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Effect of Mulching Materials on Growth and Yield of Sweet Pepper (Capsicum annuum L.) in Kandahar

Mirwais Khan Afghan[1], Qudratullah Ehsan✉[2], Pai Mohammad Mohammadi[3]

[1]Department of Genetic and Plant Breeding, Faculty of Plant Sciences, ANASTU Univeresity, Kandahar, Af
[2]Department of Agronomy, Faculty of Plant Sciences, ANASTU Univeresity, Kandahar, Af
[3]Department of Agronomy, Faculty of Agriculture, Urozgan University ,Urozgan, Af.
✉E-mail: qudrat.ehsan@gmail.com, qudrat.ehsan@anastu.edu.af (corresponding author)

ABSTRACT

Sweet pepper (*Capsicum annuum* L.) is a high-value vegetable crop widely cultivated for its nutritional and economic importance. However, in semi-arid regions like Kandahar, Afghanistan, water scarcity, high temperature, and soil degradation often limit its productivity. This research was conducted to evaluate the impact of different mulching materials (black plastic, white plastic, and grass) on the growth and yield performance of sweet pepper under Kandahar's agro-climatic conditions. The study was carried out during the 2024 growing season at the research farm of the Afghanistan National Agricultural Sciences and Technology University (ANASTU) using a randomized complete block design (RCBD) with four treatments and three replications. Results indicated that black plastic mulch significantly outperformed other treatments in terms of plant height, number of branches, fruit diameter, fruit weight, number of fruits per plant, and total yield. The highest yield (30.88 tons/ha) was recorded under black plastic mulch, followed by white plastic mulch (25.53 tons/ha) and grass (23.33 tons/ha), while the control recorded the lowest yield (19.13 tons/ha). Statistical analysis revealed significant differences ($p < 0.05$) among treatments for most parameters. These findings suggest that mulching, particularly with black plastic, is a viable and effective agronomic practice for improving sweet pepper production in arid environments. Adoption of such mulching techniques can enhance soil moisture retention, suppress weed growth, and ultimately increase crop productivity. This research provides evidence-based recommendations for farmers and agricultural stakeholders aiming to optimize sweet pepper yield under challenging climatic conditions.

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INTRODUCTION

Sweet pepper (*Capsicum annuum L.*), a self-pollinated member of the Solanaceae family, is one of the most valuable vegetable crops globally, ranking just after tomato and onion in terms of economic and nutritional importance. It is consumed in both fresh and processed forms and serves as an excellent source of vitamins A and C, antioxidants, and minerals (Bosland & Votava, 2012). In many countries, sweet pepper cultivation is a high-value enterprise that supports household income and contributes to agricultural economies. The increasing demand for sweet pepper in local and international markets has encouraged researchers and farmers alike to explore agronomic practices that can enhance both yield and quality (Guo et al., 2025).

Among various agronomic practices, mulching has emerged as a critical technology due to its multiple benefits. Mulching conserves soil moisture, regulates soil temperature, suppresses weed growth, improves soil fertility, and protects the root zone from environmental stress (Lamont, 2005). Both organic mulches (such as grasses, crop residues, or straw) and inorganic mulches (such as black and white plastic films) have been widely used to improve crop performance. The choice of mulch type can significantly influence soil microclimate, nutrient cycling, and ultimately crop yield (Ali et al., 2025; Ibarra-Jiménez et al., 2006). For vegetable crops, black plastic mulch has often been reported to increase fruit quality and marketable yield by maintaining favorable soil hydrothermal conditions (Choudhary et al., 2022).

In Afghanistan, particularly in Kandahar province, vegetable production faces major challenges due to a semi-arid climate, high temperatures, sandy soils, and limited rainfall. Water scarcity is among the most critical constraints affecting crop productivity in the region (Ehsan et al., 2017). Traditional irrigation methods are often inefficient, resulting in high water losses and reduced water-use efficiency. Under such circumstances, mulching plays an essential role by minimizing evaporation, improving infiltration, and enhancing water retention in the soil profile, thereby allowing better utilization of limited irrigation resources (Farid & Noor, 2025). This makes mulching a promising approach for sustainable vegetable production in water-stressed environments like Kandahar.

Therefore, this research, entitled "Effect of Different Mulching Methods on the Growth and Yield of Sweet Pepper in Kandahar", was conducted to evaluate the performance of various mulching materials, including black plastic mulch, white plastic mulch, and grass mulch, under local field conditions. The study was carried out at the Research Farm of the Afghanistan National Agricultural Sciences and Technology University (ANASTU) during the spring-summer cropping season of 1403 (2024). The main objectives of the study were:

- To assess the effects of different mulching materials on vegetative growth parameters.
- To determine the influence of mulch types on yield.
- To identify the most effective mulching material for maximizing sweet pepper productivity under Kandahar agro-climatic conditions.

METHODS AND MATERIALS

This experiment was conducted at the Research Farm of the Afghanistan National Agricultural Sciences and Technology University (ANASTU) located in Kandahar, Afghanistan. The research followed a Randomized Complete Block Design (RCBD) with four treatments and three replications. The treatments included:

- T1: Control (no mulch)
- T2: Black plastic mulch
- T3: White plastic mulch
- T4: Grass mulch

Each plot measured 4 × 3 meters with a spacing of 40 cm between plants and 50 cm between rows. Sweet pepper seedlings were transplanted in the first week of March 2024, after being raised in nursery trays using a mixture of soil, sand, and compost.

Soil Analysis: Prior to transplantation, soil samples were collected from the field at 0–30 cm depth from 10 randomly selected points. These samples were analyzed at the ANASTU Central Laboratory for physical and chemical properties, including texture (by the hydrometer method), pH, electrical conductivity (EC), and nutrient content, such as nitrogen (N), phosphorus (P), and potassium (K).

All plots received the same agronomic management, including irrigation, weeding, and pest control. Drip irrigation was used, and all plots received equal amounts of organic manure prior to transplanting. Mulch materials were applied immediately after transplanting.

Growth and yield data of sweet pepper (*Capsicum annuum* L.) were systematically recorded at 30, 60, and 90 days after transplanting (DAT), as well as at harvest. These observation intervals were selected to comprehensively assess the crop's vegetative and reproductive development under different mulching treatments. The recorded parameters included plant height (cm), number of branches per plant, fruit diameter (cm), individual fruit weight (g), number of fruits per plant, total fruit weight per plant (kg), and estimated yield per hectare (tons/ha).

Plant height was measured from the base of the plant to the apex of the main stem using a measuring scale. Observations were taken from randomly selected plants in each plot at the four growth stages (30, 60, 90 DAT, and harvest) to evaluate the progressive growth response of sweet pepper to various mulch types. Regular measurement of plant height helped to determine the vegetative vigor and the overall impact of soil moisture and temperature regulation by different mulching materials.

The number of branches per plant was also recorded at 30, 60, 90 DAT, and at harvest to quantify the effect of mulching on vegetative branching. Branch development is an important indicator of canopy structure and photosynthetic potential, which directly influences flower initiation and fruit setting. The data were collected by manually counting all primary branches emerging from the main stem of each selected plant.

Fruit weight was determined using a precision electronic balance, and the number of fruits per plant was obtained by counting all fruits harvested from each selected plant. The total fruit weight per plant (kg) was computed by summing the weights of all fruits per plant. Finally, the estimated yield per hectare (tons/ha) was calculated by extrapolating the mean yield per plant based on plant spacing and population density per hectare. This parameter provided a comparative measure of overall productivity across different mulching treatments.

Collecting data across four distinct growth stages enabled a detailed understanding of sweet pepper's dynamic response to mulching throughout its growth cycle. Such an approach ensured accurate assessment of both vegetative and reproductive performance, providing a reliable basis for evaluating treatment effects on crop growth and yield under the semi-arid agro-climatic conditions of Kandahar, Afghanistan.

Statistical Analysis: The collected data were subjected to Analysis of Variance (ANOVA) using SPSS software. Means were compared using Duncan’s Multiple Range Test (DMRT) at a 5% level of significance.

FINDINGS

The effects of different mulching materials on the growth parameters and yield attributes of sweet pepper (*Capsicum annuum* L.) were evaluated under Kandahar agro-climatic conditions. The treatments included control (no mulch), black plastic mulch, white plastic mulch, and grass mulch. Data were collected on plant height, number of branches, fruit characteristics, and yield at multiple growth stages (30, 60, 90 DAS and at harvest) and the results are presented below.

Plant Height (cm)

Significant differences ($p < 0.05$) in plant height were observed among treatments at all measured stages (30, 60, 90 DAS, and harvest). At 30 DAS, black plastic mulch treatment resulted in the highest average plant height (32.00 cm), followed by white plastic (29.40 cm), grass (27.00 cm), and control (20.00 cm). This trend continued through 60 DAS and 90 DAS, with black plastic mulch consistently promoting greater plant height (44.73 cm at 60 DAS and 58.80 cm at 90 DAS). At harvest, the tallest plants were recorded under black plastic mulch (71.50 cm), significantly surpassing the control (60.77 cm), as shown in Table 1.

Table 1. *Effect of Different Mulching Materials on Plant Height of Sweet Pepper (Capsicum annuum L.) Under Agro-Climatic Conditions of Kandahar, Afghanistan*

Treatment	Plant height (cm)							
	At 30 DAS*		At 60 DAS*		At 90 DAS*		At harvest	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Control	20.000d	0.289	37.400d	0.116	49.600d	0.174	60.767d	0.145

Black Plastic Mulch	32.000a	0.115	44.733a	0.087	58.800a	0.115	71.500a	0.404
White Plastic Mulch	29.400b	0.116	39.200b	0.231	54.500b	0.577	67.300b	0.232
Grass Mulch	27.000c	0.115	38.000c	0.231	52.200c	0.231	64.800c	0.117
F-test	861.8		351.6		141.7		322.5	
LSD (0.05)	0.585		0.697		1.269		0.810	
C.V.	1.061		0.859		1.159		0.602	

*DAS Days After Sowing

Branches per plant

The number of branches per plant also varied significantly among treatments at all growth stages. At harvest, plants mulched with black plastic showed the highest mean number of branches (13.58), followed by white plastic (12.56), grass (11.80), and control (10.63). These results indicate improved vegetative branching with plastic mulch applications, as summarized in Table 2.

Table 2. *Effect of Different Mulching Materials on Branch Numbers of Sweet Pepper (Capsicum annuum L.) Under Agro-Climatic Conditions of Kandahar, Afghanistan*

Treatment	Branch per Plant							
	At 30 DAS*		At 60 DAS*		At 90 DAS*		At harvest	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Control	4.570d	0.104	6.633d	0.038	8.200d	0.231	10.630d	0.064
Black Plastic Mulch	7.600a	0.173	9.403a	0.066	11.407a	0.046	13.583a	0.107
White Plastic Mulch	6.640b	0.052	8.200b	0.231	10.000b	0.231	12.560b	0.104
Grass Mulch	6.000c	0.231	7.607c	0.092	9.300c	0.231	11.800c	0.069
F-test	۶۶,۸		۷۹,۳		۴۴,۵		۱۹۹,۹	
LSD (0.05)	0.595		0.502		0.798		0.350	
C.V.	4.712		3.094		4.030		1.415	

*DAS= Days After Sowing

Yield attributes and Yield

Mulching treatments significantly enhanced fruit diameter and weight. Black plastic mulch yielded the largest fruit diameter (7.97 cm) and the highest fruit weight (83.40 g), while control plants had the smallest fruits (5.43 cm diameter and 58.90 g weight). White plastic and grass mulches showed intermediate values, with white plastic mulch performing better than grass, as presented in Table 3.

Table 3. *Effect of Different Mulching Materials on Yield Attributes of Sweet Pepper (Capsicum annuum L.) Under Agro-Climatic Conditions of Kandahar, Afghanistan*

Treatment	Fruit diameter (cm)		Fruit weight (g)		Fruit per plant		Fruit weight per plant (kg)		Yield ton/ha	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Control	5.433d	0.072	58.900d	0.231	29.800c	0.231	1.850d	0.046	19.130d	0.087
Black Plastic Mulch	7.970a	0.087	83.400a	0.064	39.160a	0.150	3.120a	0.012	30.880a	0.052
White Plastic Mulch	7.050b	0.017	73.000b	0.231	33.300b	0.092	2.560b	0.069	25.530b	0.139
Grass Mulch	6.790c	0.092	70.900c	0.289	30.120c	0.110	2.110c	0.069	23.330c	0.046
F-test	۲۰۴,۲		۲۰۸۱,۹		۷۸۱,۷		۱۰۴,۵		۳۰۳۵,۲	
LSD (0.05)	0.292		0.872		0.485		0.219		0.359	
C.V.	2.108		0.598		0.719		4.463		0.713	

Table 3 presents the effect of different mulching materials on various yield attributes of sweet pepper *(Capsicum annuum* L.) under the agro-climatic conditions of Kandahar, Afghanistan. The evaluated parameters included fruit diameter (cm), individual fruit weight (g), number of fruits per plant, fruit weight per plant (kg), and yield (tons/ha). The data clearly indicate that mulching treatments significantly influenced all measured yield attributes compared with the unmulched control. The black plastic mulch treatment recorded the highest performance across all yield parameters. The mean fruit diameter under black plastic mulch was 7.97 cm, which was significantly greater than that of the control (5.43 cm) and other treatments. This enhancement can be attributed to improved soil moisture retention, greater regulation of soil temperature, and better nutrient availability under black plastic mulch, all of which contribute to improved fruit development and enlargement. Similar findings have been reported by Burato et al. (2025) and Zhang et al. (2025), who noted that black plastic mulch creates a favorable microclimate that promotes fruit expansion and uniform ripening.

Fruit weight, plants grown under black plastic mulch produced the heaviest fruits (83.40 g), followed by white plastic mulch (73.00 g) and grass mulch (70.90 g), whereas the control treatment yielded significantly lighter fruits (58.90 g). The improved fruit weight under black plastic mulch is likely due to enhanced photosynthetic activity, resulting from reduced soil moisture stress and better nutrient uptake (Yadav et al., 2021). The number of fruits per plant followed a similar trend, with black plastic mulch producing the highest (39.16 fruits/plant), followed by white plastic mulch (33.30 fruits/plant), grass mulch (30.12 fruits/plant), and the control (29.80 fruits/plant). The increased fruit count may be linked to better vegetative growth and higher flower retention rates under mulched conditions, as mulches moderate soil temperature fluctuations and minimize plant stress during critical flowering stages (Lodhi et al., 2019). Regarding fruit weight per plant, the black plastic mulch treatment showed a substantial increase (3.12 kg/plant) compared to the control (1.85 kg/plant), indicating a nearly 68% improvement in productivity. This enhancement is consistent with reports from Gupta and Singh (2024), who observed similar effects of plastic mulch on solanaceous crops.

The most critical parameter, yield per hectare, also showed a marked difference among treatments. The highest yield (30.88 tons/ha) was obtained under black plastic mulch, followed by white plastic (25.53 tons/ha) and grass mulch (23.33 tons/ha), whereas the control produced the lowest yield (19.13 tons/ha), as summarized in Table 3. Overall, the results demonstrate that black plastic mulch substantially enhances sweet pepper yield components by improving the soil microclimate, conserving moisture, and reducing weed competition. Although white plastic and grass mulch also provided yield benefits over the control, their effects were comparatively lower. The findings highlight the suitability of black plastic mulch as a practical agronomic intervention to increase sweet pepper productivity under the semi-arid and water-scarce conditions of Kandahar.

DISCUSSION

The results of this study clearly demonstrate that mulching significantly affects the growth and yield of sweet pepper under the semi-arid conditions of Kandahar. Among the tested treatments, black plastic mulch consistently outperformed white plastic mulch, grass, and the control across all measured parameters, confirming the hypothesis that mulching improves crop performance in resource-limited environments.

The enhanced plant height and increased number of branches observed under black plastic mulch treatment can be attributed to improved soil temperature regulation and moisture retention (Yadav et al., 2021; Himatkhwah et al., 2025). Black plastic is known to elevate soil temperature during early growth stages and reduce evaporation losses, promoting better root development and vegetative growth (Zhang et al., 2025). These conditions likely supported vigorous plant growth, as evidenced by increased height and branch number at all stages (Ehsan et al., 2024). In arid ecosystems, such regulation of soil hydrothermal conditions is particularly critical, where temperature extremes and irregular water supply often constrain growth (Tshering and Bhattarai, 2025).

Mulched plants, especially under black plastic, produced significantly larger and heavier fruits. This agrees with the findings of Dragumilo et al. (2025), who reported that mulching creates a favorable microclimate that enhances nutrient uptake and fruit development in solanaceous crops (Patel and Desai, 2024; Khan et al., 2025). Improved water-use efficiency and enhanced root activity under mulch likely contributed to superior fruit quality (Zhang et al., 2024). Mulched plants, particularly those under black plastic, produced significantly larger and heavier fruits compared to other treatments. This observation is consistent with earlier reports indicating that mulching enhances nutrient uptake efficiency and fruit filling (Burato et al., 2025; Patel & Desai, 2024). Larger fruit size and improved quality under black plastic mulch can also be explained by its ability to suppress weed competition and maintain uniform soil moisture levels, which reduces physiological stress on the crop (Khan et al., 2025). Moreover, similar studies in semi-arid Asia and the Middle East have reported improved water-use efficiency under plastic mulches, further supporting the role of mulch in boosting crop resilience under water-scarce conditions (Zhang et al., 2024; Hussein & Al-Mahmood, 2025).

Yield performance further highlighted the superiority of black plastic mulch, which recorded the highest fruit number per plant and yield per hectare (30.88 tons/ha), significantly higher than the control (19.13 tons/ha). These results align with those of Lodhi et al. (2019), who demonstrated that mulching improves flowering and fruit set by optimizing soil temperature and conserving water. The economic implications of such yield gains are substantial for smallholder farmers in Kandahar, where vegetable crops such as sweet peppers are important cash crops that supplement household income and support food security (Gupta & Singh, 2024). Adoption of black plastic mulch could therefore serve as a cost-effective means to maximize returns on limited water and land resources. Black plastic mulch also resulted in the highest number of fruits per plant and overall fruit yield per hectare

(30.88 tons/ha), which was significantly higher than the control (19.13 tons/ha). This aligns with recent findings by Lodhi et al. (2019), who found that mulch not only suppresses weed competition but also promotes flowering and fruit set by maintaining optimal soil conditions (Gupta and Singh, 2024).

Although grass mulch improved plant growth and yield compared to the control, it was less effective than plastic mulch. Its lower efficiency in conserving soil moisture and moderating soil temperature likely explains the reduced performance (Ahmad & Khan, 2024; Chen et al., 2025). However, grass mulch remains a low-cost, eco-friendly alternative for resource-constrained farmers who cannot afford plastic mulch. Its organic nature also improves soil structure and microbial activity over time, offering long-term soil health benefits that synthetic mulches cannot provide (Ali et al., 2025). Nevertheless, the environmental trade-offs of synthetic mulches must not be ignored. Issues of disposal, plastic waste accumulation, and potential soil contamination are growing concerns in intensive vegetable systems (Li et al., 2024; Rahimi & Shirzadi, 2025). In this regard, biodegradable plastic mulch has emerged as a promising alternative, combining the yield benefits of conventional plastic with reduced ecological risks (Chen et al., 2025; García & Pérez, 2024). Future research in Afghanistan should focus on evaluating biodegradable mulches under local conditions, alongside cost–benefit analyses, to ensure both productivity and sustainability.

The increased yield under black plastic mulch makes it a promising practice for improving productivity in low-rainfall regions like Kandahar (Hussein and Al-Mahmood, 2025). Although grass mulch improved growth and yield compared to the control, it was less effective than plastic mulch. This may be due to its lower efficiency in conserving soil moisture and less control over soil temperature fluctuations (Ahmad and Khan, 2024; Chen et al., 2025). However, grass still presents a cost-effective and eco-friendly alternative for resource-limited farmers. While plastic mulch offers substantial yield benefits, its environmental impact cannot be overlooked. Disposal and potential soil contamination from synthetic materials remain concerns (Li et al., 2024; Rahimi and Shirzadi, 2025). Future studies may explore biodegradable plastic mulch as a sustainable alternative (García and Pérez, 2024; Guo et al., 2025). Overall, the findings emphasize that mulching, especially black plastic mulch, can play a pivotal role in addressing Kandahar's dual challenges of water scarcity and low vegetable productivity. By improving water-use efficiency, enhancing fruit quality, and increasing overall yield, mulching is a vital agronomic practice for achieving sustainable intensification in the region (Guo et al., 2025). Integrating mulching practices into extension programs could accelerate adoption and contribute to both economic uplift and food security in southern Afghanistan.

CONCLUSION

The results of this study reveal that among all treatments, black plastic mulch consistently produced the highest plant height, number of branches, fruit weight, fruit diameter, number of fruits per plant, and overall yield (30.88 tons/ha). White plastic and grass mulches also improved performance compared to the control, but were less effective than black plastic mulch. These results affirm that mulching, particularly with black plastic, can enhance soil moisture retention, suppress weed growth, and regulate temperature, thereby improving plant vigor and fruit productivity. The findings suggest that integrating mulching practices, particularly black plastic mulch, can be a cost-effective and efficient strategy for boosting sweet pepper yields in water-limited regions like Kandahar. However, long-term environmental concerns related to plastic waste should be addressed. Further research is recommended to evaluate biodegradable alternatives and conduct economic assessments of mulching systems for large-scale adoption. In conclusion, the use of black plastic mulch offers a promising agronomic solution to increase sweet pepper productivity under arid and semi-arid conditions, supporting sustainable vegetable production and improving farmer livelihoods.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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