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Effect of straw and plastic mulches on growth and yield of zero tillage potato (*Solanum tuberosum* L.) in the Coastal Khulna Region of Bangladesh

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Summary: A randomized complete block design experiment was undertaken at the field laboratory of the Agrotechnology Discipline, Khulna University, Khulna, from November 2021 to March 2022 to ascertain the impact of various mulch treatments on zero tillage potato cultivation. The experiment employed BARI Alu 78 as the planting material and utilized three replications with five distinct mulch treatments. These mulch treatments were identified as follows: Straw mulch (T_1), Mulch film (T_2), Black polythene (T_3), White polythene (T_4), and Blue polythene (T_5). The metrics that were recorded included the number of sprouts, plant height, number of leaves per plant, leaf width, leaf length, number of tubers, tuber length, tuber breadth, number of defective tubers, weight of defective tubers, and tuber weight. Different mulching techniques significantly influenced the overall crop yield and the underlying factors that influenced the results. The mulch film treatment resulted in the highest yield, with a production of 34.76 tons per hectare, followed by black polythene (28.11 tons per hectare), straw mulch (23.74 tons per hectare), white polythene (20.44 tons per hectare), and blue polythene (18.66 tons per hectare). The economic analysis revealed that mulch film had a high benefit cost ratio along with high input and output. Black polythene came in second place when the benefit cost ratio was compared to that of mulch film and the rest of the three treatments. Combining zero tillage with mulch film or black polythene demonstrates significant potential for becoming a cost-effective practice in the coastal region of Bangladesh.

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Key words: growth, mulches, zero tillage, potato, yield, economic analysis

Introduction

Potato (*Solanum tuberosum* L.) is one of the most important vegetables and ranks fourth in major agronomic crops across the world after rice, wheat, and maize (Chakraborty et al., 2000; Ahmadvand et al., 2012). It shares 37% of global food demand (Olivares & Hernández, 2019). It is mainly consumed as a vegetable (Zhang et al., 2017). The botanical name of potato is *Solanum tuberosum* L. coined by Swiss botanist Gaspard Bauhin in 1596 and belongs to the Solanaceae family. It is a nutritional food and is considered one of the richest sources of calories and dietary energy (Zarzecka et al., 2020; Reddy et al., 2018). It refers to the highest amount of energy and dry matter producer per unit area in comparison to wheat (74.5%) and rice (58%) (Ahmed et al., 2017). Worldwide, the annual production of potatoes is 370.44 million tons (FAOSTAT, 2021). About 30% of the world's potato production is shared by developing countries, which is increasing day by day (Nowroz et al., 2021). Bangladesh ranked seventh in world potato production, with potatoes ranking second after rice in Bangladesh (FAOSTAT, 2018).

Mulching is a preventive layer and an improved cultivation practice of using organic or inorganic materials to retain the soil moisture, check weed growth, maintain soil temperature by covering the surface of the soil, reduce evaporation and conserve soil moisture (Singh et al., 2008; Kader et al., 2021; Zhao et al., 2012). Potato is a shallow-rooted crop and cannot tolerate extreme water depletion circumstances (Poddar et al., 2018). However, there has some potential limitations of plastic materials and negative impact on the environment. According to Chen et al. (2017) and Lee et al. (2021) polyethylene mulching hastens the decomposition of soil organic carbon and promotes the nitrification and denitrification processes thus accelerates the release of greenhouse gases into the atmosphere. The mulch film remnants also affect the soil's permeability, porosity, fertility, water use efficiency and carbon and nitrogen ratio ultimately reduces the crop yields (Jiang et al., 2017; Zhao et al., 2021). Because of the detrimental effects that plastic mulching residues have, mulch film management has become a global concern. Black, blue, translucent, and silver plastic mulches are frequently employed in agriculture (Kader et al., 2019). Among them, black plastic mulch is mostly used because of its capacity to absorb light (Amare & Desta, 2021). Black plastic mulch boosts emergence, stem number, and plant height (Bharati et al., 2020) and increases potato tuber production by 16% compared to control or no mulch (Kang et al., 2003).

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Zero tillage is a conservation agriculture practice that triggers low-cost and eco-friendly easy adoption of conservation agricultural cultivation practices without disturbing the soil (Gajda et al., 2018; Li et al., 2020; Mangalassery et al., 2014). Conventional tillage involves soil erosion, soil health deterioration, and soil compaction (Zuber & Villamil, 2016). Zero tillage is considered a potential method for sustainable agriculture practice which conserves and protects natural resources. (Mangalassery et al., 2014). Zero tillage was practiced in 111 million hectares of land globally in 2009, whereas, more than 180 million hectares of land was practiced in 2014 (Derpsch et al. 2010; Kassam et al., 2019). It is attaining attention because of no disturbance of soil and is considered a "win-win" cultivation practice (Six et al., 2004; Gajda et al., 2018).

Crop cultivation is restricted during the Rabi season in Bangladesh's coastal saline region due to a short winter period, salinity, a lack of fresh water, and the late harvest of T. Aman rice (Ali et al., 2019). Zero tillage can alleviate these issues by enhancing productivity (Ali et al., 2019). Conservation agriculture minimizes environmental disturbance and implies sustainable water management methods (Pittelkow et al., 2015). According to Zhang et al. (2011), conservation tillage and plastic mulch for potato production improve soil health and change the soil ecosystem by enhancing yield. Bharati et al. (2020) conducted research in Nepal's Dadeldhura district and discovered that plastic mulch is the best mulching medium for potato production. By altering the crop environment, various plastic mulches and zero tillage create a relationship between soil and agroecosystem, and there has been no study of the combination of these two for potato production in the Khulna region. The goals were to find the best mulch material for maximizing potato output with zero tillage, and to assess the economic profitability of growing zero tillage potatoes using various plastic mulches.

Materials and methods

The experiment was conducted at the field laboratory of Agrotechnology Discipline, Khulna University, from November 2021 to March 2022. The latitude and longitude of the experiment site are 22.800334 and 89.531821 respectively and altitude is 8 m. The experimental area falls under sub-tropical climate which can be characterized by low temperature and short day with low rainfall during the Rabi season (October to March), and high temperature, long day with high rainfall and high humidity during the Kharif season (April to September). Five treatments were employed with three replications.

T_1 – Straw mulch (control), **T_2** – Mulch film, **T_3** – Black Polythene, **T_4** – White polythene, **T_5** – Blue polythene. Medium sized BARI Alu -78 potato tuber of around 25 g weight was collected from On Farm Division of BARI of Khulna. A Total 15 kg tuber was collected. The experiment was conducted in A Randomized complete block design (RCBD) with three replications. Each block had 5 plots for 5 treatments. The size of each plot was 6 m x 1 m. The distance between plots was 50cm and the blocks were 75 cm. No tillage or land disturbance was done. Only furrows were made beside each plot for drainage. This operation was done after harvesting T-aman rice from the field. The plot was prepared according to the experimental design. Organic matter @ 10 ton/ha, Urea 250 kg/ha, TSP 140 kg/ha and MoP 230 kg/ha. This experience was done with mulching. So, a full dose as the basal application was applied at the time of sowing ***(Table 1)***. Five type of mulch material was used, viz. straw mulch, mulch film, black polythene, white polythene and blue polythene. They were placed on five plots of each block. A PVC pipe of 3inch diameter with toothed end was used to make a hole in the polythene for germination of the tuber. Tubers of BARI Alu 78 were placed in 15 plots. 5 plots for each block. Each plot had 2 rows. At each row tuber was planted 30cm apart. Each row constituted 16 hills. A total of 32 tubers were placed in each plot. So, a total of 480 tubers were planted. The distance between two rows was 60 cm. Weeding was done as usual when necessary. Harvesting was done when plant became yellow in color after 115 days of planting.

Table 1. Doses of manure and fertilizer used (BARI, 2019).

Manure/ Fertilizers	Amount	
	Per hectare	Per plot (5 m^2)
Cow dung	10000 kg	5 kg
Urea	250 kg	125g
TSP	140 kg	70 g
MoP	230 kg	115 g

Data collection

A number of sprouts was recorded till 15 DAP. Plant height, number of leaves per plant, leaf width, leaf length, number of branches per plant at 7 days interval and the final height was recorded at 84 DAP. A Number of tubers according to grade were counted and recorded from each plot. Three representative tubers were taken from each grade for measuring the average length for each grade. Three representative tubers were taken to measure average tuber breadth. The average breadth of the tuber from each plot was measured. After harvest, the tuber was graded into 3 groups G1, G2 and G3 according to size. Grade 1 was the largest in size. Total weight of each grade tuber was recorded separately for each plot. There were a few tubers that were defective and some of them were rotten. Their number was counted and recorded thereby. A defective and rotted tubers from each plot were measured and recorded.

Statistical analysis

The collected data of various category was analyzed statistically by a computer program named STATISTIX 10. The mean was calculated and analyzed for each criterion for each treatment. Analysis of variance was done for all categories of data taken by the F test. Between pairs the significant variation was tested by Least Significant Difference (LSD) at 5% level of significance.

Economic analysis

Input costs for labor, tuber cost, mulch, fertilizers for all the operations were recorded per unit plot and converted into per hectare. Price of the harvested product was considered in market rate basis. Economic analysis was done to find out the best mulch practice for zero tillage potato cultivation, as well as gross and net return.

Table 2. Effect of different mulch material on different parameters of potato plant which affects the tuber yield.

Treatments	No. of sprouts/plot	Plant height (cm)	Number of leaves/plant	Leaf width (cm)	Leaf length (cm)	Number of brunches
T_1	25.333b	28.700bc	33.000b	9.300b	14.100bc	2.6667bc
T_2	30.333a	33.367a	44.000a	11.100a	16.433a	5.3333a
T_3	31.333a	31.033ab	40.000a	10.100ab	15.467ab	3.6667b
T_4	23.333bc	26.000cd	33.333b	9.133b	12.233cd	2.0000c
T_5	19.667c	25.067d	31.000b	7.900c	11.167d	1.6667c
Level of significance	*	*	*	*	*	*

*: Significant at 5% level of probability

Benefit cost ratio

The benefit cost ratio BCR was calculated as follows:

$$\text{Benefit cost ratio} = \frac{\text{Gross return per hectare(Tk.)}}{\text{Total cost of production per hectare(Tk.)}}$$

Results

A significant variation in number of sprouts was observed in mulch film and black polythene viz. 30.333 and 31.333 respectively (LSD). The rest of the three treatments were not significant in the sprout number. The least sprouts observed in blue polythene was 19.667 (***Table 2***). A Significant variation in plant height observed in mulch film treatment- 33.367 cm followed by black polyethene- 31.033 cm, straw mulch- 28.700 cm and, blue polythene- 25.067 cm (***Table 2***). A significant difference in number of leaves was recorded for the mulch film and black polythene viz. 44 and 40 respectively (***Appendix 1***). Compared to these two, the remaining three treatments had little impact on leaves number. The minimum number of leaves were found in blue polythene treatment (31) (***Table 2***). Significant leaf width was observed for mulch film treatment which was 11cm (***Appendix 1***). Next large width was black polythene which was 10.1. No significant variation was there among this black, white polythene and control treatment according to LSD test. The lowest was for blue polythene which was 7.9 cm (***Table 2***). There was significance in variation among treatments (***Appendix 1***). Mulch film provided the best leaf length of 16.433cm followed by black polythene of 15.467 cm. The Lowest length found form blue polythene treatment was 11.167 cm (***Table 2***). Significant number of branches was recorded at mulch film treatment (***Appendix 1***) which was 5.3333 (LSD). Followed by black polythene and straw mulch viz. 3.667 and 2.667 respectively. The Lowest was for blue polythene which was 1.6667 (LSD) (***Table 2***). A Total number of tubers was recorded according to three grades. No significant differences were found for Grade-1 & Grade-2. However, the highest tuber number was observed from blue polythene (5.00) and the lowest was from black polythene (3.33) in Grade-1. Whereas white polythene provided a higher 37.50 tuber, and straw mulch provided the lowest 19.00 tuber in Grade-2. Significant difference was found only in Grade-3. The number of tubers recorded for mulch film was 1412.3, followed by black polythene- 1034 and blue polythene- 730.7 (***Table 5***). The comparison among the treatments for 3 grades is shown in the line graph (***Figure 1***). In the case of Grade-1, the best functioning treatments were mulch film and black polythene giving tuber length of 7.47 cm and 7.1 cm respectively. The least tuber length was observed in white polythene (5.3 cm).

Grade 2 & 3 had no significant variation among the treatments. The comparison of 3 grades among treatments is shown with the line graph (***Figure 2***). A significant variation observed in Grade-1 of mulch film (5.43 cm) and black polythene (5.07 cm) and least breadth of blue polythene (4.13 cm). The non-significant variation was observed in Grade-2 for all of the treatments although a higher breadth was observed in black polythene (4.40 cm) and the minimum breadth was observed in blue polythene (3.47 cm). Grade-3 variation was also non-significant. The comparison among the treatments for 3 grades is shown below with a line graph (***Figure 3***). Defected tuber number per plot was not significantly different (***Appendix 1***) from each of the treatments. However, the mean defect number was seen higher in straw mulch treatment which was 61.33 and the lowest at black polythene treatment (17.33) ***(Table 3***). The weight of the defective tuber was also not significant among the treatments. The highest weight was found in white polythene treatment (719.00 g) and the lowest weight was found in black polythene, 218.67 g (***Appendix 1***) (***Table 4***). Tuber weight was measured in three grades. For Grade-1, mulch film showed the highest tuber weight (1.94 kg) whereas blue polythene showed the lowest weight (0.43 kg). For Grade-2, the highest tuber weight was observed in mulch film (2.37 kg) and the lowest weight was obtained from blue polythene (0.69 kg). For Grade-3, the highest tuber weight found in mulch film (13.07 kg) whereas the lowest tuber weight was observed in blue polythene (8.30 kg). Mulch film showed a significant weight of total tuber weight (17.38 kg) (***Table 5***). The comparison among the treatments for 3 grades is shown below with a line graph (***Figure 4***).

Table 3. Number of defective tuber.

Treatments	Mean number of defective tubers
Straw mulch	61.33
Mulch film	20.67
Black Polythene	17.33
White polythene	34.33
Blue polythene	24.00

Table 4. Weight of the defective tuber.

Treatments	Mean weight of defective tubers
Straw mulch	315.00 g
Mulch film	472.00 g
Black Polythene	218.67 g
White polythene	719.00 g
Blue polythene	379.67 g

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Table 5. Yield of potato

Treatments	Total number of tubers/plot	Average length (cm)	Average breadth (cm)	Total weight (kg/plot)	Yield (t/ha)
Straw mulch	843.00c	4.97ab	3.72bc	11.87c	23.74c
Mulch film	1412.30a	5.67a	4.28a	17.38a	34.76a
Black Polythene	1068.80b	5.31a	4.00ab	14.11b	28.21b
White polythene	784.20c	4.21bc	3.51cd	10.22d	20.44d
Blue polythene	769.00c	4.06c	3.36d	9.33d	18.66d
CV	10.84	9.26	5.07	6.13	6.13
Level of significance	*	*	*	*	*

*: Significant at 5% level of probability

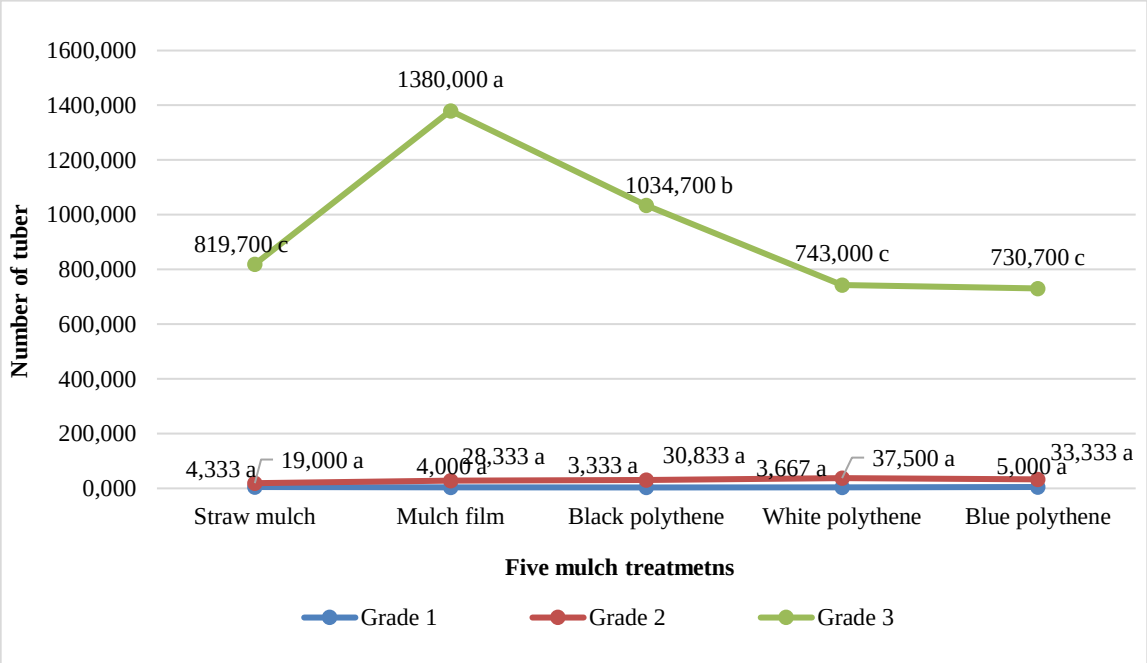

Figure 1: Tuber number of 3 grade for 5 mulch treatments

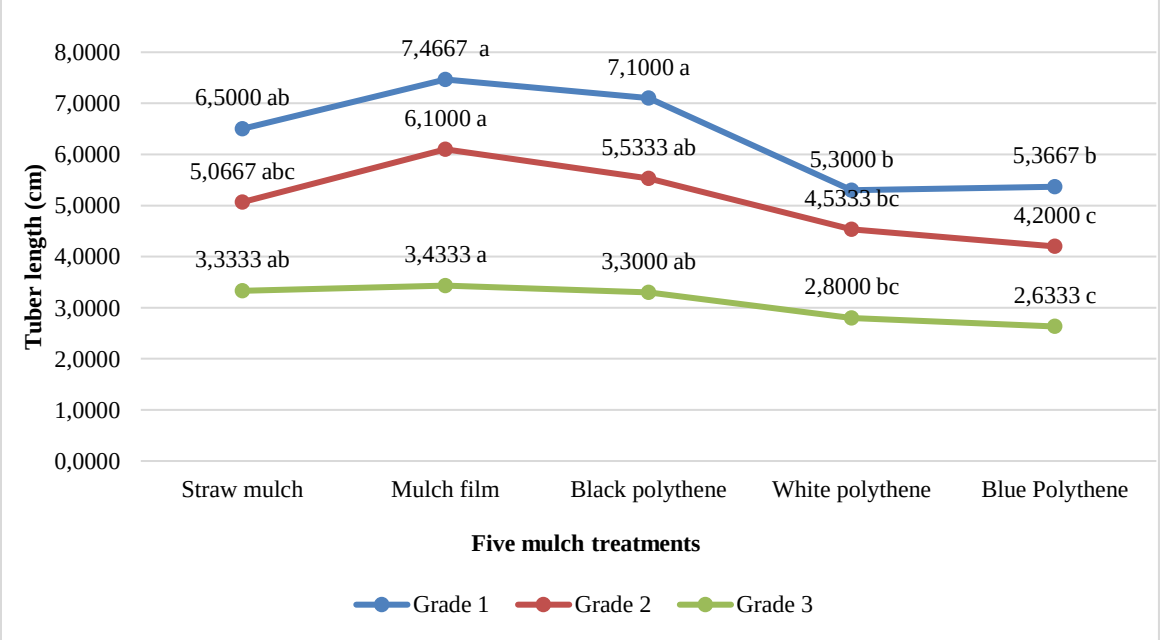

Figure 2: Tuber length of 3 grade for 5 mulch treatments

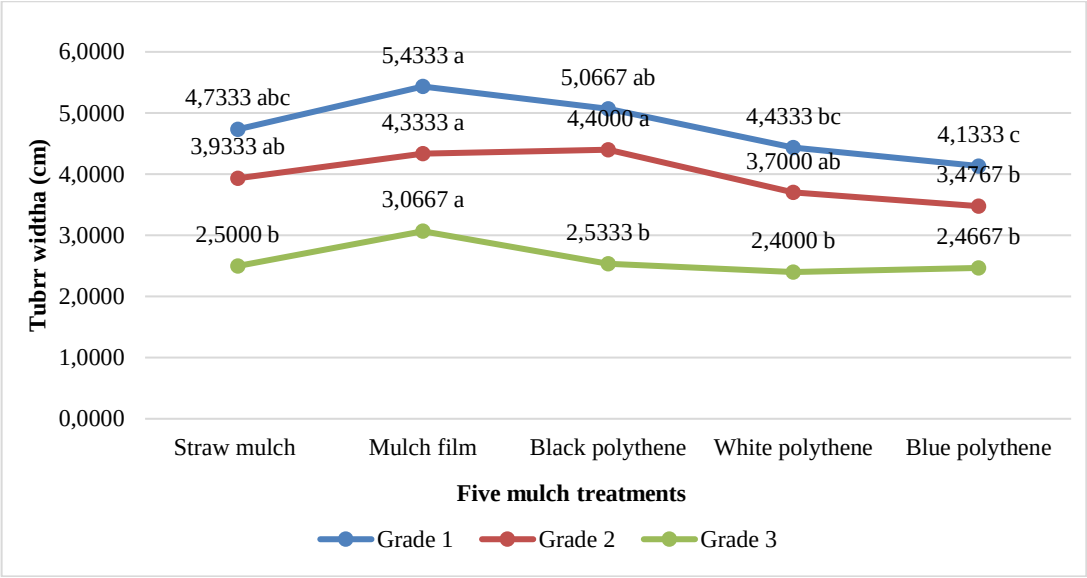

Figure 3: Tuber breadth of 3 grade for 5 mulch treatments

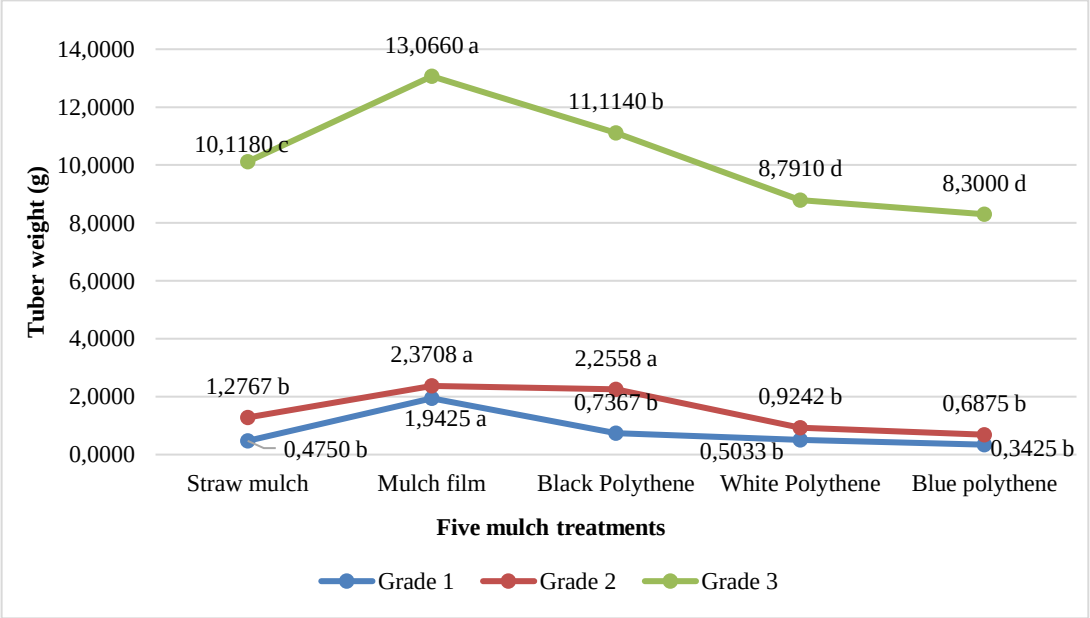

Figure 4: Tuber weight of 3 grade for 5 mulch treatments

From the correlational study, we can see that yield (t/ha) has a positive and significant correlation at 1% with other yield contributing parameters which indicates the effect of mulch film on those parameters and in terms provided at different amount of yield. A significant difference in yield was seen for mulch film (34.76 t/ha) which is the standard yield from conventional production (33.98 – 61.35 t/ha, BARI 2019) followed by black polythene (28.21 t/ha), and straw mulch (23.74 t/ha). Lowest yield was observed from blue polythene (18.66 t/ha) (***Table 7***). Mulch film had the highest cost of production (204000 Tk) while straw treatment had 184000 Tk. Production cost. The rest of the three treatments cost about same (174000 Tk.) (***Table 7***). The highest gross return was obtained from mulch film (521370 Tk) which was the most significant, followed by black polythene 423210 Tk. The lowest return was obtained from blue polythene (279900 Tk) (***Table 7***). A significant net return was found for mulch film (317370 Tk) followed by black polythene (249210 Tk) and straw mulch (172100 Tk). The lowest net return was obtained from blue polythene (105900 Tk) (***Table 7***). In case of benefit cost ratio, the most significant ratio was obtained from mulch film and black polythene which was 2.56 and 2.43 respectively. The lowest ratio was obtained from blue polythene (1.60) (***Table 7***).

Table 6. Correlation of yield with other yield contributing parameters.

Yield contributing parameters	Correlation to yield
Plant height	0.75**
Number of leaves	0.83**
Leaf width	0.73**
Leaf length	0.67**
Number of branches	0.81**
Total number of tubers	0.92**
Average tuber length	0.82**
Average tuber breadth	0.75**

**: Correlation is significant at 0.001 level

Table 7. Economic analysis.

Treatments	Yield (t/ha)	Cost (.000 Taka/ha)	Gross return (.000 Taka/ha)	Net return (.000 Taka/ha)	Benefit cost ratio (BCR)
Straw mulch (Control)	23.74c	184.00	356.10c	172.1c	1.93b
Mulch film	34.76a	204.00	521.37a	317.37a	2.56a
Black polythene	28.21b	174.00	423.21b	249.21b	2.43a
White polythene	20.44d	174.00	306.60d	132.60d	1.76c
Blue polythene	18.66d	174.00	279.90e	105.90e	1.60d
CV	6.13		3.29	6.35	3.28
Level of significance	*	NS	*	*	*

Discussion

In our study, we examined the impact of five distinct mulch treatments on crop yield and associated yield-contributing factors. Among these treatments, it was evident that both mulch film and black polyethylene yielded significantly higher results in terms of crop output and related parameters, as compared to straw mulch, white polyethylene, and black polyethylene. Specifically, mulch film and black polyethylene treatments produced yields of 34.76 tons per hectare and 28.21 tons per hectare, respectively, with the lowest yield observed in the case of blue polyethylene mulch, amounting to 18.66 tons per hectare.

These findings align with the results obtained in a study conducted by Ghimire et al. in 2021. Ghimire and colleagues reported that mulch film, specifically silver plastic mulch, and black plastic mulch treatments resulted in significantly higher sprout percentages (98.75%) and a greater average number of tubers (14.15 and 8.28, respectively) when compared to straw mulch, which achieved an 87.50% sprout percentage. Furthermore, the black plastic mulch treatment in their study exhibited taller plant heights (21.57 cm) in contrast to straw (16.12 cm).

Our observations are in line with the findings of another study conducted by Bhatta et al. in 2020. Bhatta and his team reported a higher number of leaves per hill in the mulch film (394.70) and black plastic mulch (362.00) treatments when compared to the control group (229.45). Additionally, both mulch film and black plastic mulch treatments demonstrated greater stem diameters (14.45 mm and 13.46 mm, respectively) in comparison to the control group (12.24 cm) in potato cultivation. Furthermore, a higher average number of tubers was observed for the mulch film and black plastic mulch treatments (8.30 and 7.95, respectively) in contrast to the control group (7.40).

The application of mulching film treatment resulted in notable increases in plant height, with an average of 33.367 cm, while the black polyethylene treatment also exhibited significant growth, reaching an average of 31.033 cm. Furthermore, the mulch film treatment displayed a noteworthy increase in the number of branches, with a mean count of 5.3333 branches per plant (LSD), followed by the black polyethylene treatment and the control, which showed respective branch counts of 3.667 and 2.667. Regarding the number of tubers, a significant difference was observed only in the third grade. Notably, the mulch film and black polyethylene treatments proved to be the most effective in promoting tuber length, yielding respective measurements of 7.4667 cm and 7.1 cm for Grade-1, 6.1 cm and 5.5333 cm for Grade-2, and 3.4333 cm and 3.3333 cm for Grade-3. In terms of tuber breadth, a significant variation was evident in the first grade, with mulch film and black polyethylene treatments yielding measurements of 5.4333 cm and 5.0667 cm, respectively. For Grade-3, only the mulch film treatment displayed a significant difference, with a breadth measurement of 3.0667 cm. The most effective treatment in terms of tuber weight was observed in the mulch film treatment, producing weights of 1.94 kg for Grade-1 tubers, 2.37 kg for Grade-2, and an impressive 13.07 kg for Grade-3 tubers. It is important to note that the number and weight of defective tubers did not show significant differences across the various treatments.

In our cost-benefit analysis, mulch film was more expensive (204,000 Tk per hectare) than black polyethylene (184,000 Tk per hectare). However, mulch film proved more profitable, yielding 317,370 Tk per hectare compared to 249,210 Tk for black polyethylene. The benefit-cost ratios for both mulch film and black polyethylene were similar at 2.56 and 2.43, respectively. Other mulch treatments did not show profitability.

This aligns with Ghimire et al.'s findings in 2021, where mulch film and black plastic mulch outperformed the control in terms of net returns (1,073.468 NRs and 964.093 NRs, respectively) and benefit-cost ratios (3.63 and 3.37, respectively), surpassing straw mulch (2.59). These results emphasize the economic advantages of mulch film and black polyethylene in agriculture, despite higher initial costs.

Conclusion

The study revealed that the choice of mulch materials had a significant impact on growth and yield-contributing parameters. The results of this study suggest that mulch film and black polyethylene mulch treatments are highly effective in enhancing crop yield and related parameters, despite their relatively higher costs. The cost-benefit analysis further demonstrates that, in terms of profitability, mulch film is a superior choice, with a favorable benefit-cost ratio. These findings contribute to the growing body of evidence supporting the use of mulch film and black polyethylene mulch as valuable practices in agricultural practices, highlighting their potential for improved crop productivity and economic returns. Zero tillage combined with either mulch film or black polythene shows significant potential for adoption as a cost-effective practice in the coastal region of Bangladesh.

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Appendix 1: Analysis of variance of the data on yield and yield contributing characters of zero tillage potato cultivation influenced by different types of mulching

Source of variation	Degrees of freedom	Mean Square (M.S) Value											
		Number of sprouts	Plant height	Number of leaves per plant	Leaf width	Leaf length	Number of brunches per plant	Tuber number grade 1	Tuber number grade 2	Tuber number grade 3	Total tuber number	Tuber length grade 1	Tuber length grade 2
Replication	2	26.600	50.224	78.067	5.760	32.888	6.467	9.267	840.350	7147	3263	0.148	0.050
Treatment	4	71.167*	35.718*	90.567*	4.240*	14.369*	6.5667*	1.233	143.725	224744*	222256*	2.926*	1.739
Error	8	4.017	3.119	5.567	0.393	1.2413	0.467	7.183	100.038	10931	11180	0.504	0.487

Source of variation	Degrees of freedom	Mean Square (M.S) Value											
		Tuber length grade 3	Average tuber length	Tuber breadth grade 1	Tuber breadth grade 2	Tuber breadth grade 3	Average tuber breadth	Number of defected tubers	Defected tuber weight	Tuber weight grade 1	Tuber weight grade 2	Tuber weight grade 3	Total tuber weight
Replication	2	0.078	0.039	1.718	0.836	0.480	0.660	4771.670	907403	0.171	0.510	0.378	0.3452
Treatment	4	0.385	1.436*	0.785*	0.476	0.217*	0.412*	954.270	108966	1.284*	1.778*	10.965*	31.505*
Error	8	0.108	0.201	0.140	0.178	0.060	0.037	539.42	97216	0.150	0.260	0.238	0.595

Appendix 2: Analysis of variance of the data in economic analyzation.

Source of variation	Degrees of freedom	Mean Square (M.S) Value			
		Yield (ton/ha)	Gross return (.000 Taka/ha)	Net return (.000 Taka/ha)	Benefit cost ratio (BCR)
Replication	2	1.38	0.20	0.2	0.00004
Treatment	4	126.02*	28348.90*	22701.9*	0.52*
Error	8	2.381	154.2	154.2	0.0046

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