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Varietal and Organic Mulching Effects on Growth, Yield, and Quality Performance of Beetroot (*Beta vulgaris* L.)

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ABSTRACT

Beetroot (*Beta vulgaris* L.) is a highly nutritious root vegetable with great potential for enhancing dietary diversity, wider adaptation, and intensification in Bangladesh. An experiment was conducted at Horticulture Farm, Bangladesh Agricultural University, Mymensingh, from October 2023 to March 2024 to assess the effects of varieties and organic mulching on the growth, yield, and quality of beetroot. It comprised two varieties: Heart Beet (V_1) and Red Baby (V_2), and four mulches: T_0 (control), T_1 (rice straw), T_2 (water hyacinth), and T_3 (leaf mulch). A randomized complete block design (RCBD) with three replications was used to measure plant height, leaf count, root length, root diameter, fresh weight, yield, and total soluble solids (TSS). Significant varietal and mulching effects were observed for all parameters studied. Red Baby (V_2) performed better than Heart Beet (V_1) in terms of root diameter (3.81 cm versus 3.46 cm), fresh weight (42.01 g versus 34.52 g), and yield (4.14 t/ha against 3.48 t/ha). In contrast, Heart Beet (V_1) exhibited a total soluble solids (TSS) level of 16.63 °brix, indicating a greater processing potential. Among the mulches, leaf mulch (T_3) produced the best results, with the longest roots (4.15 cm), largest diameter (3.93 cm), highest fresh weight (47.34 g), and greatest yield (4.70 t/ha). The interaction of Red Baby with leaf mulch (V_2T_3) produced the highest root yield (4.89 t/ha), highlighting a strong synergistic benefit.

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Introduction

Beetroot (*Beta vulgaris* L.) commonly referred to as red beet, garden beet, or table beet, belongs to the Chenopodiaceae family and can be consumed either fresh or cooked. It is rich in essential nutrients (magnesium, sodium, potassium), vitamin C, and betalain that boost immunity, reduce blood pressure, improve digestion, possesses anti-inflammatory properties and exhibit antibacterial, antiviral, and anti-cancer properties (Neha *et al.*, 2018). In Eastern and Central Europe, beetroot is a highly esteemed vegetable but less so in Western Europe and the United States. The primary producers and consumers of table beet are European countries, especially France and England, which grows best at 18–25°C and a soil pH of 6.5–7.5 (Neelwarne *et al.*, 2012).

In Bangladesh, beetroot is a novel crop, which can be cultivated and commercialized successfully in diverse regions to produce phytonutrient-rich dishes, such as pasta, cake, cookies, jam, pickles, and others. Research on the productivity of beetroot vegetables in Bangladesh has been minimal, while farmers facing issues such as seed shortages, high labor costs, and heavy rainfall. Nevertheless, approximately sixty percent of farmers consented to accept technical assistance from the agricultural department amidst these challenges (Rashid *et al.,* 2020). In light of this challenges, selection of beetroot varieties that perform well under Bangladesh’s climatic conditions with improved cultivation practices, while maintaining optimal root conditions for better growth, quality and increased yield. Organic mulching, produced using various organic materials (crop residues, leaf litter, husks, grass, and water hyacinth), has been suggested as an effective agronomic strategy for numerous reasons. It improves soil moisture retention, hydrothermal dynamics, organic matter accumulation, and nutrient recycling. Moreover, it suppresses weeds, pests, and diseases, regulates soil physical, chemical, and biological conditions, reduces water and nutrient loss, leading to enhanced crop yield and optimized water-use efficiency (Patel *et al.,* 2013). Crop residue, leaf litter, husks, grass, and water hyacinth are among the various organic materials utilized to produce mulch. The adverse impacts of deficit irrigation on crop productivity can be mitigated by implementing appropriate moisture conservation techniques, such as mulching (Sajjad *et al*., 2003).

Bangladesh's table beet yield and quality are inferior to those of other producing countries globally, attributed to insufficient nutrition management and a lack of diversity. Research on the yield of beetroot vegetables in Bangladesh has been minimal. From a Bangladeshi perspective, beetroot may be cultivated successfully in diverse regions, and both its cultivation and commercialization seem to be profitable. Moreover, cultivating beetroot vegetables could offer a novel chance for the food sector to produce phytonutrient-rich dishes, such as pasta, cake, cookies, jam, pickles, and others. Therefore, this study aims to address the knowledge gap on beetroot cultivation in Bangladesh, while promoting a nutrient-rich crop to meet farmer’s demand at once. Specifically, it focuses on identifying suitable high performing beetroot varieties, the role of organic mulching, and how these factors interact to influence growth, yield, and quality of beetroot.

Materials and Methods

Experimental Site

The experiment was carried out in the horticulture farm and Laboratory of the Department of Horticulture, Bangladesh Agricultural University, Mymensingh, Bangladesh to evaluate the effects of variety and organic mulches on growth, yield and quality of beetroot during the period from October 2023 to March 2024. The experimental site was medium high land belonging to the Old Brahmaputra Floodplain under the Agro-Ecological Zone 9 having non-calcareous dark gray floodplain soil (UNDP and FAO 1988). The soil of the experimental plot was silty loam in texture and a pH range of 5.5 to 6.8. Additionally, the area was located in a subtropical zone with an optimal climate (18-25°C, minimal rainfall) suitable for this exotic crop.

Experimental Design and Treatments

The experiment was conducted in a Randomized Complete Block Design (RCBD) with three replications. It followed a two-factor design of variety and organic mulching, resulting in 8 treatment combinations. Factor A involved two red beet varieties: Heart Beet and Red Baby. Factor B consisted of three organic mulches and one control treatment: T_0 (Control: No mulches), T_1 (Rice straw), T_2 (Water hyacinth), T_3 (Leaf mulch). The experimental area was divided into 3 blocks, each containing 8 plots (1 square meter per plot), with 24 plots in total. Plots were spaced 0.3 meters apart, and blocks were separated by 0.5 meters.

Land Preparation, Seed Sowing and Transplanting of Seedlings

The experimental field was prepared according to the experimental design by ploughing, cross ploughing, leveling, breaking large clods and removing debris by October 30, 2023. Seeds of two beet varieties were sown in a shaded seedbed at the Horticulture Farm, BAU on November 7, 2023. Seedlings were transplanted on December 7, 2023, with 25 cm plant-to-plant and 30 cm row-to-row spacing, totaling 12 seedlings per plot in three consecutive rows.

Intercultural operations

To control weed proliferation during the early fragile seedling stage, weeding was performed manually three times at 15, 30, and 45 days after planting (DAP). Three to four weeks after planting, thinning and gap filling were carried out to maintain 25 cm plant-to-plant spacing and proper plant population. Irrigation was applied every three days during the first month due to low soil moisture, then every ten days in the second month and every fifteen days in the third month after mulching. Earthing up was done at 60 DAP using a khurpi to cover the root base, improve drainage, and promote root growth. To manage Rhizoctonia root rot disease in specific plots, azoxystrobin (2 ml/L) was applied using a hand sprayer, while no insecticide was applied as no significant insect infestation occurred.

Data Collection and Harvesting

Data on certain plant characteristics and yield components were obtained from five randomly selected sample plants per plot, and the total beetroot yield was recorded for the entire plot post-harvest. Harvesting was done at 90 days after planting. Three plants from each plot were uprooted, then the dried and dead parts were removed, rinsed, and transported to the threshing floor for data documentation.

Parameters Measured

Vegetative growth of plants such as plant height in centimeters (cm) and number of leaves per plants were measured at 30, 45, 60, 75, and 90 days after planting (DAP) for five randomly chosen plants from each plot.
Post-harvest parameters, including root length (cm), root diameter (cm) and fresh weight of root per plant (g) were measured from three randomly selected plants per plot. Then total root yield was calculated as tons per hectare (tons/ha).

$$\text{Total root yield (t/ha)} = \frac{\text{Fresh weight of root (kg/plot)}}{1000\,x\,\text{Net plot size}}\; x\; 10000$$

The total soluble solids (TSS) of the roots were measured at harvest using a hand refractometer and expressed in (^{0} brix).

Statistical Analysis

The experimental data were analyzed using R programming software (version 4.2.2) for the RCBD two-factor design. Initially, data normality was assessed using the Shapiro-Wilk test. Analysis of variance (ANOVA) was then performed, followed by an F-test to evaluate the significance of treatment effects. For multiple comparisons, LSD test was conducted at a 5% significance level using the agricolae package, following the methodology described by Gomez and Gomez (1984). Correlation analysis was carried out using the metan package while principal component analysis (PCA) was performed with the factoextra package. Graphs were constructed using the ggplot2 package.

Control **Rice Straw** **Water Hyacinth** **Leaf Mulch**

Plate 1. Different Types of Organic Mulches

Plate 2. Harvested Beet root

Results and Discussion

Plant height

Variety and organic mulching significantly influenced the plant height of beetroot (Figure 1). Plant height increased until 60 days after planting (DAP) and then gradually declined. At 60 DAP, Heart Beet (V_1) showed greater plant height of 19.71 cm than Red Baby (V_2), plant height of 18.33 cm. That reveals the superior vegetative growth properties of Heart Beet. Among mulching treatments, Rice straw (T_1) produced the highest plant height (20.68 cm), while Control (T_0) showed the lowest (17.43 cm). The combined effect revealed that Red Baby with rice straw (V_2T_1) achieved the tallest plants (21.17 cm), whereas Heart Beet with control (V_2T_0) had the shortest plant height (16.2 cm). These results show the positive effect of mulching on early vegetative development, which align with Acharyya *et al.* (2020), who noted that rice straw mulch releases nutrients in a controlled manner, which promotes consistent plant growth.

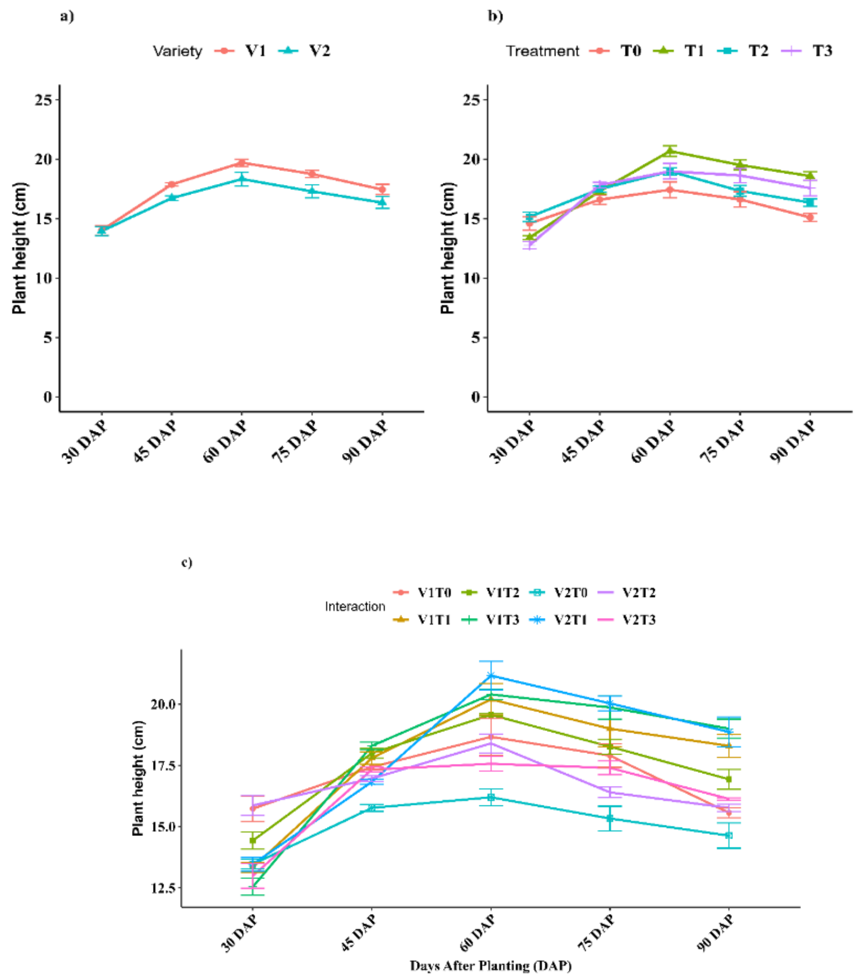

Figure 1. Effects of varieties and organic mulching on the plant height of beetroot. a) Main effects of varieties, b) Main effects of organic mulching, c) Interaction effects of varieties and organic mulching. (Data are presented as mean ± SE, n = 3). V_1: Heart Beet, V_2: Red Baby; T_0: Control, T_1: Rice Straw, T_2: Water Hyacinth, T_3: Leaf Mulch.

Number of leaves per plant

The number of leaves per plant varied significantly among varieties and mulching treatments (Figure 2). Leaf count increased gradually until 60 days after planting (DAP), peaked at 75 DAP, and then declined. At 75 DAP, Heart Beet (V_1) had more leaves (18.76) than Red Baby (V_2) (17.29). Organic mulching, rice straw (T_1) produced the highest leaf count (19.52), while control T_0 had the lowest (16.62). The combined effect of variety and organic mulching showed that Red Baby with rice straw (V_2T_1) had the most leaves (20.03), whereas the same variety under control (V_2T_0) had the fewest (15.33). These findings are consistent with Yordanova *et al.* (2016), who demonstrated that barley straw mulch improves nutrient availability, moisture retention, and weed suppression, which promotes foliar growth.

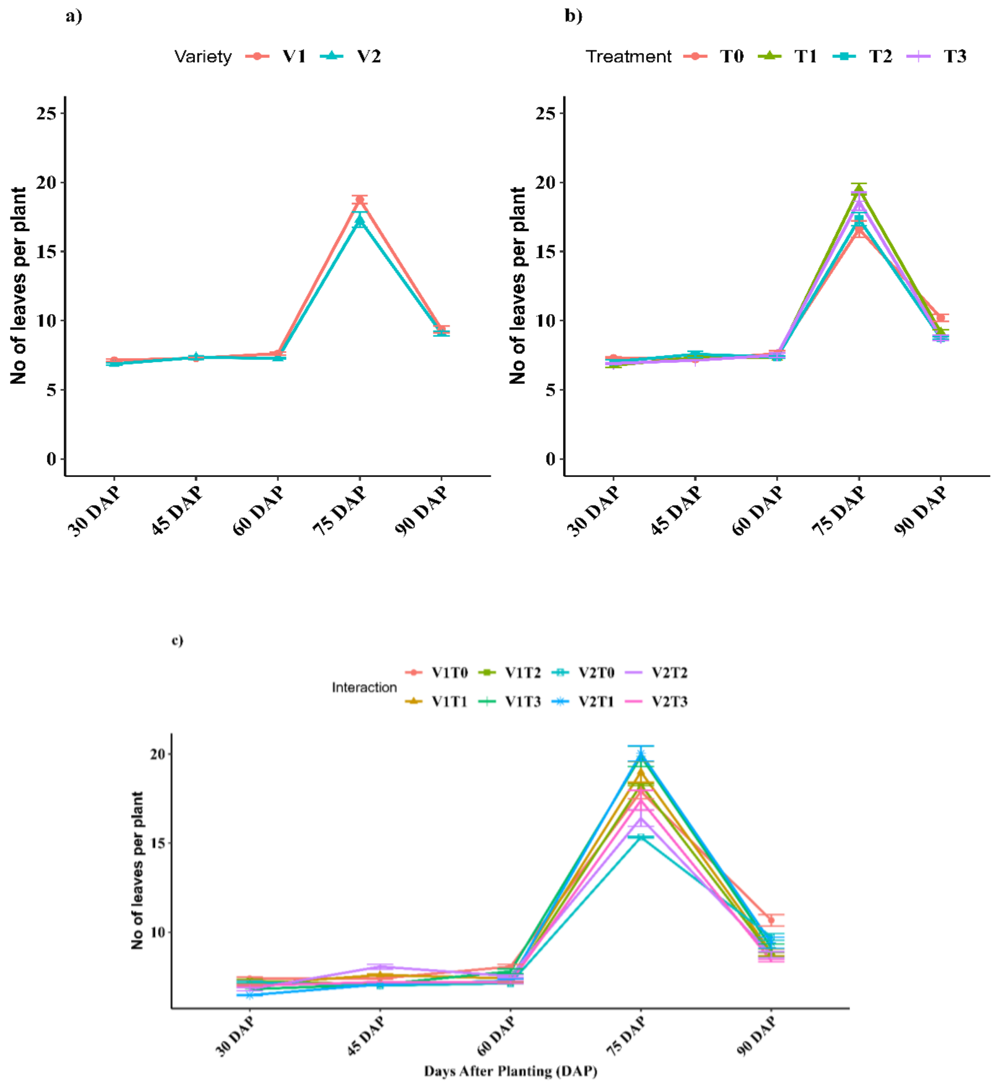

Figure 2. Effects of varieties and organic mulching on the number of beetroot leaves. a) Main effects of varieties, b) Main effects of organic mulching, c) Interaction effects of varieties and organic mulching. (Data are presented as mean ± SE, *n* = 3). V_1: Heart Beet, V_2: Red Baby; T_0: Control, T_1: Rice Straw, T_2: Water Hyacinth, T_3: Leaf Mulch

Root length

No significant difference was found between varieties in root length. Both Heart Beet (V_1) and Red Baby (V_2) exhibited root length of 3.61 cm at harvest (90 DAP) (Table 1). However, organic mulching had a significant effect, as leaf mulch (T_3) produced the longest roots (4.15 cm) and control (T_0) the shortest roots (3.24 cm). In case of combined treatments, differences were insignificant; the longest root (4.21 cm) was recorded in Heart Beet with leaf mulch (V_1T_3), and the shortest root length (3.23 cm) in Red Baby with T_0 (V_1T_0). These results indicate that fallen leaves mulching promotes root growth by improving soil moisture and nutrient availability (Patel et al., 2013).

Root diameter

Root diameter varied significantly between two varieties and mulching treatments (Table 1). At 90 days after planting (DAP), Red Baby (V_2) showed a larger root diameter of 3.81 cm than Heart Beet (V_1) of 3.46 cm. Sharma and Singh (2018) indicate that early-maturing beetroot varieties, which prioritize resource allocation towards root development instead of excessive foliage. The elevated yield potential of Red Baby enhances its suitability for fresh market sales, where consistent root size and weight are essential for consumer preference. Comparable findings were documented by Yasaminshirazi *et al.* (2020), revealing that cylindrical beetroot varieties such as demonstrated enhanced marketable yields in contrast to round genotypes. Among mulching treatments, leaf mulch (T_3) produced the largest diameter (3.93 cm), while control (T_0) had the smallest root diameter (3.28 cm). In combined treatments, Red Baby with leaf mulch (V_2T_3) had the greatest root diameter (4.09 cm), whereas Heart Beet with control (V_1T_0) had the smallest root diameter (3.19 cm), showing the potential shortcomings of neglecting mulching in beetroot cultivation. The utilization of organic mulches, especially leaf mulch, significantly enhances root formation, while contributing to soil health and sustainability (Malik *et al.*, 2018).

Root fresh weight

The individual root fresh weight exhibited significant variations between varieties and organic mulching treatments (Table 1). At 90 days after planting (DAP), Red Baby (V_2) showed higher root fresh weight (42.01 g) than Heart Beet (V_1) (34.52 g). Among mulching treatments, leaf mulch (T_3) produced the highest root weight (47.34 g), while T_0 showed the lowest root weight (28.72 g). The combined effect revealed that Red Baby with leaf mulch (V_2T_3) had the greatest root fresh weight (49.45 g), whereas Heart Beet with control (V_1T_0) had the lowest (27.77 g). The improvement in root development and weight under organic mulching aligns with the findings of Olfati *et al.* (2008), who reported that organic mulch enhances carrot root development, yield, and total soluble solids content.

Root yield per hectare

A significant variation in root yield was observed between varieties and organic mulching treatments (Table 1). Red Baby (V_2) produced a higher yield (4.14 t/ha) than Heart Beet (V_1) (3.48 t/ha). The findings align with earlier investigations (Mia and Rashid, 2023; Sapkota et al., 2021), indicating that varietal differences had a substantial impact on both yield and quality. Among organic mulching treatments, leaf mulch (T_3) gave the highest yield (4.70 t/ha), while control (T_0) produced the lowest yield (2.83 t/ha). In case of combined effect, Red Baby with leaf mulch (V_2T_3) achieved the greatest yield (4.89 t/ha), whereas Heart Beet with control (V_1T_0) had the lowest yield (2.80 t/ha). This result aligns with Dixit and Majmudar (1995), who reported that the yield and starch content of potato increased by 27.9% and 18.18%, respectively, under rice straw mulches compared to un-mulched plots, highlighting the positive effect of organic mulching on root crop productivity.

Total soluble solids (^{0}brix)

Total soluble solids (TSS) varied significantly among varieties and mulching treatments (Table 1). At 90 days after planting (DAP), Heart Beet (V_1) showed higher total soluble solids (TSS) content (16.63 °Brix) than Red Baby (V_2) (16.04 °Brix). The increased TSS in Heart Beet corresponds with research by Šlosár *et al*. (2020), which showed that specific beetroot genotypes possess a genetic tendency for enhanced sugar accumulation, total phenolic content (TPC) and antioxidant activity (AOA), which improved their nutritional value. Among organic mulching treatments, control (T_0) had the highest TSS content (17.32 °Brix), while leaf mulch (T_3) had the lowest (15.68 °Brix). In the combined effect of varieties and organic mulching, Red Baby with control (V_2T_0) recorded the highest TSS content (17.93 °Brix), whereas Red Baby with water hyacinth (V_2T_2) showed the lowest (14.60 °Brix).

Table 1. Effects of varieties and organic mulching on post-harvest parameters (root length, root diameter, root weight, root yield, TSS) of beetroot

Variety	Root length (cm)	Root diameter (cm)	Root weight (g)	Root yield (t ha^{-1})	TSS (^{0}brix)
V_1	3.61	3.46	34.52	3.48	16.633
V_2	3.61	3.81	42.01	4.141	16.042
LS	NS	***	***	***	NS
LSD (5%)	0.047	0.113	1.11	0.165	0.61
Treatment					
T_0	3.24	3.275	28.717	2.83	17.317
T_1	3.71	3.863	42.778	4.277	16.25
T_2	3.34	3.475	34.205	3.437	16.1
T_3	4.15	3.928	47.335	4.697	15.683
LS	***	***	***	***	**
LSD (5%)	0.067	0.16	1.56	0.233	0.87
Interaction					
V_1T_0	3.25	3.19	27.77	2.804	16.7
V_1T_1	3.71	3.66	36.89	3.725	16.633
V_1T_2	3.28	3.22	28.19	2.883	17.6
V_1T_3	4.21	3.77	45.22	4.507	15.6
V_2T_0	3.23	3.363	29.667	2.857	17.933
V_2T_1	3.71	4.063	48.667	4.828	15.867
V_2T_2	3.41	3.73	40.22	3.992	14.6
V_2T_3	4.1	4.09	49.45	4.887	15.767
LS	*	*	***	***	***
LSD (5%)	0.095	0.22	2.21	0.33	1.23

*** =Significant at 0.1% level of probability, ** =Significant at 1% level of probability, * =Significant at 5% level of probability, NS=Non-significant. V_1: Heart Beet, V_2: Red Baby; T_0: Control, T_1: Rice Straw, T_2: Water Hyacinth, T_3: Leaf Mulch

Principal Component Analysis (PCA) Biplot

The PCA biplot illustrates the variation present in a multivariate dataset influenced by various treatments, highlighting two principal components: Dim1 (60.2%) and Dim2 (24%), which together account for 84.2% of the total variance. The representation of the data consists of points, ellipses, and vectors, where Dim1 indicates the highest variance and Dim2 indicates the second highest variance. The treatment groups exhibit distinct separation, with T0 and T1 predominantly differentiated along Dim1, whereas T3 shows clear separation with vectors RD, RW, and RL. The arrangement and orientation of vectors offer valuable information regarding the variables that contribute to this separation, thereby aiding in the identification of treatment effects and variable relationships in complex biological, agricultural, or environmental research.

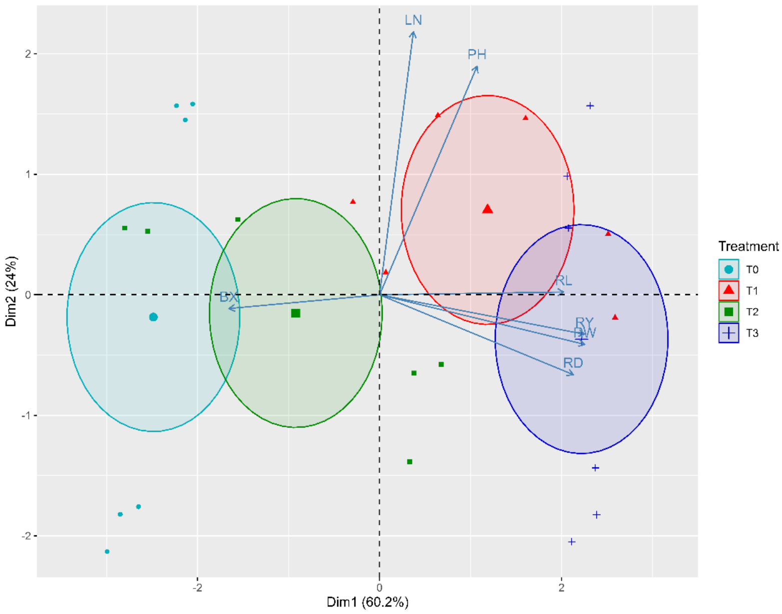

Figure 3. Principal Component Analysis (PCA) biplot representing the relationships among different growth and yield parameters of beetroot under various organic mulching treatments. (PH = Plant height, LN = Number of leaves per plant, RL = Root length, RY = Root yield, RW = Root weight, RD = Root diameter, BX = Total soluble solids (% Brix).

Pearson's Correlation Matrix Heatmap

The analysis of correlations among plant traits reveals significant positive relationships between plant height, root weight, root diameter, root yield, and root length. Increased plant heights correlate with the development of longer, thicker, and heavier roots, suggesting a synchronized growth response. On the other hand, elevated BX levels show a negative correlation with root growth and yield metrics, indicating a possible inhibitory influence on root development. There are minimal or negligible correlations observed with PH and LN, while RY exhibits weak correlations with PH, RD, and RW. The correlation matrix indicates a positive clustering of PH, RW, and RD in the PCA, whereas BX's strong negative correlations affirm its unique position in the PCA. Grasping these connections is essential for deciphering biological impacts and pinpointing important characteristics for upcoming studies or breeding goals.

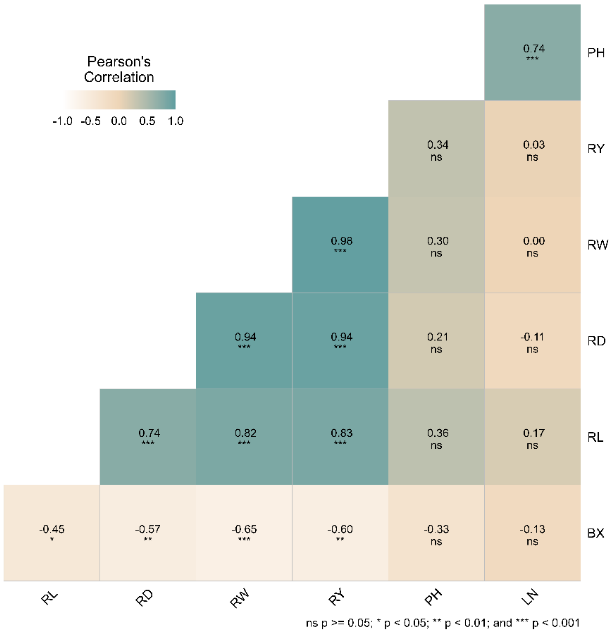

Figure 4. Correlation heatmap illustrating the relationships among various growth and yield parameters of beetroot. (PH = Plant height, LN = Number of leaves per plant, RL = Root length, RY = Root yield, RW = Root weight, RD = Root diameter, BX = Total soluble solids (% Brix)

Conclusion

The study showed that variety and organic mulching significantly affected growth, yield, and quality of beetroot. Red Baby (V_2) outperformed Heart Beet (V_1) in root diameter, fresh weight, and yield, while Heart Beet showed higher plant height and TSS content. Leaf mulch (T_3) enhanced root development and yield, and the combination of Red Baby with leaf mulch (V_2T_3) produced the highest yield, root weight, and diameter. Overall, selecting a high-yielding variety along with organic mulching is effective for improving beetroot productivity and quality.

Conflict of interest

The authors did this research and wrote the article and there is no conflict of interest.

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