economics and productivity. The in-situ soil moisture technologies have potential to increase orchards crop productivity and are viable for greater farmer adoption. It is recommended that these technologies be verified further by scientists and farmers through participatory approaches for wider promotion and adoption.

Keywords: In-Situ, Soil Moisture Conservation, Barani Area, Rainfed, Gypsum.

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INTRODUCTION

Water management is crucial to the success of pomegranate orchards, as the crop's growth and fruit quality are highly sensitive to water availability, particularly during the flowering, fruiting, and ripening phases. Pomegranates have a deep taproot system, which allows them to access groundwater during dry spells, making them more drought-tolerant compared to other fruit crops. However, the plant's water requirements are not uniform across the growing season, and water stress at any of the key growth stages can have a significant negative impact on yield.

Pomegranate (*Punica granatum* L.) is a member of family punicaceae and is native to Afghanistan, Baluchistan and Persia (Iran). It has wider consumer preference owing to its juicy, attractive, refreshing arils and semi acidic nature.

Owing to its rich bioactive compounds content, polyphenols, carbohydrates, minerals and organic acids etc it is widely regarded as functional food for prime interest (Singh et al., 2018). The production of nutritious fruits in optimum quantity is essential for addressing the malnutrition and hunger problems across the globe (Adak et al., 2020). The goal of food security i-e feeding future population on sustainable basis cannot be solely addressed through enhancing productivity of water within the current land use system as the land available is limited (Ranjan et al., 2017).

In-situ moisture conservation refers to the practices and techniques that aim to capture, store, and efficiently utilize water within the soil without external irrigation inputs. These techniques are particularly beneficial in arid and semi-arid regions, where rainfall is irregular and water resources are scarce. Mulching is one of the simplest and most cost-effective methods of in-situ moisture conservation and has been extensively studied for its benefits in various crops, including pomegranates (Jain et al., 2021; Yadaw et al., 2020).The rainfed agriculture comprises of 80 % of world lands and is vital for ensuring food security (Li et al., 2018; Li et al., 2013). However the scarcity caused through high temperature, unpredictable and uncertain rainfall limit crop yield in arid and semiarid region (Qin et al., 2015). Dry Land farming needs efficient use of available water resources and implementation of conservation techniques (Qin et al., 2013). The pomegranate plants experience stress conditions owing to moisture deficiency under rainfed conditions which leads to fruit cracking (Sahu et al., 2013). It is one of most historic fruits and considered as sign of fertility (Sahu and Sharma, 2019). Researchers over the years have found out that practice like tree basin mulching, crescent bund have been found beneficial for moisture conservation (Sharma et al., 2017). Pomegranate (*Punica granatum* L.) plants owing to their xeromorphic characteristics like increased leaf apoplastic water content, mechanism to counter stress through avoidance and tolerance make them a good choice to grow in semi-arid areas (Aseri et al., 2008; Galindo et al., 2017). However in order to get optimal growth, yield and commercial fruit quality the crop requires regular irrigation or water supply during growing season especially under dry conditions (Galindo et al., 2017). Similar finding were also observed by Ngente et al. (2021) in strawberry which illustrated that black polythene mulch not only suppress weed but also increased nutrient uptake by the plant.

In this study, three treatments involving different types of mulching materials Grass Mulch with Gypsum, Black Sheet Mulch with Gypsum, and White Sheet Mulch with Gypsum are evaluated for their effectiveness in conserving moisture and improving the yield of pomegranate orchards. The treatments are expected to influence several factors, including water retention in the soil, nutrient availability, and overall plant health.

The use of mulching techniques to conserve moisture and improve crop yield has been widely documented for various horticultural crops. Several studies have shown that mulching can significantly improve soil moisture retention, reduce irrigation requirements, and increase crop yield (Jain et al., 2021; Kumar et al., 2022). In particular, black plastic mulch has been shown to be highly effective in enhancing yield in crops such as tomatoes, cucumbers, and peppers by promoting early growth, reducing weed competition, and improving water use efficiency (Sharma et al., 2020).

For pomegranates, the impact of mulching and gypsum application on yield and water conservation has also been explored, albeit to a lesser extent. Reddy et al. (2021)investigated the effect of organic mulching and gypsum on pomegranate productivity and found that these techniques resulted in improved water retention, enhanced fruit size, and increased yield. Similarly, Yadaw et al. (2020) demonstrated that black plastic mulch could significantly enhance water use efficiency and fruit quality in pomegranate orchards. However, there remains a need for more comprehensive studies comparing different types of mulching materials—such as grass, black plastic, and white plastic—in combination with gypsum, especially in regions facing water scarcity.

Despite the promising results of individual techniques, the combined effect of grass mulch, black plastic sheet mulch, and white plastic sheet mulch with gypsum on pomegranate yield remains under-researched. This study aims to fill this gap by evaluating the impact of these treatments on pomegranate orchards in a water-limited environment.

The primary objectives of this study are as follows:

To evaluate the impact of Grass Mulch with Gypsum, Black Sheet Mulch with Gypsum, and White Sheet Mulch with Gypsum on the yield of pomegranate orchards.

To assess the effectiveness of these treatments in conserving soil moisture and improving water use efficiency.

To determine the effects of these treatments on fruit size, fruit quality, and overall plant health.

To identify the most effective in-situ moisture conservation technique for pomegranate orchards in water-scarce regions.

MATERIALS AND METHODS

Experimental Site and Duration

The experiment was conducted in a pomegranate orchard located at the Soil and Water Conservation Research

Institute, Chakwal, Pakistan, over a period of 2019 to 2021. The region is characterized by a semi-arid climate, with a hot, dry summer and limited rainfall, making it an ideal location to evaluate the effectiveness of in-situ moisture conservation techniques for pomegranate cultivation. The site has a typical pomegranate-growing environment, with soil conditions, temperature, and water availability reflecting the challenges faced by growers in arid and semi-arid regions.
The pomegranate orchard at SAWCRI has well-established pomegranate trees, and the experiment was carried out on a plot with uniform soil texture, fertility, and other growth conditions to ensure the results were attributable to the treatments under investigation rather than variations in the soil or micro-environment.

Figure 1. Picture of experimental site.

Experimental Design

The experiment was laid out using a Randomized Complete Block Design (RCBD) to minimize the effects of variability in the experimental field. In an RCBD, treatments are randomly assigned to different blocks to ensure that any variability between experimental units (blocks) does not confound the results of the treatments. The use of RCBD ensures that differences in tree performance due to factors such as slope, shading, and microclimate are accounted for, making the results more reliable. The experimental treatments were as follows as mentioned in Table 1,

Table 1. In-situ moisture conservation treatments.

Treatments	Details
T_1	Control with Gypsum
T_2	Grass mulch with gypsum
T_3	Black Polythene sheet mulch with gypsum
T_4	White Polythene sheet mulch with gypsum

Treatment Details

Control with gypsum (T_1)

In this treatment, no mulching was applied, and pomegranate trees received only the standard irrigation and agronomic practices. Gypsum was applied to the soil to improve soil structure, reduce salinity, and enhance water infiltration. Gypsum Application: 500 kg/ha applied at the beginning of the growing season (early spring) and incorporated into the soil using a rotary tiller.

Grass mulch with gypsum (T_2)

A layer of fresh grass mulch was applied to the soil surface around the base of the trees. The mulch helped to conserve moisture, suppress weeds, and regulate soil temperature. Grass mulch was chosen for its availability and organic matter content, which could also improve soil fertility as it decomposes. Grass Mulch Application: A 10-15 cm layer of grass was applied around the base of the trees, ensuring that it covered the root zone area. Gypsum Application: Same as T1, 500 kg/ha applied in early spring.

Black sheet mulch with gypsum (T_3)

A 100-micron thick black polythene sheet was used to cover the soil surface around the base of the trees. Black plastic mulches have been shown to reduce evaporation, suppress weed growth, and enhance soil warming, which can promote early growth. Black Sheet Mulch Application: Sheets were carefully placed around the base of each

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tree, ensuring complete coverage of the root zone. Holes were made in the sheets to allow for proper tree growth.Gypsum Application: Same as T1, 500 kg/ha applied in early spring.

White sheet mulch with gypsum (T_4)

White polythene sheets were used in this treatment to conserve moisture and reduce soil temperature compared to black sheets. The white sheets reflect sunlight, helping to keep the soil cooler during hot weather, which can be beneficial in reducing heat stress on the plants. White Sheet Mulch Application: Sheets were laid around the trees, ensuring that the root zone was fully covered. Holes in the sheets were made for the trees to grow freely. Gypsum Application: Same as T1, 500 kg/ha applied in early spring.

Experimental management practices

Soil Fertility Management: In addition to gypsum application, the orchard received routine nutrient management practices, including the application of nitrogen, phosphorus, and potassium fertilizers, based on soil test recommendations. Irrigation: All treatments received the same amount of irrigation based on the crop's evapotranspiration needs. Drip irrigation was used to ensure that water was applied directly to the root zone to maximize water use efficiency.

Pruning and plant care

Standard agronomic practices for pomegranate orchards, including pruning, pest and disease management, and tree training, were followed uniformly across all treatments to ensure consistency in plant care.

Pest and disease management

Integrated pest management (IPM) strategies were employed to control pests and diseases. Pesticides and fungicides were used sparingly, based on the pest pressure, with an emphasis on organic options where possible.

Harvesting

The pomegranates were harvested at their optimum maturity stage, based on color and firmness, typically between late August and early October, depending on the climatic conditions of the year.

Data collection

Data were collected on several parameters to assess the effects of the treatments on pomegranate yield and growth performance:

Soil moisture content

Soil moisture was measured at different depths (0-30 cm, 30-60 cm) using a soil moisture probe at regular intervals throughout the growing season, particularly during critical stages of fruit development. This data was used to monitor the effectiveness of each treatment in conserving moisture.

Growth parameters

Plant height

The height of the trees was measured from the ground level to the highest point of the plant at the beginning and end of each growing season.

Plant spread (width)

The horizontal spread of the tree canopy was measured at two perpendicular points (north-south and east-west) to assess the overall growth and canopy development.

Stem girth

The girth of the main stem (trunk) was measured at 30 cm above the soil surface using a measuring tape.

Yield parameters

Number of Fruits per Tree

The total number of fruits produced by each tree was counted at harvest.

Fruit weight

The average weight of a sample of 50 fruits per tree was measured and recorded at harvest.

Fruit size and diameter

The diameter of pomegranates was measured using a digital caliper for a sample of 50 fruits per treatment.

Fruit yield per tree

The total yield per tree was calculated based on the number of fruits and their average weight.

Fruit quality

Fruit crack percentage

The percentage of fruits exhibiting cracks was recorded at harvest, as cracking is a common problem in pomegranate production under water stress conditions.

Fruit color

The external color of the fruit was visually assessed and scored according to the standard maturity index for pomegranates.

Statistical Analysis

All data were analyzed using Analysis of Variance (ANOVA) to determine the significant differences between the treatment means. The results were subjected to Least Significant Difference (LSD) at a 5% level of significance to compare the means of different treatments. The statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) software (Version 26).

Data Analysis and Interpretation

The results from the experiment were analyzed to evaluate the impact of each treatment on:

Soil moisture retention and efficiency,

Growth parameters (plant height, spread, and girth),

Yield (number of fruits, fruit weight, and yield per tree)

Fruit quality (crack percentage and fruit size).

By comparing the performance of the four treatments, the study aimed to identify the most effective in-situ moisture conservation technique for enhancing pomegranate yield under semi-arid conditions.

RESULTS

Plant spread (m)

The plant spread refers to the horizontal expansion of the plant canopy, which can indicate how much space a plant occupies and potentially how well it competes for resources like light, water, and nutrients. In this study, the plant spread is greatest under the Black Polythene Sheet Mulch with Gypsum treatment (4.76 m), followed by the White Polythene Sheet Mulch with Gypsum (4.6 m) and Grass Mulch with Gypsum (4.46 m) (Table 2) The Control (4.2 m) showed the smallest spread, likely because, without any mulch, plants might be under more stress from environmental factors like water loss or soil temperature fluctuations, limiting their ability to spread effectively. Despite these trends, none of the differences between treatments exceeded the LSD of 1.2666 m, meaning the differences in plant spread were not statistically significant at the 5% level. This suggests that although mulching

Treatments	Plant spread(m)	Plant Height(m)	Plant Girth(m)
Control	4.21 ±0.07 c	2.96±0.09 c	1.85±0.12 b
Grass mulch with gypsum	4.46±0.05 b	3.36±0.05 b	1.95±0.06 ab
Black Polythene sheet mulch with gypsum	4.76±0.02 a	3.63±0.07 a	2.18±0.04 a
White Polythene sheet mulch with gypsum	4.62 ±0.05 b	3.46±0.03 b	2.13±0.09 a
LSD @ 5 percent	1.2666	0.4995	0.3286

seems to promote a wider plant canopy, the differences are not large enough to confidently say one treatment outperforms another in terms of spread.

Table 2. Plant growth parameter of pomegranate.

Plant height (m)

Plant height is an important indicator of vertical growth and is often related to overall plant vigor and the ability to access sunlight. In this study, plants under Black Polythene Sheet Mulch with Gypsum had the tallest plants (3.63 m), which may be due to the mulch's ability to retain moisture, regulate soil temperature, and reduce weed competition, all of which could encourage greater vertical growth. The White Polythene Sheet Mulch with Gypsum and Grass Mulch with Gypsum treatments also showed higher plant heights (3.46 m and 3.36 m, respectively) compared to the Control (2.96 m), indicating that the mulching treatments generally promoted taller plants. The differences in plant height between the Control and the mulched treatments, particularly the black polythene, are statistically significant since the difference (0.67 m) exceeds the LSD of 0.4995 m. This suggests that mulching, especially with black polythene, creates more favorable growing conditions that support taller plants.

Plant girth (m)

Plant girth measures the thickness of the plant stem and is an important indicator of the plant's overall health and robustness. A larger girth typically correlates with greater structural strength and improved capacity for nutrient and water transport, which can contribute to higher productivity. In this study, the Black Polythene Sheet Mulch with Gypsum treatment resulted in the largest girth (2.18 m), closely followed by the White Polythene Sheet Mulch with

Gypsum treatment (2.13 m). These mulches may have helped plants grow thicker stems by improving soil moisture retention and reducing environmental stressors. The Control had the smallest girth (1.85 m), which may reflect less optimal growing conditions, such as higher water stress or nutrient deficiencies, leading to weaker stem development. The difference in girth between the Controland the mulched treatments (especially the black polythene) was statistically significant, as it exceeded the LSD of 0.3286 m, suggesting that mulching contributes to thicker stems, which could potentially enhance the plant's productivity and resistance to external factors.

Fruit Set (%)

The fruit set percentage is the proportion of flowers that successfully develop into fruits, which is an important indicator of plant reproductive success and overall productivity. In this study, the Black Polythene Sheet Mulch with Gypsum treatment resulted in the highest fruit set percentage at 40.5%, followed by the White Polythene Sheet Mulch with Gypsum at 37.7% (Table 3). The Grass Mulch with Gypsum treatment also showed a relatively good fruit set of 34.3%, while the Control (no mulch) had the lowest fruit set percentage at 32.6%.

The use of Black Polythene Sheet Mulch with Gypsum likely created optimal conditions for fruit set, possibly by improving soil moisture retention, temperature regulation, and reducing competition for resources. These conditions would be particularly beneficial during the critical flowering and fruiting stages. The differences between the Control and the mulched treatments, especially Black Polythene Sheet Mulch, are statistically significant, as the difference of 7.9% between Control (32.6%) and Black Polythene (40.5%) exceeds the LSD of 4.2969%. This indicates that mulching with black polythene significantly improved the fruit set percentage compared to the control.

Table 3. Fruit parameter of pomegranate.

Treatments	Fruit set %	Fruit drop%	Fruit crack %
Control	32.6±0.08 b	26.6±0.05 a	2.1±0.15 a
Grass mulch with gypsum	34.3±0.06 bc	24±0.09 d	1.9±0.09 b
Black Polythene sheet mulch with gypsum	40.5±0.09 a	16.3±0.06 b	1.8±0.06 b
White Polythene sheet mulch with gypsum	37.7±0.03 b	18±0.08 c	1.8±0.05 b
LSD @ 5 percent	4.2969	2.9219	0.4379

Fruit Drop (%)

The fruit drop percentage refers to the proportion of flowers or fruits that fall off the plant before reaching maturity. High fruit drop can indicate unfavorable environmental conditions, nutrient deficiencies, or stress during the reproductive phase. In this study, Black Polythene Sheet Mulch with Gypsum showed the lowest fruit drop percentage at 16.3%, followed by White Polythene Sheet Mulch with Gypsum at 18%, and Grass Mulch with Gypsum at 24%. The Control had the highest fruit drop percentage at 26.6%.

The reduction in fruit drop under the mulched treatments, particularly under the Black Polythene Sheet Mulch, suggests that the mulch may have helped reduce stress on the plants by moderating soil moisture levels and temperature fluctuations, which can lead to better fruit retention. The differences between the Control and mulched treatments are statistically significant, as the Control's fruit drop (26.6%) is notably higher than the Black Polythene Sheet Mulch (16.3%), and this difference exceeds the LSD value of 2.9219%. This indicates that the mulches, especially black polythene, were effective in reducing fruit drop, likely improving overall yield potential.

Fruit Crack (%)

Fruit crack percentage refers to the proportion of fruits that split or crack, often due to environmental factors like rapid changes in moisture or temperature, or physiological stress in the plant. The fruit crack percentage in this study is relatively low across all treatments. Control had a fruit crack percentage of 2.1%, while the Grass Mulch with Gypsum and both Polythene Sheet Mulch treatments (black and white) all showed slightly lower fruit crack percentages (1.9% and 1.8%, respectively).

The slight reduction in fruit crack under the mulching treatments suggests that the mulch may have had some role in moderating moisture levels around the fruits, helping to reduce the risk of splitting. However, the overall differences in fruit crack percentage are very small, and the statistical significance is less pronounced due to the small changes in fruit crack across treatments. The largest difference between treatments is between the Control and the mulched treatments, with a difference of 0.3% (Control = 2.1% vs. Black Polythene Sheet Mulch = 1.8%), but this is still within the LSD of 0.4379%, meaning that the differences in fruit crack percentage are not statistically significant.

Number of Fruits per Plant

The number of fruits per plant is a crucial determinant of overall yield potential, as it directly reflects reproductive success. The study showed that mulching treatments significantly increased the number of fruits per plant compared to the Control. The Black Polythene Sheet Mulch with Gypsum treatment yielded the highest fruit count at 34 fruits per plant, followed by the White Polythene Sheet Mulch with Gypsum (32 fruits) and Grass Mulch with Gypsum (30 fruits). The Control plants produced the fewest fruits at 28 (Table 4). This increase in fruit number under mulched treatments suggests that mulching provided a more favorable growing environment, likely improving moisture retention, temperature regulation, and reducing competition for nutrients. The difference between the Control and the Black Polythene Sheet Mulch was statistically significant, indicating that mulching, especially with black polythene, effectively promoted fruit production.

Table 4. Fruit yield parameter of pomegranate.

Treatments	No. of fruits/ plant	Fruit diameter(cm)	Fruit weight(gm)	Fruit yield kg/ plant
Control	28±0.09 d	8.2±0.06 b	194±0.08 c	6.03±0.12d
Grass mulch with gypsum	30±0.15 c	8.4±0.09 b	197±0.14 c	6.46±0.08 c
Black Polythene sheet mulch with gypsum	34±0.13 a	9.4±0.10 a	204±0.09 a	7.5±0.03 a
White Polythene sheet mulch with gypsum	32±0.06 b	9.2±0.13 ab	200±0.07b	7.16±0.07 b
LSD	5.9192	0.2601	15.593	0.9489

Fruit diameter (cm)

The fruit diameter is an important quality trait, with larger fruits often being more desirable in terms of marketability and nutritional value. In this study, the Black Polythene Sheet Mulch with Gypsum resulted in the largest fruits, with a diameter of 9.4 cm, followed closely by White Polythene Sheet Mulch with Gypsum at 9.2 cm. The Control plants produced fruits with a diameter of 8.2 cm, indicating that the mulching treatments contributed to larger fruit size. The larger fruit diameter under the mulching treatments can likely be attributed to improved environmental conditions, such as enhanced moisture retention and temperature stabilization, which are conducive to better fruit development. The difference between the Control and Black Polythene Sheet Mulch was significant, confirming that the black polythene treatment had a marked effect on increasing fruit size compared to the unmulched control.

Fruit weight (gm)

Fruit weight is another critical factor that contributes to overall yield and quality. The Black Polythene Sheet Mulch with Gypsum treatment resulted in the heaviest fruits, with an average weight of 204 grams, while the White Polythene Sheet Mulch with Gypsum produced fruits weighing 200 grams. The Control had the lightest fruits, at 194 grams. This increase in fruit weight under mulching treatments indicates that the mulches likely improved the growth conditions for the plants, leading to the production of heavier fruits. While the difference between the Control and Black Polythene Sheet Mulch was not statistically significant at the 5% level, the mulching treatments did seem to enhance fruit weight compared to the unmulched control, particularly in the case of the black polythene.

Fruit yield (kg/plant)

The fruit yield per plant, which combines both the number and size of the fruits, was significantly higher in the mulched treatments compared to the Control. The Black Polythene Sheet Mulch with Gypsum produced the highest yield at 7.5 kg/plant, followed by White Polythene Sheet Mulch with Gypsum at 7.16 kg/plant. The Grass Mulch with Gypsum treatment resulted in a yield of 6.46 kg/plant, while the Control yielded only 6.03 kg/plant. The increased fruit yield in mulched treatments can be attributed to the combined effects of higher fruit set, larger fruit size, and improved plant health due to better moisture retention and temperature regulation. The difference in yield between the Control and the Black Polythene Sheet Mulch treatment was statistically significant, further emphasizing the positive impact of mulching on overall productivity.

DISCUSSION

This study investigates the effect of different mulching treatments on the growth, fruit set, fruit quality, and yield of plants. The treatments included Control, Grass Mulch with Gypsum, Black Polythene Sheet Mulch with Gypsum, and White Polythene Sheet Mulch with Gypsum, and their effects were compared using various parameters such as plant spread, plant height, plant girth, fruit set, fruit drop, fruit crack, number of fruits per plant, fruit diameter, fruit weight, and fruit yield. Below is a discussion of the results based on these parameters, referencing relevant literature to support the findings.

Plant spread, height, and girth

Plant spread, height, and girth are essential indicators of overall plant growth and health. The Black Polythene Sheet Mulch with Gypsum resulted in the highest plant spread (4.76 m), height (3.63 m), and girth (2.18 m), followed by White Polythene Sheet Mulch with Gypsum and Grass Mulch with Gypsum. The Control showed the smallest plant spread (4.2 m), height (2.96 m), and girth (1.85 m). The increase in these parameters under mulching treatments can be attributed to the improved moisture retention, soil temperature regulation, and reduced weed competition provided by mulching. This is consistent with the findings of Ochieng et al. (2020), who reported that plastic mulches significantly improve plant growth by creating optimal soil conditions. The LSD values (1.2666 for plant spread, 0.4995 for plant height, and 0.3286 for plant girth) indicate that the differences between the mulched treatments and the Control are statistically significant, particularly the increase in plant spread and height under the Black Polythene Sheet Mulch. These findings are in line with the work of van Iersel and Nemali (2004) and Hadli and Raijadhav (2004) who found that increased soil moisture favored more leaf growth which ultimately leads to increased growth and yield of plant. Similar finding were reported by Farmahan and Sharma (2003) and Singh and Sharma (2010) in case of pomegranate and olive respectively. The beneficial impact of mulching with black polythene were observed by Sharma et al. (2017) in pomegranate, Iqbal et al. (2015) in case of canola crop and Pandey et al. (2016) in case of strawberry.

Fruit set, fruit drop, and fruit crack

Fruit set percentage, fruit drop, and fruit crack are crucial indicators of reproductive success and fruit quality. Black Polythene Sheet Mulch with Gypsum resulted in the highest fruit set (40.5%) and the lowest fruit drop (16.3%), followed by White Polythene Sheet Mulch with Gypsum with a fruit set of 37.7% and a fruit drop of 18%. The Control had the lowest fruit set (32.6%) and the highest fruit drop (26.6%).The lower fruit drop under the Black Polythene Sheet Mulch can be attributed to improved environmental conditions such as better soil moisture retention and a more stable temperature regime, both of which reduce stress during the fruiting period. These findings align with the work of Challa and Reddy (2015), who observed that plastic mulching helps plants retain moisture and regulate temperature, resulting in lower fruit drop and improved fruit set. Similarly, Singh et al. (2017) reported that mulches improve fruit retention by providing more favorable conditions for pollination and fruit development.

Fruit crack was low across all treatments, but Black Polythene Sheet Mulch (1.8%) and White Polythene Sheet Mulch (1.8%) showed slightly less cracking than the Control (2.1%). The minimal difference in fruit crack percentage suggests that mulching had a mild effect on reducing cracking, but this was not as pronounced as the improvements seen in fruit set and fruit drop. The statistical analysis showed no significant differences in fruit crack between treatments, with the LSD value of 0.4379 being smaller than the observed differences.

Number of fruits per plant

The number of fruits per plant is a direct indicator of yield potential. Black Polythene Sheet Mulch with Gypsum resulted in the highest number of fruits per plant (34), followed by White Polythene Sheet Mulch with Gypsum (32), Grass Mulch with Gypsum (30), and the Control (28). The increase in fruit number under the mulching treatments supports findings from Dinesh et al. (2020)**,** who reported that mulches significantly increase fruit number by enhancing soil moisture and promoting better plant health. The difference between Control and Black Polythene Sheet Mulch (6 fruits) was significant, as the difference exceeded the LSD value of 5.9192.

Fruit diameter, weight, and yield

Fruit diameter, fruit weight, and fruit yield are key measures of fruit quality and overall productivity. Black Polythene Sheet Mulch with Gypsum resulted in the largest fruit diameter (9.4 cm), followed by White Polythene Sheet Mulch with Gypsum (9.2 cm), and Control (8.2 cm). Similarly, Black Polythene Sheet Mulch with Gypsum produced the heaviest fruits (204 g), followed by White Polythene Sheet Mulch with Gypsum (200 g), Grass Mulch with Gypsum (197 g), and Control (194 g). The increase in fruit diameter and weight under mulching treatments is consistent with the findings of Singh et al. (2017), who showed that mulching improves fruit size by reducing water stress and enhancing nutrient availability.

The fruit yield per plant was significantly higher under mulching treatments, with Black Polythene Sheet Mulch with Gypsum producing 7.5 kg/plant, followed by White Polythene Sheet Mulch with Gypsum (7.16 kg/plant), Grass Mulch with Gypsum (6.46 kg/plant), and the Control (6.03 kg/plant). The differences in yield between the Control and the mulched treatments were statistically significant, especially when compared to the Black Polythene Sheet Mulch, where the increase of 1.47 kg/plant exceeded the LSD value of 0.9489, suggesting that mulching, particularly with black polythene, significantly boosted fruit yield. The better fruit quality is related to increased moisture content, weed free field area and efficient nutrient uptake under the condition of black polythene mulch in strawberry (Kumar and Reddy, 2018). The in-situ water and moisture conservation techniques has improved cashew yield from 4.8 to 6.6 tonnes per hectare while mulching treatments has helped in reducing yield gap in Jujube (Jin et al., 2018). Mulch also serves as home for friendly soil microorganism which plays a vital role in nutrient cycling and uptake by plants (De Biman et al., 2021).

Plastic mulches, particularly black and white polythene sheets, are widely used in horticultural crops to reduce evaporation, suppress weeds, and improve soil temperature. These mulches are highly effective in conserving moisture and improving yield, especially in regions where water is limited. Black plastic mulches have the added benefit of warming the soil, which can promote early plant growth, while white plastic mulches help in maintaining cooler soil temperatures (Kumar et al., 2022; Sharma et al., 2020). Researchers investigated that mulching can boost yields, water use and crop growth (Abdrabbo et al., 2017; Chaudhary et al., 2003; Mozaffari, 2022). Gathala et al. (2020) suggested that technological interventions are necessary for yield cum water enhancement as well as energy productivity. Gypsum, a naturally occurring mineral, has been shown to improve soil structure, increase water infiltration, and reduce soil salinity, making it an effective soil amendment for pomegranate orchards. When applied alongside mulching, gypsum can further enhance the soil's moisture retention capacity, allowing for more efficient water use by pomegranate trees (Reddy et al., 2021).

CONCLUSION

The study demonstrates that mulching, especially with Black Polythene Sheet Mulch with Gypsum, significantly improves several key aspects of plant growth, fruit quality, and yield. These treatments increased plant spread, plant height, plant girth, fruit set, fruit yield, and fruit quality compared to the Control. The results are consistent with previous research that highlights the benefits of mulching in regulating soil moisture, improving plant health, and enhancing yield. The use of mulches, particularly with Black Polythene Sheet Mulch, proved to be an effective strategy for improving crop productivity, and these findings contribute to the growing body of evidence supporting the use of mulching as a sustainable agricultural practice.

AUTHOR CONTRIBUTIONS

All authors contributed equally to this research.

COMPETING OF INTEREST

The authors declare no competing interests.

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