

Impact of plantlet type and mulching materials interaction on strawberry (*Fragaria x ananassa*) cv. Festival growth, yield and quality in Bangladesh

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Abstract

Plantlet type and mulching materials considerably influence the quantitative and qualitative characteristics of strawberries, but their combined effect remains underexplored in Bangladesh, particularly with the cultivar Festival. An experiment was designed to study the impacts of plantlet type (tissue culture and runner) and mulching materials (no mulch, rice straw, sawdust, black polythene, and red polythene) on production and quality traits of strawberry cv Festival using a randomized complete block design (RCBD) with three replications. The experimental findings revealed that tissue culture plantlets combined with black polythene mulch produced the highest plant height at the fruiting stage, surpassing the lowest recorded height under runner plantlets without mulch by 80.6%. Similarly, the number of fruits plant⁻¹ increased by 50.4%, single fruit weight by 41.9%, fruit length by 39.3%, and yield plant⁻¹ by 110.7% compared to the least effective combination. For quality traits, this interaction also exhibited the maximum TSS, vitamin C, total phenolic content, and reducing sugars, exceeding the lowest values by 85.1%, 51.5%, 83.8%, and 88.2%, respectively. Results indicated that tissue culture plantlets with black polythene mulch are the most effective approach for strawberry cultivation in Bangladesh and similar agro-climatic regions.

Key words: Strawberry, tissue culture, runner, yield, quality

Introduction

Strawberry (*Fragaria x ananassa*) is among the tastiest fruits worldwide, with increasing demand in Bangladesh. It is a perennial, stoloniferous herb in the Rosaceae family. It is a non-climacteric and an aggregate fruit having wide climatic adaptations ranging from tropical to temperate (Khunte *et al.*, 2020). It is distinguished from other berry fruits by its attractive red colour and substantial nutritional content (Islam *et al.*, 2021). It promotes human health and well-being, comprising carbohydrates, organic acids, antioxidants, carotenoids, phenolic compounds, volatile compounds, vitamins, and minerals (Kilic *et al.*, 2021; Roussos *et al.*, 2022). Meanwhile, strawberry productivity is impacted by several factors, including cultivar types, growing practices, climatic conditions, and geographical origin (Pinheiro *et al.*, 2021; Roussos *et al.*, 2022). Specifically, cultivation practices, such as the selection of plantlets and mulching materials, strongly influence strawberry plant growth, fruit production, and quality (Kilic *et al.*, 2021; Pinheiro *et al.*, 2021; Roussos *et al.*, 2022).

Micropropagation or tissue culture technique becomes attractive due to quick, efficient, and large-scale propagation of virus-free planting materials (Valliath and Mondol, 2023). Conventional propagation through runners is unsuitable for large-scale commercial cultivation of strawberry as it is time-consuming, labour-intensive and spread viral diseases (Torrice *et al.*, 2018). A

substantial body of research proves that plants propagated through tissue culture exhibit superior performance to conventional methods, including higher yield and disease resistance against soil pathogens (Irshad *et al.*, 2023). According to Olagunju *et al.* (2021), gibberellins used in culture media induced plant development by increasing cell division and elongation. Moreover, tissue culture plantlets can convert more light into chemical energy than runners (Al-khayyt *et al.*, 2024).

Mulching is a key cultural practice, as it reduces weed competition, manages soil moisture, and regulates the soil's heated environment (Ali *et al.*, 2023; Hama *et al.*, 2023). It significantly impacts strawberry production regarding yield and quality (Sharma and Kumar, 2012). Mulches regulate the root zone temperature, which plays a vital role in plant physiology, root development, mineral uptake and ultimately enhanced yield (Amare and Desta, 2021). It provides better plant-growing conditions through nutrient availability, weed suppression, reduced evaporation and improved soil health with organic amendments (Singh *et al.*, 2021; Jat *et al.*, 2024). Mulch materials significantly improve crop performance and reduce harvest duration by enhancing nutrient availability (Li *et al.*, 2021; Mena *et al.*, 2025). Mulches promote reproductive development by better plant photosynthate accumulation (Thakur *et al.*, 2019; Dhatt and Ravikumar, 2024).

Though strawberries are a promising fruit crop in Bangladesh,

they face natural challenges like sudden temperature changes and low soil moisture, particularly during flowering and fruiting. Bangladesh currently meets obstacles in obtaining high-quality planting material for strawberries, and the exploration of tissue culture plantlets in combination with different mulching techniques is timely and relevant for local agricultural practices. However, the selection of plantlet type, whether tissue culture or runner, significantly influences strawberries' growth, yield, and fruit quality. Besides, the performance of plants is directly impacted by temperature, moisture content, and weed suppression, all of which can be optimized with mulching. Although the individual effects of plantlet type and mulching materials on strawberry production are well established, their combined impact remains underexplored, especially for Bangladesh's widely cultivated Festival variety. Based on this, the research focuses on investigating the effect of tissue culture and runner plantlets with different mulching materials for developing sustainable cultivation practices that will enhance productivity and fruit quality of strawberry cv Festival.

Materials and methods

Planting materials and growing conditions: A field experiment was conducted from November 2021 to April 2022 at the horticulture farm of Sher-e-Bangla Agricultural University, Bangladesh. The strawberry plantlets (tissue culture and runner) cv. Festival were planted in a raised bed following a planting system of 60 cm×30 cm. Among the various mulch materials, *i.e.*, no mulch (control), rice straw, sawdust, black polythene, and red polythene. This study used a randomized complete block design (RCBD) with three replications. All plots received consistent cultural methods and plant protection measures during the experiment. The mean values for growth, floral development, yield, and quality parameters were determined after selecting three plants randomly for observation in each treatment.

Growth characteristics: Plant height and number of leaves plant⁻¹ were recorded at different growth stages, including vegetative, flowering, and fruiting. The height of the plant was measured from the base to the top of the main stem, whereas the leaf numbers were calculated by estimating all the leaves on each plant.

Floral features: Days to first flowering and fruiting were counted by visual observation from the date of plantlet transplanting. By counting the buds and flowers of each plant, the number of buds plant⁻¹ and the number of flowers plant⁻¹ were determined.

Yield components: Yield plant⁻¹ (g) was calculated by multiplying the weight of a single fruit and number of fruits plant⁻¹ for each treatment. The average of all harvests from three randomly chosen plants per treatment was used to calculate the ultimate yield. There were six or seven strawberry pickings in total, occurring every two days. By counting the fruits of each selected plant, the number of fruits per plant⁻¹ was determined. Besides, an Electronic Precision Balance was used to measure single fruit weight in grams. A Digital Caliper was used to calculate the fruits' length (cm) and diameter (mm).

Total soluble solids content: The total soluble solid (TSS) was measured directly from the fruit pulp of strawberry using a digital hand refractometer (Tokyo, Japan) at room temperature and expressed in °Brix.

Vitamin-C content: Following the Oxidation Reduction Titration process, the vitamin-C content of strawberry fruits was measured (Tee *et al.*, 1988). Whatman No. 1 filter paper was used to combine and filter the single fruit. A 5% oxalic acid solution made a 100 mL volume. For titration, the dye solution 2, 6-dichlorophenol indophenol was used. Using L-ascorbic acid as a known sample, the mean observations demonstrated the amount of dye needed to oxidize a certain volume of L-ascorbic acid solution at an unknown concentration. Titration was always carried out using a 5 mL solution, and the pink colour indicated the endpoint of titration, which lasted for 10 seconds. After that a record of the burette reading was made.

pH value: A digital pH meter was used to measure the pH after the fruit pulp from each treatment was filtered separately.

Phenolic content: The Singleton *et. al.*, (1999) method was used to measure the phenolic content. 85% methanol was used to homogenize 250 mg of fresh fruit samples. The extract was then centrifuged at 3, 000 g for 15 minutes at 10°C, and the supernatant was collected. After that, Folin–Ciocalteu's reagent (2 mL) was added to 2 mL of the supernatant, followed by the addition of a 7.5% sodium carbonate solution (2 mL) to each test tube. Following a 30 to 45 min incubation period, the absorbance at 725 nm was measured in comparison to a reagent blank. Gallic acid was used to produce a standard curve determining the total phenol amount in the unknown sample.

Sugar content: For total sugar, a 5-mL aliquot was collected from a 100-mL sample, combined with three drops of HCl, and stored overnight. The following day, 2-3 drops of phenolphthalein indicator were added, and a 30% sodium hydroxide (NaOH) solution was used to neutralize it. It was titrated using methylene blue as an indicator against 1.0% glucose in boiling solution. The endpoint was defined as the appearance of brick red, and the findings were reported as a percentage for total sugar (Lane and Eynone, 1923). For reducing sugars, 10g pulp was smashed with distilled water and the volume was made up to 100 mL after filtering with muslin cloth. Next, with methylene blue as an indicator, 5 mL of fehling solution "A" and "B" were combined in a 100 mL conical flask and titrated against a 1% glucose solution while boiling. Non-reducing sugar was calculated by subtracting the amount of reducing sugar from the total sugars and multiplying the result by 0.95. Non-reducing sugar (%) = Total sugar (%) - Reducing sugar (%) × 0.95. The appearance of brick red was used to indicate the endpoint.

Statistical analysis: IBM SPSS Statistics 21 (IBM Corp, Armonk, NY, USA) software program was used for performing the analysis of variance (ANOVA) on the data, and the least significant difference (LSD) at P < 0.05 was used to compare the average values of the data.

Results

Growth characteristics: Plantlets and different mulch materials significantly affected plant height and number of leaves plant⁻¹ of strawberry at various growth stages (Table 1). Observations revealed that plant height ranged between 18.8 cm to 13.1 cm at the vegetative stage, 22.7 cm to 14.8 cm at the flowering stage and 24.2 cm to 13.2 cm at the fruiting stage (Table 1). Moreover, the maximum number of leaves plant⁻¹ (7.5, 14.3 and 21.4 at the

vegetative, flowering and fruiting stage, respectively) was achieved in tissue culture with black polythene mulch whereas the minimum number of leaves plant⁻¹ (4.6, 6.8 and 12.0 at the vegetative, flowering and fruiting stage, respectively) was seen in runner plants having no mulch materials (Table 1).

Floral features: Days to first flowering, days to first fruiting, number of buds plant⁻¹ and number of flowers plant⁻¹ of strawberry showed notable in variation by plantlets and different mulches (Table 2). Tissue culture plants growing with black polythene produced early flowering (40.7 days) and fruiting (45.7 days) in comparison with all other treatments, where the runner plants under no mulch took more time to flowering (53.6 days) and fruiting (62.8 days). Meanwhile, tissue culture plantlets growing under black polythene displayed the highest number of buds (39.1 plant⁻¹) and flowers (37.7 plant⁻¹). In contrast, the lowest number of buds (29.4 plant⁻¹) and flowers (28.3 plant⁻¹) was attained in runner plantlets without mulch at the mature stage.

Yield components: Data regarding the number of fruits plant⁻¹, single fruit weight, fruit length, fruit diameter and yield plant⁻¹ of strawberry revealed significant variation due to different plantlets with mulch conditions (Table 3). The largest number of fruits plant⁻¹ was recorded in tissue culture plantlets with

Table 1. Interaction effect of different plantlets and mulch materials on the growth characteristics of strawberry

Plantlets	Mulch materials	Plant height (cm)			Number of leaves plant ⁻¹		
		Vegetative stage	Flowering stage	Fruiting stage	Vegetative stage	Flowering stage	Fruiting stage
Tissue culture	Control	13.3±0.7d	15.8±1.1de	15.4±0.8fg	4.7±0.2ef	7.5±0.2ef	13.1±1.0de
	Rice straw	16.0±0.5bc	20.5±0.8abc	21.1±1.2bc	6.4±0.1bc	11.5±0.3bc	17.7±1.4abc
	Saw dust	15.6±0.3bcd	19.5±0.8bc	22.1±0.8ab	6.6±0.6b	10.2±0.44cd	19.0±1.3ab
	Black polythene	18.8±1.6a	22.7±1.3a	24.2±0.8a	7.5±0.03a	14.3±0.2a	21.4±1.7a
	Red polythene	15.0±0.4bcd	19.4±0.9bc	20.1±0.4bc	5.7±0.3cd	10.5±0.8cd	16.4±1.3bcd
Runner	Control	13.1±0.9d	14.8±0.1e	13.4±0.8g	4.6±0.2f	6.8±0.1f	12.0±0.7e
	Rice straw	14.4±0.9bcd	19.3±1.3bc	17.1±0.9def	5.6±0.3cde	10.0±1.3cd	13.7±1.0cde
	Saw dust	14.2±0.9cd	18.0±1.5bcd	18.6±1.0cde	5.2±0.4def	9.3±0.5de	15.5±1.3b-e
	Black polythene	16.9±0.3ab	20.8±0.7ab	19.3±1.3bcd	6.9±0.1ab	12.7±0.7ab	16.3±1.3bcd
	Red polythene	14.1±0.2cd	17.3±0.4cde	16.4±0.9ef	5.0±0.2def	8.8±0.4de	13.0±1.6de
<i>P</i> value		0.002	0.001	0.000	0.000	0.000	0.001
CV (%)		7.78	8.08	7.6	7.19	8.46	13.17

Table 2. Interaction effect of different plantlets and mulch materials on the floral features of strawberry

Plantlets	Mulch materials	Days to first flowering	Days to first fruiting	Number of buds plant ⁻¹	Number of flowers plant ⁻¹
Tissue culture	Control	51.8±1.20ab	58.6±1.09ab	30.3±2.0c	29.3±1.66cd
	Rice straw	44.7±1.36bcd	50.7±3.84bcd	37.4±2.08ab	36.1±1.59ab
	Saw dust	43.3±3.44cd	47.6±4.33cd	34.4±1.9abc	33.1±1.54a-d
	Black polythene	40.7±2.89d	45.7±3.18d	39.1±2.03a	37.7±2.01a
	Red polythene	45.7±1.76bcd	51.6±0.88bcd	33.2±2.1abc	31.9±1.71bcd
Runner	Control	53.6±0.73a	62.8±1.48a	29.4±2.0d	28.3±1.66d
	Rice straw	49.3±3.22abc	55.7±4.37abc	31.9±1.9bc	30.6±1.52bcd
	Saw dust	48.6±2.67abc	53.6±3.76abcd	31.5±2.2bc	30.2±2.42cd
	Black polythene	46.7±1.20abcd	53.3±2.91abcd	36.2±1.7abc	34.9±1.45abc
	Red polythene	49.8±1.59abc	56.7±3.48abc	30.2±2.0c	29.4±1.96cd
<i>P</i> value		0.013	0.038	0.039	0.014
CV (%)		7.52	9.7	10.2	9.3

Table 3. Interaction effect of different plantlets and mulch materials on yield components and yield of strawberry

Plantlets	Mulch materials	Number of fruits plant ⁻¹	Single fruit weight (g)	Fruit length (cm)	Fruit diameter (mm)	Yield plant ⁻¹ (g)
Tissue culture	Control	25.1±1.09cd	19.9±1.0d	4.11±0.22de	23.33±1.58d	496.9±24.2e
	Rice straw	30.4±1.96b	25.1±1.5abc	4.81±0.28abc	30.23±0.94bc	765.4±81.5bc
	Saw dust	29.9±1.87bc	24.7±1.5a-d	4.56±0.17bcd	27.56±1.26bcd	736.0±50.0bc
	Black polythene	36.4±1.82a	28.1±2.1a	5.28±0.20a	35.20±0.76a	1014.3±24.1a
	Red polythene	29.7±1.67bc	23.2±1.6bcd	4.27±0.26cde	26.28±0.95cd	685.5±31.7cd
Runner	Control	24.2±1.01d	19.8±1.7d	3.79±0.20e	19.04±0.97e	481.3±43.5f
	Rice straw	25.2±1.63cd	22.0±1.7cd	4.16±0.17cde	25.93±1.87d	553.9±56.3de
	Saw dust	26.5±1.08bcd	21.7±1.0cd	4.11±0.21de	25.52±1.59d	574.3±28.1de
	Black polythene	30.8±1.03b	27.0±1.5ab	4.95±0.13ab	31.25±1.25b	830.5±35.6b
	Red polythene	25.2±1.69cd	20.2±0.65d	4.06±0.20de	23.47±1.83d	509.6±39.7e
<i>P</i> value		0.000	0.004	0.001	0.000	0.000
CV (%)		8.81	11.15	8.1	8.66	11.11

Note. Values represent means ± SE (n = 3) along with DMRT values (P < 0.05). Different letters in a row for a trait indicate significant differences. DMRT = Duncan multiple range test; SE = Standard error; CV = Coefficient of variation.

black polythene mulch at harvest, 50.4% more than the runner plantlets using no mulch materials, where the least number was found. When tissue culture plantlets were planted in black polythene mulch, the fruit weight increased by 41.9% compared to the runner without mulch. Meanwhile, tissue culture plants growing under black polythene generated the highest fruit length (5.28 cm) and fruit diameter (35.20 mm), respectively. However, the lowest fruit length (3.79 cm) and fruit diameter (19.04 mm) were attained in runner plants having no mulch. Moreover, the fruit yield ranged between 1014.3 g plant⁻¹ in tissue culture having black polythene mulch to 481.3 g plant⁻¹ in runner without mulch, showing 110.7% enhancement.

Quality traits: Total soluble solid, vitamin-C, pH value, total phenolic content, non-reducing sugar and reducing sugar of strawberry fruit were significantly influenced by the different plantlets and mulch materials (Fig. 1). The tissue culture plants planted with black polythene mulch revealed the maximal total soluble solid (11.27 °B) values when compared to all other treatments, while the runner plants using no mulch materials showed the minimal total soluble solid (6.09 °B) values (Fig. 1A). When compared to all other treatments, tissue culture with black polythene demonstrated the superior vitamin-C content (42.82 mg/100 g), showing 51.52% advancement (Fig. 1B). The pH value (3.17) of strawberry fruit

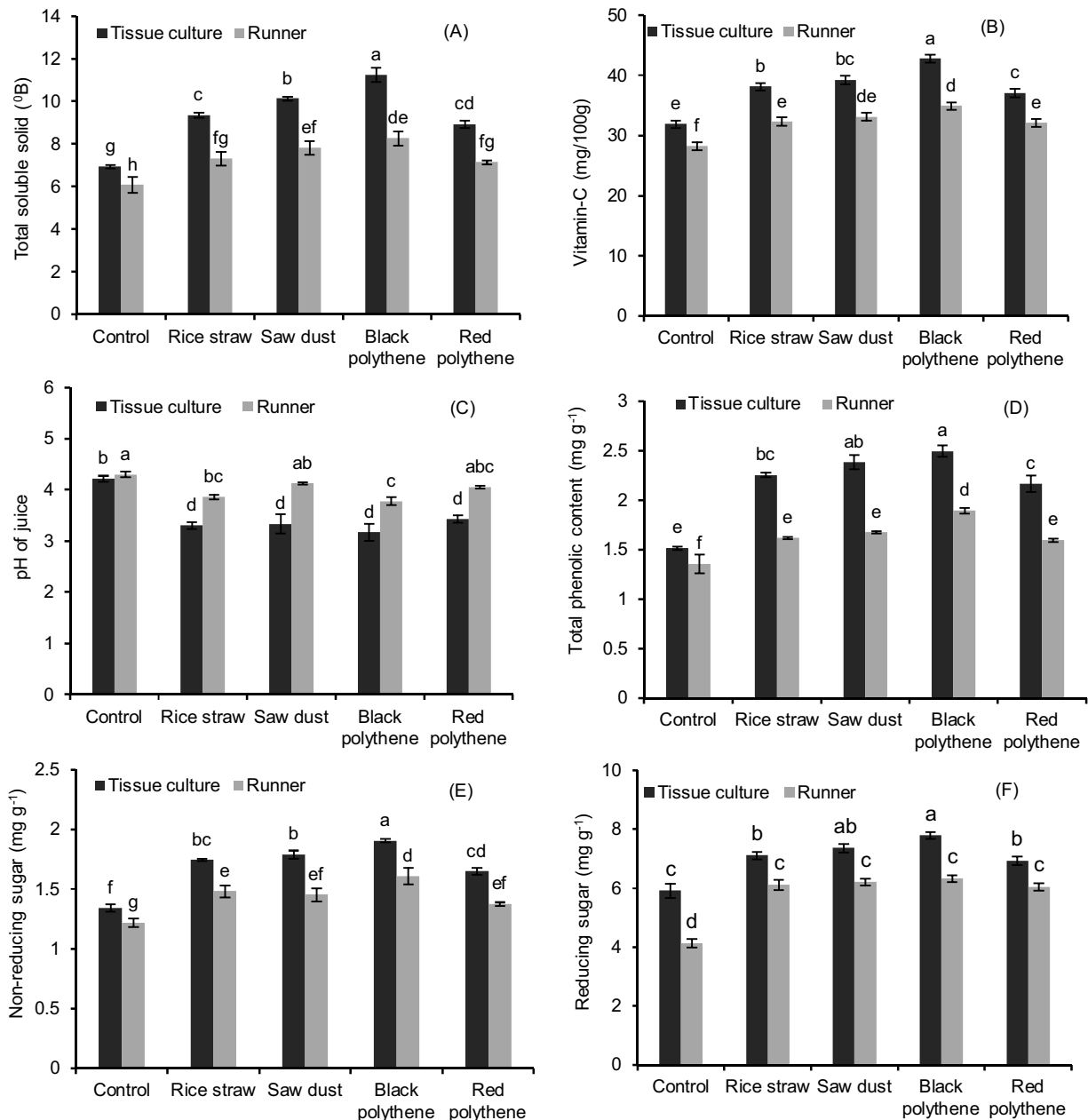


Fig. 1. Quality traits (A) total soluble solid (B) vitamin C (C) pH value (D) total phenolic content (E) non-reducing sugar and (F) reducing sugar of strawberry under different plantlets and mulching materials. Values represent mean \pm SE (n = 3); vertical bars indicate SE. Different letters within a trait indicate significant differences.

juice was significantly lower in tissue culture planted with black polythene mulch whereas the higher pH value (4.30) was seen in runner having no mulch (Fig. 1C). The total phenolic content ranged between 2.50 mg g⁻¹ FW to 1.36 mg g⁻¹ FW in tissue culture plants with black polythene to runner plants using no mulch, presenting 83.82% increased (Fig. 1D). The tissue culture plants mulched with black polythene exposed the highest non-reducing sugar (1.91 mg g⁻¹ FW) and reducing sugar (7.79 mg g⁻¹ FW), while the lowest non-reducing sugar (1.22 mg g⁻¹ FW) and reducing sugar (4.14 mg g⁻¹ FW) was observed in runner plants without mulch (Fig. 1E and Fig. 1F)

Discussion

The combined effect of plantlets and mulch materials notably increased strawberry plant height and leaf numbers. The highest plant height and number of leaves plant⁻¹ were recorded in tissue culture plantlets and mulch with black polythene. This may be due

to plant growth regulators used in the culture media during tissue culture plantlet production. The current results are consistent with Olagunju *et al.* (2021), who stated that gibberellins used in culture media induced plant growth by increasing cell division and elongation. Mon *et al.* (2021) revealed that *in vitro* rhizospheric and endophytic bacterial inoculation significantly increased plant height in tissue culture banana plantlets compared to conventional propagation. Meanwhile, black polythene mulch exhibited superior performance in terms of plant height and leaf number of strawberries at different growth stages. This might be due to the favourable growing conditions provided by the mulch. Singh *et al.* (2021) revealed that mulch provides better growing conditions for plants through nutrient availability, weed suppression, and adding organic matter into the soil. Similarly, black polythene mulch increased leaf number by approximately 26.4% in tomatoes (Adamczewska-Sowińska *et al.*, 2025) and 25% in lettuce (Jahan *et al.*, 2018) compared to other organic and

inorganic mulch materials. These results are also aligned with Ngente *et al.* (2021).

The results indicate that using tissue culture plantlets in interaction with black polythene mulch substantially promoted early flowering and fruiting, while also leading in the maximum number of buds and flowers (Table 2). This might be because of the impact of plant growth regulators usually used during the micropropagation, which reduced the duration of flowering and fruiting. Holmes *et al.* (2021) revealed that using plant growth regulators such as gibberellins (GAs) and paclobutrazol is crucial in inducing early flowering and fruiting in tissue culture plantlets. Similar results are also found by Olagunju *et al.* (2021). Furthermore, tissue culture plantlets generate more buds and flowers than conventionally propagated runner plants because of their genetic stability (Naing *et al.*, 2019). Black polythene mulch accelerates the onset of flowering and fruit setting by 6 to 8 days by creating a favourable microclimate that promotes hormonal balance in strawberry (Singh *et al.*, 2023 and Rannu *et al.*, 2018). Similar results were also seen in rose (Thakur *et al.*, 2019) and in gladiolus (Dhatt and Ravikumar, 2024) by better accumulation of photosynthates in the plants. Likewise, mulching with black polythene resulted in an 83% increase in bud formation and a 90% higher flower count than non-mulched conditions due to conserved soil moisture (Misra *et al.*, 2023).

The highest yield and contributing components were recorded in tissue culture plantlets with black polythene mulch (Table 3). Micropropagated plantlets are virus-free and have a better root system than runner plantlets, leading to better nutrient and water uptake, which increases the number of fruits. This is in line with Valliath and Mondol (2023), who reported that plantlets produced through tissue culture technique are virus-free and exhibit higher fruit production than traditional runner plants. Meanwhile, plants under black polythene mulch also produced higher number of fruits. This could be due to improved soil water retention, better nutrient and water uptake, and plant hormonal balance (Rannu *et al.*, 2018). This result also aligns with Singh *et al.* (2023) and Ngente *et al.* (2021). Single fruit weight is a crucial factor for determining the yield of a crop. In our study, interaction of tissue culture plants and black polythene mulch was supreme for the single fruit weight of strawberry. Plantlets generated through tissue culture have a greater capacity for photosynthesis, which accelerated more carbohydrate production and as a result fruit weight increased. It was reported that tissue culture plantlets have ability to convert more light into chemical energy than runner (Al-khayy *et al.*, 2024). Moreover, the active participation of enzymes in promoting growth and development also contributed to an increase in the weight of individual fruits of plants grown under black polythene. In cucumbers, Torres-Olivar *et al.* (2016) also noted similar results. In the case of fruit length and diameter, tissue culture plantlets had better results as compared to runner plants. It might be due to the cell division accelerated by the plant growth regulators used in the tissue culture technique that enhanced fruit size. Supporting these findings, Olagunju *et al.* (2021) revealed that gibberellins used in micropropagation has a positive effect on cell division. Similarly, black polythene mulch promotes reproductive development by better accumulation of photosynthates in the plant, resulting longer and bigger fruits (Thakur *et al.*, 2019; Dhatt and Ravikumar, 2024). However, tissue

culture plants mulched with black polythene not only enhanced plant growth but also impacted positively in reproductive traits such as fruit number and fruit weight, leading to increased yield. Similar findings were also seen by Nyochembeng and Mankolo (2021) in pepper plants.

The current experiment shows that combination of tissue culture plantlets and black polythene mulch produced the highest amount of total soluble solids, vitamin C, pH value, total phenolic content, non-reducing sugar, and reducing sugar of strawberry fruit (Fig. 1A-F). Tissue culture plantlets promoted the breakdown of starch due to positive impact of plant growth regulators, which increased TSS in fruits. This is in line with the statement of Rathod *et al.* (2021), who concluded that the use of NAA during tissue culture in strawberry plants enhances the TSS levels by boosting the concentration of volatile compounds and promoting the breakdown of starches. Similarly, tissue culture plants have a greater capability to convert light into energy, leading to increased vitamin-C content in strawberry fruits (Al-khayy *et al.*, 2024). Meanwhile, using black polythene also increased TSS and vitamin-C content of strawberry fruits by improving light exposure and supporting photosynthesis. These results are in accordance with Nyochembeng and Mankolo (2021). According to Muñoz *et al.* (2022), black polythene mulch enhances production of larger and juicier fruits by soil moisture retention in strawberry fields, resulting lower pH of fruits. This statement is in aligns with our current findings. In our experiment, we found the maximum phenolic content in the tissue culture plants grown under black polythene mulch. A similar result was noted by Irshad *et al.* (2023), who reported that total phenolic content of strawberry was approximately 30% higher in tissue culture plantlets than other propagating materials. Similarly, black polythene mulch has proved to be effective to increase phenolic component in lettuce plant (Öz, 2023). Our findings show that tissue culture plants with black polythene mulch recorded the highest non-reducing and reducing sugar in strawberry fruits. This might be due to the increased photosynthesis and enzymatic processes in tissue culture plants, which enhanced sugar production in fruits. Al-khayy *et al.* (2024) showed that tissue culture plants have greater ability to convert more light into chemical energy.

In summary, tissue culture plantlets, when combined with black polythene mulch, consistently outperformed other combinations, resulting in superior plant height, number of leaves, early flowering, higher fruit yield, and enhanced quality parameters such as TSS, vitamin C, and sugar levels. These findings suggest that the integration of tissue culture propagation with black polythene mulch represents a highly effective strategy for optimizing strawberry production in Bangladesh, especially for Festival variety.

Author contribution: F.I. and M.M.R. proposed and designed research programs; M.S.R. and M.R.S analyzed data. M.H and J.U. supervised the research process. M.M.R. and M.K.C. drafted the manuscript. All authors have read the manuscript.

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