Pertanika J. Trop. Agri. Sci. 46 (4): 1293 - 1308 (2023)

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Watermoss Mulching Stimulates the Productivity and Physiochemical Properties of Strawberry in the Tropical Ecosystem of Southern Bangladesh

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ABSTRACT

Strawberry is one of the most lucrative antioxidants and phytochemicals enriched temperate fruits. Nevertheless, good-quality fruit production requires special soil management practices like mulching and other strategies in tropical and sub-tropical regimes with short and dry winters. In the present research, strawberry var. BARI Strawberry-3 was cultivated using Asian watermoss (AW), water hyacinth (WH), paddy straw (PS), black polythene (BP), and silver polythene (SP) mulching along with control at the tropical weather-inclined southern part of Bangladesh from October 2018 to April 2019. The aim was to evaluate the comparative influences of those organic and synthetic mulches on root and shoot growth phenology along with subsequent reproductive behaviors, fruit yield, and fruit biochemical properties of strawberries under such an ecosystem. The experiment was conducted in a randomized complete block design with four replications. Mulching exhibited statistical superiority over control for strawberry growth, yield, and fruit quality indicators, where organic mulches performed better than others. Among the mulches, AW mulching produced the healthiest plant, having maximum plant height (20.40 cm), leaf number (23.33 per plant), canopy diameter (34.30 cm), single leaf area (100.06 cm^2), and root length (19.05 cm) resulting in

ARTICLE INFO

Article history:
Received: 02 June 2023
Accepted: 06 July 2023
Published: 02 November 2023

DOI: https://doi.org/10.47836/pjtas.46.4.14

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ISSN: 1511-3701
e-ISSN: 2231-8542

the highest root and shoot biomass. Though the plants received AW mulch required maximum duration from transplanting to flowering (47.88 days) and flowering to harvest (29.60 days), those plants produced the highest number of flowers (21.20 per plant) as well as fruits (19.63 per plant), and ultimately the utmost fruit yield (370.02 g/plant and 15.42 kg/ha) being significantly dissonant from all other treatments. Thus, a 57.57% yield increase over control was recorded from AW mulching. Furthermore, statistically, the maximum total soluble solids (TSS) (9.93%), TSS/acidity ratio (17.37), and vitamin C (58.30 mg/100 g), but the minimum titratable acidity (0.57%) content of strawberry was noticed in AW treatment. WH and BP mulches had statistical consistency with the best treatment for a few attributes. Therefore, crop residues, aquatic plants, or their by-products can be used as mulch for quality strawberry production in dry winter, especially in tropical and subtropical regions.

Keywords: Fruit crop, organic and inorganic mulching, plant growth, tropical environment, yield and quality

INTRODUCTION

Sustainable fruit production requires balanced nutrients, cultural practices, and a favorable environment for optimal quality and high biological value. Strawberries (*Fragaria x ananassa* Duch.), being one of the most fascinating and important temperate fruits, are well adapted in diverse geographical areas and, therefore, can be grown in the tropics and sub-tropics (Bakshi et al., 2014) provided that effective management practices are ensured. Besides its pleasant taste and other organoleptic attributes, strawberry can be regarded as a functional fruit since the fruit contains significant levels of bioactive compounds such as phenols, flavonoids, vitamin C, and anthocyanins that have antioxidant activity to support human health and immunity (D'Urso et al., 2015; Fernandes et al., 2012).

Despite its diverse climatic adaptability, the crop is very sensitive to moisture and nutrient fluctuations due to its surface-feeding nature. Therefore, moisture and temperature conditions in the topsoil layer largely influence the crop's growth and development. In Bangladesh, it grows well in the winter, especially October-November, the best planting time to complete its life cycle before the temperature rises in March (Paul et al., 2017). Being a winter or dry season crop, it has to face a lot of natural adversities like poor soil moisture and temperature fluctuation, especially during flowering and fruiting in tropical and sub-tropical areas like Bangladesh. Again, as its fruits lay in soil, soil-dwelling pathogens can easily invade and destroy it. Hence, the application of mulching to the crop field is an appropriate intercultural operation that can facilitate several advantages of conserving soil moisture, suppressing weed growth, checking soil erosion, and preventing berries from direct contact (Barche et al., 2015; Sharma & Goel, 2017).

Moreover, mulches suppress extreme fluctuations in soil temperature (daily and seasonal), reducing soil moisture loss through evaporation and assisting in maintaining soil fertility (Iqbal et al., 2016; Slathia & Paul, 2012). However, mulching practices can be executed with locally available organic or commercially inorganic materials. Besides Bangladesh being a Gangetic Delta, stagnant water bodies as well as water logging for more than eight months a year has been common scenario particularly in the mid to southern part (Awal & Islam, 2020; M. H. R. Khan et al., 2015), where water hyacinth (*Eichhornia crassipes* L.) and Asian watermoss (*Salvinia cucullata* Roxb.) are the two very commonly observed noxious aquatic weeds (Islam & Atkins, 2007).

In addition, *Salvinia cucullata* is one of the base materials for floating bed agriculture in the wetlands and water-stagnant southern region of the country (Irfanullah et al., 2011; Mondal et al., 2022; Sunder, 2020). At the same time, water hyacinth and paddy straw are two of the easily obtainable and well-known mulch materials for crop production (L. Kaur et al., 2021; Parsottambhai & Rawat, 2020; Sarangi et al., 2021). Therefore, the present research using naturally occurring plant products and readily feasible colored polythene mulch materials was conducted to evaluate the vegetative and reproductive growth influencing the yield and physiochemical properties of strawberries in tropical conditions of southern Bangladesh.

MATERIALS AND METHODS

Experimental Site, Design, and Layout

The present research was conducted in the research field (22.7881°N and 90.2926°E) and laboratory of the Regional Agricultural Research Station (RARS), Bangladesh Agricultural Research Institute (BARI), Barishal, Bangladesh from October 2018 to April 2019. The soil characteristics of the experiment site were silty clay in texture with neutral to slightly alkaline in the top- and sub-soil under the Barisal series of Gangetic Alluvium Soil Tract (Agroecological Zone 13: Ganges Tidal Floodplain) and about 10 m above the sea level (Z. H. Khan et al., 1998). The site's climate is tropical, with a hot and dry summer, long and humid monsoon, and short and dry winter (Table 1).

The experiment was set in a randomized complete block design (RCBD) with four replications. Plants were spaced 60 cm × 40 cm on 1.6 m × 1.2 m beds, each bed representing a replication, and beds were raised 24 cm above the main field with 60 cm space between beds. Each bed had 8 plants in two adjacent rows 60 cm apart. Twenty-five-day-old strawberry saplings were transplanted in the well-prepared beds on November 14, 2018, followed by providing intercultural operations and fertilization as required. Well-acclimatized tissue-cultured saplings of the variety BARI Strawberry-3 were brought from the Biotechnology Division, BARI, Bangladesh, and kept in nursery condition for three days prior to planting. Five different types of naturally available and synthetic materials viz., paddy straw (*Oryza sativa* L.), water hyacinth (*Eichhornia crassipes* L.), Asian watermoss (*Salvinia cucullata* Roxb.), silver shine polyethylene (Toughsheet, United Kingdom), and black polythene (Toughsheet, United Kingdom) in addition to control (no mulch) were used as mulch components. All types of mulches were applied two days prior to transplanting the saplings.

Table 1
Monthly mean temperature (maximum and minimum), relative humidity, wind speed, rainfall, and solar radiation from October 2018 to April 2019

Month	Air temperature (ºC)			Rainfall (mm)	Relative humidity (%)		Sunshine (hrs/day)	Solar Radiation (g-cal/cm²/day)
	Max.	Min.	Mean		7 a.m.	1.30 p.m.		
October 2018	30.56	23.19	26.87	2.79	94.32	66.81	5.33	302.01
November 2018	29.91	14.42	21.31	0.60	94.40	40.93	6.62	296.20
December 2018	24.43	13.77	19.10	0.14	89.74	55.23	5.27	241.80
January 2019	25.93	12.06	18.99	0.00	88.35	35.97	6.87	292.06
February 2019	28.47	15.20	21.84	2.35	89.79	48.57	7.15	345.56
March 2019	31.61	20.54	26.07	1.23	88.23	51.23	7.94	417.06
April 2019	33.05	22.95	28.00	2.61	91.93	55.47	8.36	447.72

Note. Max. = Maximum; Min. = Minimum

Nutrient Analysis of Mulch Materials

Organic mulch samples as applied to crop were taken to the laboratory for their physical and nutritional analyses where paddy straw, water hyacinth, and Asian watermoss were analyzed for organic carbon (C), nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), and boron (B) following the standard guidelines as described in Official Methods of Analysis (Baur & Endminger, 2012). Organic C content in mulch samples was determined according to the wet oxidation method and expressed in percent. N content in the mulches was determined in the Kjeldhal procedure, and P was estimated by the modified Olsen method. While K, Ca, and Mg content was determined using the ammonium acetate (NH_4OAc) (Merck, Germany) method. On the other hand, S and B content in the mulch materials were estimated by calcium dihydrogen phosphate (Merck, Germany) extraction procedure and calcium chloride (Wako, Japan) extraction method, respectively. No analysis was done for polythene mulches. The analysis report is presented in Table 2.

Table 2
Analysis report of paddy straw, water hyacinth, and Asian watermoss

Sample	Organic C (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B (ppm)
Paddy straw	0.32	0.44	0.12	1.42	0.35	0.24	0.075	10
Water hyacinth	1.79	1.16	0.19	0.61	2.78	1.43	0.097	215
Asian watermoss	2.41	1.86	0.42	1.18	5.30	2.72	0.206	173

Measurement of Growth and Yield of Strawberry

Vegetative growth of the strawberry plant as affected by mulching was assessed by measuring plant height (cm), number of leaves per plant, petiole length (cm), canopy diameter (cm), individual leaf area (cm^2), and leaf relative greenness as Soil Plant Analysis Development (SPAD) value were recorded at full blossom stage preferably at 75 days after transplanting. On the other hand, individual leaf area (cm^2) and SPAD value were measured by an electric leaf area meter (Model: LI 3000, LI-COR, USA) and portable chlorophyll meter (Model: SPAD-502Plus; Konica Minolta, Japan), respectively, at full blossom. Runners developed by the transplants were removed as and when noticed on any plant. Flowering started on December 29, 2018, and various reproductive data, namely the number of days required from transplanting to the first flowering and first harvest, flowering to harvest duration, number of flowers, and fruits per plant, were noted against each replication under treatment.

Fruit was harvested when the color of the fruit changed from pink to red. Harvesting was initiated on January 25, 2019. Immediately after harvest, fruits were weighed (g), followed by measuring the fruit length (cm) and diameter (cm); sepals were removed and stored at -20ºC for biochemical analyses from fruit flesh. Fresh fruit samples were also dried in an electric oven at 72 ± 3ºC for three days to assess the dry matter content. Plants were carefully taken out of the ground with rhizosphere soil after the fruit harvest, the root systems and shoots were separated, they were washed under running water, and fresh weight (g) was recorded. Root length (cm) was also estimated, and dry weight (g) of the shoot and root was measured by drying the samples at 60ºC in the oven for a week.

Assessment of Biochemical Attributes

The stored as well as harvested fresh fruits were utilized for biochemical analyses. TSS, titratable acidity, TSS/acidity ratio, and vitamin C were estimated using standard procedures (Baur & Endminger, 2012). At room temperature, TSS was determined using a digital refractometer (Model: PAL-α, ATAGO, Japan). Results were expressed as percentages. Titratable acidity (TA) was measured using 5 g of fruit pulp, homogenized with 20 ml of purified water, and filtered to obtain a pure extract. Each extract (5 ml) was titrated against sodium hydroxide solution (0.1 N NaOH) (Sigma-Aldrich, Germany) using a phenolphthalein indicator. Results obtained were expressed in the percentage of citric acid. The ratio of TSS to titratable acidity was also assessed. Vitamin C was measured using 2,6-dichlorophenol indophenol dye (Sigma-Aldrich, Germany) and expressed in mg/100 g of fresh fruit.

Statistical Analysis

All the collected data were gathered, analyzed, and presented as treatment means ± standard errors (SE) of four replicates (8 plants at each replication) after performing a one-way analysis of variance (ANOVA) where treatment means were separated using Fisher's protected least significance difference (LSD) test at $p \leq 0.05$. Statistix 10.0 analytical software was used for data analysis.

RESULTS

Shoot and Root Growth

Plant height, number of leaves per plant, petiole length, canopy diameter, single leaf area, leaf relative greenness (SPAD value), as well as root length of strawberry plants at full blossom varied significantly ($p \leq 0.05$) among the treatments (Table 3; Figure 1). Significantly, the tallest strawberry plant was noticed in the T_3 treatment (20.40 cm), being statistically unique with that of T_2 (19.70 cm), followed by both T_4 and T_5 treatments, respectively. Control treatment (T_0) exhibited the shortest plants (15.48 cm) at full blossom (Figure 1a). The number of leaves at full blossom was counted significantly maximum in T_3 (23.33 per plant), statistically different from all other treatments, followed by T_2 treatment (21.55 leaves/plant). Leaf petiole length was measured statistically similarly in all the mulch treatments but different from T_0 plants with shorter petiole. Again, plants under T_3 mulching exhibited a significant maximum canopy diameter (34.30 cm) at full blossom, which had statistical harmony with the T_2 treatment (32.68 cm).

Furthermore, single leaf area (100.06 cm^2), as well as leaf SPAD value (49.35), was also noticed to be significantly maximum in T_3 treatment; plants under T_2 treatment had statistical harmony in terms of single leaf area (99.95 cm^2) and leaf SPAD value (48.43), and the two-polythene mulch treatment (T_4 and T_5) followed the best treatment (Figures 1c and 1d). Control plants exhibited statistical inferiority in terms of number of leaves (15.95 per plant), petiole length (11.15 cm), canopy diameter (26.13 cm), single leaf area (84.46 cm^2), and leaf relative greenness (SPAD value 46.10) at full blossom having statistical consonance with that of T_1 treatment (Table 3). Root growth (length) of the plants was estimated significantly the best in T_3 (22.78 cm) and the worst in control plants (16.10 cm) (Figure 1b).

Shoot and Root Biomass

Different organic and inorganic mulch treatments had significant ($p \leq 0.05$) and positive influences on fresh and dry weight of shoot and root of strawberries recorded after complete fruit harvest (Table 4). Among the treatments, plants cultured with T_3

Table 3
Effect of organic and inorganic mulches on the number of leaves per plant, petiole length, and canopy diameter of strawberry at full blossom

Treatment	Number of leaves per plant	Petiole length (cm)	Canopy diameter (cm)
T_0	15.95 ± 0.72 d	11.15 ± 0.31 b	26.13 ± 0.75 c
T_1	16.08 ± 0.64 d	12.85 ± 0.52 a	28.13 ± 0.76 c
T_2	21.55 ± 0.43 b	13.50 ± 0.39 a	32.68 ± 0.72 ab
T_3	23.33 ± 0.37 a	13.60 ± 0.49 a	34.30 ± 0.42 a
T_4	18.63 ± 0.87 c	13.45 ± 0.53 a	31.83 ± 0.68 b
T_5	19.48 ± 0.69 c	13.28 ± 0.40 a	32.05 ± 0.41 b
$LSD_{0.05}$	1.76	1.43	2.10
CV (%)	6.11	7.29	4.51
Level of significance	**	*	**

Note. Vertical bars on the top of the columns represent the standard errors of means of four replicates (n = 20). Different letters indicate the statistical differences among the treatments at $p \leq 0.05$. T_0 = Control; T_1 = Paddy straw; T_2 = Water hyacinth; T_3 = Asian watermoss; T_4 = Silver polythene; and T_5 = Black polythene

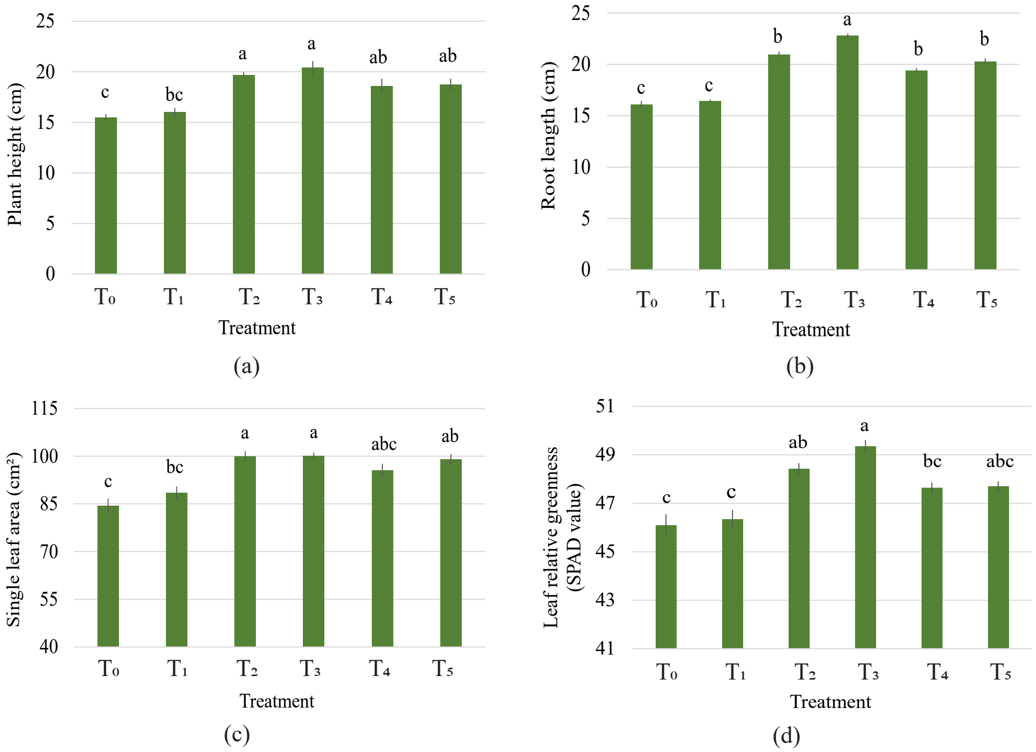

Figure 1. (a) Average plant height (cm), (b) root length (cm), (c) single leaf area (cm^2), and (d) leaf relative greenness (SPAD value) of strawberry var. BARI Strawberry-3 at full blossom as influenced by mulch treatments
Note. Vertical bars on the top of the columns represent the standard errors of means of four replicates (n = 20). Different letters indicate the statistical differences among the treatments at $p \leq 0.05$. T_0 = Control; T_1 = Paddy straw; T_2 = Water hyacinth; T_3 = Asian watermoss; T_4 = Silver polythene; and T_5 = Black polythene

treatment possessed statistically maximum shoot weight on fresh and dry basis (166.97 and 40.98 g, respectively), having statistical unity with T_2 and T_5 mulches for shoot fresh weight and dissonance from all the treatments for shoot dry weight. Similarly, root fresh and dry weight was recorded as the highest (19.05 and 13.78 g, respectively) in T_3, statistically consonant with that of T_2 mulch. The earlier trend control plants had the lightest root (12.10 and 8.98 g in fresh and dry weight basis, respectively).

Table 4
Effect of organic and inorganic mulches on fresh and dry biomass of shoot and root of strawberry

Treatment	Shoot fresh weight (g)	Shoot dry weight (g)	Root fresh weight (g)	Root dry weight (g)
T_0	113.15 ± 4.82 d	27.08 ± 1.04 e	12.10 ± 0.53 e	8.98 ± 0.38 e
T_1	126.45 ± 4.46 c	30.48 ± 1.04 d	13.43 ± 0.44 d	10.03 ± 0.36 d
T_2	160.28 ± 4.92 a	38.38 ± 1.09 b	17.95 ± 0.29 ab	13.05 ± 0.27 ab
T_3	166.97 ± 3.34 a	40.98 ± 0.69 a	19.05 ± 0.31 a	13.78 ± 0.24 a
T_4	145.08 ± 3.64 b	34.55 ± 0.98 c	15.95 ± 0.67 c	11.63 ± 0.38 c
T_5	158.80 ± 3.91 a	38.43 ± 0.73 b	17.15 ± 0.40 bc	12.58 ± 0.31 b
$LSD_{0.05}$	9.47	2.04	1.30	0.75
CV (%)	4.33	3.88	5.42	4.26
Level of significance	**	**	**	**

Note. Values are means ± standard errors of four independent replications (n = 20). Different letters within the column indicate statistically significant differences among the treatments according to LSD at $p \leq 0.05$. T_0 = Control; T_1 = Paddy straw; T_2 = Water hyacinth; T_3 = Asian watermoss; T_4 = Silver polythene; and T_5 = Black polythene

Reproductive Traits

Significant variations ($p \leq 0.05$) among the treatments were registered for the reproductive parameters of strawberries except for several days required for transplanting to the first-time fruit harvest (Table 5). Control plants-initiated flowering within the shortest possible time from transplanting (46.93 days) followed by T_2 (47.80 days) and T_3 (47.88 days) mulches. Plants under T_1 treatment took a longer time (52.55 days) to emerge the first flower. Again, the duration from flowering to harvesting ranged from 23.48 to 29.60 days, where fruits of control plants ripened early from flowering (23.48 days) being statistically identical with that of T_1 treatment (24.33 days) while significant maximum duration between flowering and harvesting (29.60 days) was recorded in T_3 treatment. Besides, the number of flowers and fruits was statistically different in different treatments, where T_3 mulch-treated plants produced maximum flowers

(21.20 per plant), as well as fruits (19.63 per plant) with a fruit set percentage of 92.66. Significantly, the minimum number of flowers (14.90 per plant) and fruits (12.98 per plant) was counted in control plants; T_1 plants had statistical parity with control treatment.

Table 5
Effect of organic and inorganic mulches on reproductive traits of strawberry

Treatment	Number of days required			Number of flowers per plant	Number of fruits per plant	Fruit set (%)
	Transplanting to the 1st flowering	Transplanting to the 1st harvest	Flowering to harvest			
T_0	46.93 ± 1.64 c	75.93 ± 2.80	23.48 ± 0.62 c	14.90 ± 1.00 c	12.98 ± 0.48 e	87.63 ± 2.76 bc
T_1	52.55 ± 1.18 a	82.30 ± 1.76	24.33 ± 0.69 c	15.50 ± 0.49 c	13.58 ± 0.44 de	87.73 ± 2.97 bc
T_2	47.80 ± 1.01 bc	80.05 ± 1.91	27.28 ± 0.57 b	18.73 ± 0.54 b	17.38 ± 0.36b	92.87 ± 1.28 a
T_3	47.88 ± 1.35 bc	80.63 ± 2.00	29.60 ± 0.28 a	21.20 ± 0.67 a	19.63 ± 0.44 a	92.66 ±0.99 a
T_4	51.38 ± 1.00 ab	79.63 ± 0.77	24.90 ± 0.50 c	18.00 ± 0.62 b	15.45 ± 0.85 cd	85.70 ± 2.32 c
T_5	48.58 ± 1.21 abc	80.33 ± 2.22	27.80 ± 0.58 b	18.75 ± 0.49b	17.20 ± 0.80 bc	91.60 ± 2.02 ab
$LSD_{0.05}$	4.00	6.09	1.58	2.12	1.89	4.93
CV (%)	5.40	5.06	4.01	7.90	7.84	3.64
Level of significance	*	NS	**	**	**	*

Note. Values are means ± standard errors of four independent replications (n = 20). Different letters within the column indicate statistically significant differences among the treatments according to LSD at $p \leq 0.05$. T_0 = Control; T_1 = Paddy straw; T_2 = Water hyacinth; T_3 = Asian watermoss; T_4 = Silver polythene; and T_5 = Black polythene

Yield Attributes

Except for individual fruit weight, strawberry yield characteristics such as fruit size (length and breadth) and fruit yield (g/plant and kg/ha) significantly ($p \leq 0.05$) differed in the different types of mulch treatments (Figure 2). Individual fruit weight of BARI Strawberry-3 under study ranged between 17.88 to 18.88 g (Figure 2a). Though fruit length was noted as a minimum in T_4 mulch (3.97 cm), fruit breadth was recorded as a minimum in control (T_0) plants (3.02 cm), whereas T_2 fruits had a maximum length (4.98 cm) and T_3 fruits got maximum breadth (3.57 cm) (Figure 2b). In addition, T_3 exhibited statistical superiority over other treatments in terms of fruit yield (370.02 g/plant and 15.42 kg/ha) followed by T_2 and T_5 mulches; contrarily, the minimum yield was obtained from untreated plots (234.83 g/plant and 9.78 kg/ha) (Figure 2c). Therefore, an increase in fruit yield over control was noted due to mulching, where a maximum 57.57% yield enhancement was noticed in the T_3 treatment and a minimum of 6.99% in the T_1 treatment; T_2 and T_5 mulching had a yield increment of 37.51 and 34.54%, respectively (Figure 2d).

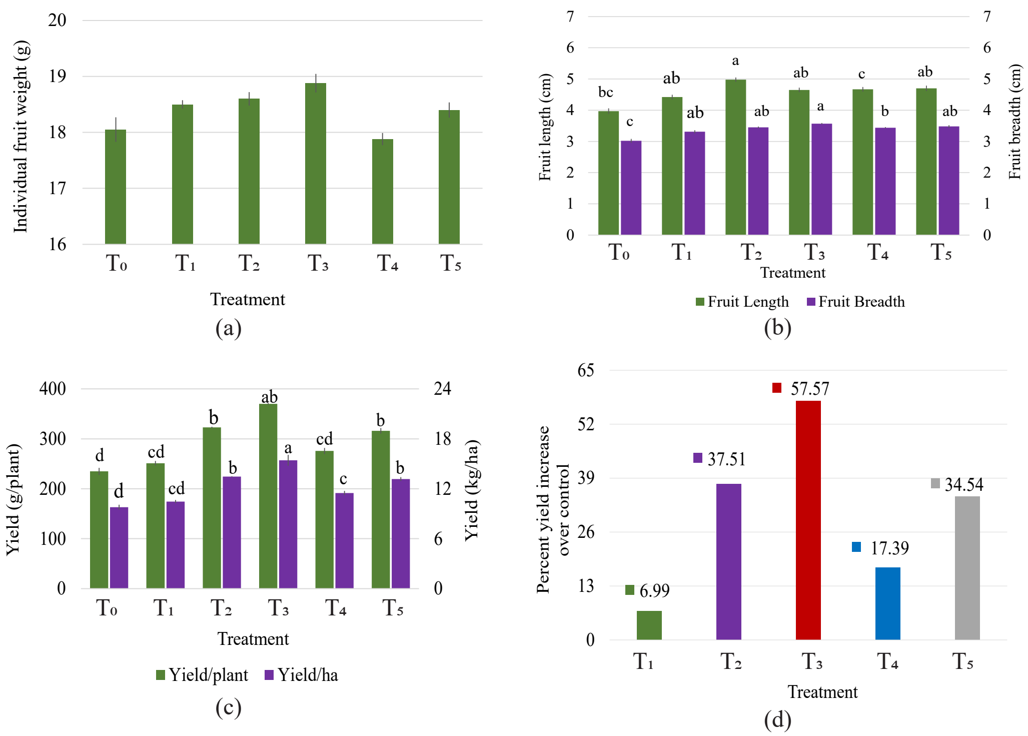

Figure 2. (a) Average individual fruit weight (g), (b) fruit length (cm) and breadth (cm), (c) fruit yield (g/plant and kg/ha), and (d) percent yield increase over control of strawberry var. Different organic and inorganic mulches influence BARI Strawberry-3

Note. Vertical bars on the top of the columns represent the standard errors of means of four replicates (n = 20). Different letters indicate the statistical differences among the treatments at $p \leq 0.05$. T_0 = Control; T_1 = Paddy straw; T_2 = Water hyacinth; T_3 = Asian watermoss; T_4 = Silver polythene; and T_5 = Black polythene

Physiochemical Properties of Fruit

Significant ($p \leq 0.05$) variations in fruit physical and biochemical attributes were noted due to organic and inorganic mulching in strawberries (Table 6). Fruits of all the treatments, except T_1, had statistically similar dry matter content numerically high in T_3 treatment (9.68%). Likely, fruits obtained from the T_3 treatment exhibited the highest TSS content (9.95%), while T_1 fruits showed minimum TSS (7.75%). TA was estimated maximum in the T_1 treatment (0.66%) and the same minimum TA (0.58%) in both T_3 and T_5 treatments. Consequently, the TSS/acidity ratio was significantly the highest (17.08:1) in the fruits of the T_3 treatment, being statistically different from all other treatments. Fruits under T_1 had statistically minimum TSS/acidity ratio (11.74:1). Furthermore, T_3-treated strawberry transplants produced fruits with significantly maximum vitamin C content (58.16 mg/100 g), which was statistically identical to that of T_2, T_4, and T_5 mulch treatments. Control treatments had fruits with statistically minimum vitamin C content (47.23 mg/100 g).

Table 6
Effect of different mulches on the content of fruit dry matter, total soluble solids, titratable acidity, TSS/acidity ratio, and vitamin C of strawberry

Treatment	Dry matter (%)	Total soluble solids (%)	Titratable acidity (%)	TSS/acidity ratio	Vitamin C (mg/100 g)
T_0	8.86 ± 0.32 ab	8.05 ± 0.21 cd	0.59 ± 0.01 b	13.59 ± 0.16 c	47.23 ± 1.74 c
T_1	8.22 ± 0.26 b	7.75 ± 0.24 d	0.66 ± 0.02 a	11.74 ± 0.07 d	51.94 ± 1.69 bc
T_2	9.42 ± 0.27 a	9.50 ± 0.39 ab	0.62 ± 0.02 ab	15.43 ± 0.17 b	56.62 ± 1.50 ab
T_3	9.68 ± 0.19 a	9.95 ± 0.17 a	0.58 ± 0.01 b	17.08 ± 0.05 a	58.16 ± 1.68 a
T_4	9.27 ± 0.34 a	8.95 ± 0.37 bc	0.58 ± 0.01 b	15.49 ± 0.93 b	57.24 ± 1.65 a
T_5	9.41 ± 0.21 a	9.35 ± 0.27 ab	0.61 ± 0.01 ab	15.26 ± 0.14 b	55.23 ± 1.13 ab
$LSD_{0.05}$	0.89	0.95	0.05	1.24	5.13
CV (%)	6.45	7.03	5.4	5.57	6.25
Level of significance	*	**	*	**	**

Note. Values are means ± standard errors of four independent replications (n = 20). Different letters within the column indicate statistically significant differences among the treatments according to LSD at $p \leq 0.05$. T_0 = Control; T_1 = Paddy straw; T_2 = Water hyacinth; T_3 = Asian watermoss; T_4 = Silver polythene; and T_5 = Black polythene

DISCUSSION

Mulching, an age-old cultural practice of curing the soil surface, is laying various covering materials on the soil/ground surface surrounding the plant base for the best possible outcome of making soil environment for plant growth, development, and efficient crop production. Besides many other soil management strategies, mulching measures can efficiently regulate soil temperature by reducing soil temperature in hot weather, maintaining soil temperature during the cold season, and improving the physical properties of the soil (Iqbal et al., 2016). In the present experimental site, the cultivable winter (rabi season) had almost no rain, atmospheric humidity below par, extreme day temperature, and solar radiation not up to the mark (Table 1). Studies also opined that winter occurs for no longer than three months, with hotter winter days in the southern region of Bangladesh, a phenomenon in recent years (M. H. R. Khan et al., 2019).

In such adversities, enhanced plant growth, development, yield, and fruit biochemical properties were noticed in organic and inorganic mulch-treated plants compared to the control. Appropriate mulching can accelerate plant root and shoot growth by generating congenial soil physical, chemical, and biological conditions that potentially increase the soil water holding capacity, microbial community, soil texture and aeration, and nutrient availability, making the soil more productive and fertile. All these conditions favor enhanced crop growth and yield even under adverse climate situations.

Qu et al. (2019) and Zhang et al. (2009) demonstrated that mulching promotes soil microbial activity by improving agro-physical properties, which augments soil nutrient uptake and improves vegetative growth. Mulching also improves crop-water use efficiency and reduces fertilizer leaching during excess irrigation and rains (Almeida et al., 2015; Barche et al., 2015; Iqbal et al., 2016). All these auspicious events might occur here to increase the shoot and root growth of strawberries that consequently influenced the accumulation and translocation of photosynthates to the sink, resulting in the significant quantity of fruits having eminent post-harvest qualities.

Similar instances of accelerated growth and development in strawberries due to mulching over control were noted in several studies (Abdalla et al., 2019; Bakshi et al., 2014; Deb et al., 2014; P. Kaur & Kaur, 2017; Patil et al., 2013; Sharma & Goel, 2017). Not only strawberry, mulching improves vegetative growth remarkably and yield in other similar crops like potato (Bhatta et al., 2020; Li et al., 2018), tomato (Biswas et al., 2016; Mendonça et al., 2021), and eggplant (R. R. Kumar et al., 2019).

Again, among the natural and synthetic mulches, Asian watermoss exhibited superiority over the other treatments in inducing strawberry yield and quality. Water hyacinth mulch had some resemblances in some cases. The results meant that organic mulch materials had a better impact than inorganic mulching in the present environmental and soil conditions. Again, the average air temperature at the early growth and reproductive stage went beyond 30°C, which was not congenial for strawberry growth. The rise in air temperature corresponds to the increment in soil temperature. Here, organic mulching with Asian water might prevent the soil temperature from rising excessively while not allowing the soil temperature to be too low by facilitating the slow release of ground temperature during the whole growth phase of the strawberry.

Regulation of temperature made proper ground for the soil microbes along with many more advantages for better crop growth and yield. D. Kumar and Sharma (2018), as well as Lal (2013), noticed that organic mulch had much soil cooling capacity than colored synthetic mulch. Soil temperature rise in extremely cool periods might be beneficial, but it may be pernicious in places where moderate to relatively higher air temperature prevails in winter. Organic mulches provide harbor and food for numerous soil microorganisms essential for promoting soil granulation and preserving soil health (Barche et al., 2015; Kader et al., 2017).

Besides, organic mulch has the maximum capacity to retain soil water and extends all sorts of basic soil properties by adding organic carbon to the soil during decomposition (Qu et al., 2019). As an organic mulch material, the use of water hyacinth mulch and the resultant improvement in crop growth, yield, and fruit nutrient contents have been reported (Adnan et al., 2017; Indulekha & Thomas, 2018; Sil et al., 2020). Though evidence of applying

Asian watermoss as mulching is scant (Arzoo et al., 2021), it has been widely used as the structural material for bed preparation in floating agriculture (Irfanullah et al., 2011; Mondal et al., 2022; Sunder, 2020), where it undergoes gradual decomposition, and the cultivated seedlings and vegetable crops receive necessary nutrients from it.

Again, as partial decomposition of organic mulches occurs in the field, Asian watermoss added more mineral matter due to its higher mineral compositions than water hyacinth and paddy straw mulch. Besides, the nutrient analysis also revealed that Asian watermoss had a C:N ratio with higher levels of organic C and mineralizable N. The moss *Salvinia* is also reported as highly potent organic manure (Hussain et al., 2018; Sangla et al., 2006). Thereby, there was every chance for the improvement of soil health most efficiently upon Asian watermoss mulching, which contributed to the best growth, yield, and biochemical properties of strawberries in the tropical southern region of Bangladesh.

CONCLUSION

Strawberry being a sensitive surface feeding winter fruit, the topsoil must have appropriate biological, chemical, and physical properties. It was noted that superior vegetative growth with maximum root and shoot biomass of strawberries was obtained from Asian watermoss mulching, and water hyacinth mulch had similar contributions. Reproductive growth, mainly the number of flowers and fruits, as well as fruit yield, was distinctly eminent in Asian water moss-applied plots. Once again, fruit quality characteristics followed similar trends. Overall, mulching had a statistically profound impact on strawberry production, and organic mulch performed better than inorganic mulch in the tropical ecosystem of southern Bangladesh.

ACKNOWLEDGEMENTS

The authors express profound respect and heartiest gratitude to the Bangladesh Agricultural Research Institute for providing logistic and physical support in accomplishing this research. Besides, the publication was supported by the "Research, extension and popularization of vegetables and spices cultivation on floating bed" Project with the funding code MoA-224117501.

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