



Effects of Foliar Application of Gibberellic Acid on Growth, Yield, and Postharvest Quality of Beetroot (*Beta vulgaris* L.)

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ABSTRACT

A pot experiment was conducted at the Horticulture Farm, Bangladesh Agricultural University, Mymensingh, during the Rabi season of 2023-2024 to evaluate the effect of gibberellic acid (GA₃) with different concentrations on the growth, yield, and postharvest quality of two beetroot varieties when applied as foliar spray. The experiment was laid out in a completely randomized design (CRD) with three replications, comprising two varieties Red Baby (V₁) and Heart Beet (V₂) and four GA₃ concentrations: 0 ppm (T₀), 100 ppm (T₁), 200 ppm (T₂), and 300 ppm (T₃). Results revealed that GA₃ application significantly enhanced growth and yield parameters compared to the control. The 200 ppm GA₃ treatment (T₂) produced the maximum leaf length (37.22 cm), leaf breadth (8.00 cm), root diameter (5.02 cm), root weight (58.17 g), and yield (5.81 t ha⁻¹). Postharvest weight loss was lowest (32.26%) at 200 ppm GA₃, indicating improved shelf life. Among the varieties, Heart Beet (V₂) outperformed Red Baby (V₁) in most growth and yield attributes, while Red Baby exhibited higher anthocyanin content (0.055 μmol m⁻²) and total soluble solids (21.00%). The findings suggested that Heart Beet is more suitable for yield-focused production, especially with 200 ppm GA₃, while Red Baby with 100 ppm GA₃ is better for enhanced sweetness and nutritional quality. Overall, foliar application of GA₃ at 200 ppm proved optimal for improving growth, productivity, and postharvest quality of beetroot.

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1. Introduction

Beetroot (*Beta vulgaris* L.) is a prominent member of the Chenopodiaceae family which is rich in essential nutrients such as vitamins B-complex and C, minerals, fiber, proteins, and diverse bioactive phenolics (Bangar et al., 2022). Beetroot is an annual or biennial crop originating from the Middle East and is now widely grown across the America, Europe, and Asia. In recent years, beetroot has received considerable attention in Bangladesh due to its high nutritional value and potential industrial applications, leading to its widespread cultivation in both home gardens and commercial fields (Mantaqaa et al., 2023). It is not only packed with essential nutrients but is also recognized for its wide range of health-supporting properties. It has been associated with benefits like reducing inflammation, fighting oxidative stress, supporting liver function, managing blood sugar and blood pressure, aiding in wound healing and even offering anticancer potential (Mirmiran et al., 2020). Both the leaves and tuberous roots of beetroot are edible and can be consumed in various forms, including raw, cooked, or canned. The deep purple,

swollen roots of beetroot are typically consumed boiled, roasted, or in salads, either alone or mixed with other salad vegetables. Additionally, table beet is prepared boiled or cooked with other vegetables, and is utilized in pickles, chutneys, and canned food products. (Sarker et al., 2023). In addition to its culinary uses, beetroot is utilized in the production of juice, extracts and as a food colorant as well as an additive in cosmetics (Ceclu and Nistor, 2020).

Beetroot, often called garden beet in places like Western Europe and the USA, is especially popular in Eastern and Central Europe, where it's a common part of the diet. It's grown mainly for its thick, edible roots. Among European countries, England and France are known for both producing and enjoying a lot of table beet. This vegetable does best in soil with a pH between 6.5 and 7.5, and it grows well in mild temperatures around 18 to 25°C (Neelwarne et al., 2012).

Beetroot cultivation in Bangladesh is gradually gaining popularity. About 53% of farmers grow beetroot as a hobby, while 32% do so commercially. Most farmers

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(65%) sell their produce in local markets, with 40% earning profits over 4,000 BDT per decimal of land. However, 46.7% struggle with seed shortages, and 60% require technical support. Despite these issues, 95% of farmers are interested in continuing cultivation (Rashid et al., 2020).

Gibberellic acid (GA_3) significantly enhances growth, yield, and quality parameters in beet (*Beta vulgaris* L.). GA_3 acts mainly by reducing growth inhibition inside the plant. After GA_3 is perceived by the GID1 receptor, it promotes degradation of DELLA proteins, which normally suppress growth (Schwechheimer, 2012). Once DELLA repression is removed, cell division, cell elongation, stem growth, flowering, and seed germination are promoted (Davière & Achard, 2013). Application up to 150 mg/L promotes vegetative growth, increases root biomass, and improves fresh and dry weights. GA_3 also elevates sucrose content and proline levels, contributing to better yield and stress resilience, particularly under drought conditions. Moreover, improvements in stomatal traits and physiological responses indicate its role in enhancing drought tolerance. Overall, GA_3 application supports improved beet productivity and quality, making it a valuable tool in stress-adaptive cultivation strategies.

Gibberellic acid (GA_3) at 200 ppm significantly enhanced sugar beet growth, yield, and quality. It increased root length in the first season and improved root diameter, fresh weight, and purity in the second season. GA_3 also boosted sucrose content and both root and sugar yields, highlighting its effectiveness in promoting both growth and quality in sugar beet (Selim et al. 2009). Gibberellic Acid (GA_3) improves sugar beet growth and yield, particularly root size and weight, but higher concentrations reduce sugar content and TSS. The optimal GA_3 application for growth and yield is 160 mg L⁻¹ at 60 days after planting, combined with 275 kg N ha⁻¹ nitrogen fertilization. For better quality (higher sugar and TSS), lower nitrogen (165 kg N/ha) is recommended, though it may reduce yield. Adjusting GA_3 concentration and timing helps balance yield and quality according to cultivation goals (Leilah & Khan, 2021).

The application of exogenous gibberellic acid (GA_3), through ProGibb and FalGro, improved both the yield and quality of table beet by boosting foliar health (e.g., leaf size, petiole diameter, NDVI, and dry weight) and adjusting root size distribution. GA_3 reduced tiny roots (<19 mm) and increased small roots (19.1–44.5 mm) with no effect on small/medium root proportions or disease severity. The most effective application timing was between 40 and 62 days after planting (DAP), while late-season applications (>80 DAP) had no significant impact (Pethybridge et al., 2024).

A significant proportion of the Bangladeshi population experiences inadequate intake of essential nutrients, particularly micronutrients such as vitamin A, iron, zinc, folate, vitamin B12, vitamin D, and calcium, with vulnerable groups including children and women of reproductive age most affected (UNICEF Bangladesh, 2015; Ahmed et al., 2017). To help combat this issue, our focus has been directed toward cultivating nutrient-enriched crops through low-cost, easily adoptable farming practices. Among these, red beet has received special attention due to its high mineral content.

Several studies have reported beneficial effects of GA_3 on growth and yield of sugar beet under different environmental conditions. However, limited information is available on the combined influence of beetroot variety and GA_3 concentration on growth, yield and quality traits under Bangladeshi agro-climatic conditions. Therefore, the present study was carried out to find out the suitable variety of beetroot from the two varieties used and optimum concentration of GA_3 solution for improving the production and quality of beetroot in Bangladesh. It was hypothesized that application of GA_3 solution would affect the used varieties of beetroot differently and optimum concentrations of applied solution would improve plant growth, yield and quality attributes significantly.

2. Methodology

2.1. Experimental site, soil and climatic condition

The pot experiment was carried out at the Horticulture Farm of the Bangladesh Agricultural University, Mymensingh, during the period of November 2023 to February 2024. The experimental site was located at 24075' N latitude and 90050' E longitude at an average altitude of 18 m above sea level. The potting soil was collected from the Old Brahmaputra Floodplain (AEZ-9), characterized by non-calcareous dark grey soil and silty-loam in texture, with a pH ranging from 5.5 to 6.8. The collected soil was air-dried, crushed, and sieved to ensure uniformity before being filled into experimental pots. The experimental area was located under a subtropical zone during the period of November to February which is comparatively cool, with less rainfall and an average temperature range of 18–25° C which is favorable for exotic crops like beetroot.

2.2. Experimental treatments and design

The experiment included two factors viz., variety and doses of GA_3 . The varieties are Red Baby (V1) and Heart Beet (V2). This study included three GA_3 doses (T1: 100 ppm, T2: 200 ppm and T3: 300 ppm) and one control (T0: No GA_3) treatment. Seeds of two varieties of beetroot namely: Heart beet and Red Baby and GA_3 powder were collected from local seed market in Mymensingh district. The experiment was conducted in a completely randomized design (CRD) with three replications under pot conditions. A total of 24 pots were used, with each replication consisting of 8 pots. The pots were uniformly arranged with appropriate spacing to ensure proper growth conditions and minimize edge effects. Plant to plant distance was about 5–7 cm. The distance between pots in a replication was 0.15 m while the distance between two replications was 0.3 m. Each pot represented an experimental unit. The treatments were randomly assigned to the pots according to the experimental design.

2.3. Seedbed preparation, media preparation and transplanting

Although beetroot is commonly sown directly in the field under normal conditions, a seedbed with 1 m of width and 2 m of length was prepared in a shady area to raise uniform seedlings for this pot experiment. This approach helped ensure that seedlings of similar age, size, and vigour were transplanted into all pots, thereby reducing variation among experimental units. Well-decomposed cow dung was incorporated into the seedbed at the rate of 10 t/ha to enhance soil fertility. The soil was then leveled

and lightly irrigated to maintain adequate moisture for seed germination. Though seedbeds were treated only with cowdung, a form of organic fertilizer, pot media were treated with both organic and inorganic fertilizers. Each pot was uniformly treated with Cowdung (@ 1 kg pot⁻¹), Mustard oil cake (@ 50 g per pot) and Vermicompost (@ 200 g per pot) with 10 kg pot⁻¹ of soil mixture (Muthukannan et al., 2024) before transplanting. In addition to the organic manures, a small quantity of chemical fertilizers were applied as a basal dose at 35 DAT. Urea and Muriate of potash (MoP) were mixed together in a ratio of 60:40 and this mixture was applied to the pot soil at a rate of 10 grams per pot and incorporated into the soil for better growth. The seedlings were transplanted on the pots on December 4, 2023, at 26 DAS at a rate of 3 seedlings per pot. The seedlings were spaced approximately 5 cm to 7 cm apart within each pot, considering the limited space available for proper growth.

2.4. Experimental treatment

A 100 ppm GA₃ solution was prepared in the laboratory mixing 100mg of GA3 with distilled water and the volume was made up to 1 liter by mixing distilled water again. Solutions of 200 ppm and 300 ppm concentrations were also prepared in the same manner. The prepared GA₃ solutions were applied as foliar spray at 45 DAT using a hand sprayer. Approximately 20–25 mL solution per pot was sprayed uniformly until all leaves were completely wetted without runoff.

2.5. Intercultural operation

According to BSRI (2010), uncontrolled weed growth may decrease yield of Beta vulgaris crops such as sugar beet by as much as 30–54%. At 15, 30 and 45 DAT, hand weeding was carried out to keep the beetroot crop free from weeds to ensure that any crop-weed competition was eliminated. To maintain the appropriate plant population, gap filling was carried out three weeks after planting. To cover the root base, allow drainage, and promote optimal root growth, earthing up was carried out at 60 DAT. It was reported that, depending on the soil types and the rainfall, the sugar beet crop requires 8-10 irrigations depending on the availability of soil moisture. The soil of the experimental pots did not contain a sufficient amount of moisture. For this reason, irrigation was done after every three alternate days in the first month, seven alternate days in the second month and 15 alternate days in the third month of transplanting by watering can.

2.6. Harvesting and data collection

Harvesting was done at 80 DAT. All plants were carefully uprooted at harvest. After washing and cleaning, the plant samples were brought to the threshing floor for data recording. Before and after harvest, data on various parameters i.e. Number of leaves per plant, leaf length (cm), leaf breadth (cm), plant height (cm), root length (cm), root diameter (cm), fresh weight of root (g), root yield per pot (kg), dry matter content of root (%), weight loss at different days after storage (%), total soluble solids (TSS Brix %) and anthocyanin content of the leaves (μmol m⁻²), were collected from all 3 plants of each pot (Dhakad et al., (2022)). Root samples from each treatment combination were separated for destructive and non-destructive measurements. For determination of Total Soluble solids (TSS Brix %), a representative root sample was cut, and juice was extracted for measurement using a hand

refractometer. Since this procedure damaged the root tissue, the same root was not used for storage evaluation. The used plastic pots were about 10 inches of diameter with 12 inches of depth containing approximately 10 kg processed soil per pot. Three beetroot plants were maintained in each pot with a plant-to-plant spacing of approximately 5–7 cm.

2.7. Statistical analysis

All the collected data were analyzed statistically following the analysis of variance (ANOVA) technique and the significance of mean differences was calculated by Least Significance Difference (LSD) at 5% and 1% levels of probability as described by (Gomez and Gomez, 1984).

3. Result and discussion

3.1. Leaf length

The effect of variety and GA₃ concentration on leaf length of beetroot at different growth stages is presented in Table 1. Both varieties exhibited an increasing trend in leaf length with the advancement of plant age. V2 (Heart beet) consistently produced longer leaves than V1 (Red baby) at all stages. At 35 DAT, V2 reached 22.59 cm compared to 20.24 cm in V1. By 80 DAT, V2 attained 34.11 cm while V1 reached 31.32 cm. All GA₃-treated plants (T1-T3) exhibited greater leaf length compared to the control (T0). Measurements were recorded at 35, 50, 65, and 80 DAT. At 35 DAT, T2 recorded 23.87 cm, while T0 reached only 17.83 cm. By 80 DAT, T2 attained 36.05 cm, significantly surpassing T0 which remained at 27.94 cm. Leaf length increased progressively with plant age under all treatments, but marked variation was observed due to both variety and GA₃ application. At 35 DAT, the maximum leaf length (25.47 cm) was recorded in V2T2, which was statistically superior to all other treatments, while the minimum (16.58 cm) was noted in V1T0. At 50 DAT, significantly higher leaf length was observed in V2T2 (33.39 cm) and V1T2 (33.28 cm), whereas V1T0 (22.39 cm) produced the shortest leaves. Similarly, at 65 DAT, V2T2 maintained the longest leaves (34.72 cm), closely followed by other GA₃ treatments, while V1T0 (24.22 cm) recorded the lowest value. At 80 DAT, V2T2 (Heart Beet × 200 ppm GA₃) again produced the longest leaves (37.22 cm) which is significantly higher than all other treatments, whereas V1T0 (26.17 cm) showed the minimum. This agrees with earlier studies showing GA3 boosts leaf growth where GA3 (ProGibb 30 ppm) clearly increased table beet leaf length at 40–62 DAP (Pethybridge et al., 2024).

3.2. Leaf breadth

Leaf breadth of beetroot was markedly influenced by both variety and GA₃ treatments throughout the growth period in Table 1. Among the two varieties, V2 (Heart beet) consistently exhibited greater leaf breadth than V1, Red Baby (3). At 35 DAT, the lowest leaf breadth was recorded in V1 (5.45 cm), while V2 showed a significantly higher value (6.11 cm). The maximum leaf breadth was noted at 80 DAT in V2 (7.51 cm), with V1 slightly lower at 7.16 cm. The effect varied across treatments, with the 200 ppm GA₃ (T2) consistently producing the widest leaves, while the control (T0) recorded the narrowest at each stage. Among the treatments, the highest overall leaf breadth was recorded with 200 ppm GA₃ (T2), reaching 8.61 cm at 50 DAT. In contrast, the lowest overall leaf breadth was

observed in the control treatment (T0), measuring 5.29 cm at 35 DAT. Among the treatments, V2T2 (Heart Beet × 200 ppm GA₃) consistently produced the widest leaves, reaching 6.61 cm at 35 DAT and maintaining high breadth values of 8.61 cm at 50 and 65 DAT and 8.00 cm at 80 DAT. In contrast, V1T0 exhibited the narrowest leaves at all stages, with values of 5.02 cm at 35 DAT and 6.16 cm at 80 DAT. GA₃ application, particularly at 200 ppm (T2), significantly enhanced leaf expansion in both varieties,

with the V2 variety showing a stronger response than V1. These results indicate that GA₃ can effectively improve leaf breadth. The present finding also agreed with the result of (Bose et al., 2013). They observed that Gibberellic acid (GA₃) significantly increases leaf width by promoting cell elongation and division. Foliar application of GA₃ at 150 ppm significantly increased leaf breadth in *Gerbera* cultivars (Uddin et al., 2020).

Table 1. Effect of gibberellic acid on vegetative growth of Beetroot

Interac tion effect	Leaf length (cm)				Leaf breadth (cm)				Number of leaves plant-1				Plant height (cm)
	Days after transplanting (DAT)												
	35	50	65	80	35	50	65	80	35	50	65	80	
V ₁ T ₀	16.58 ^h	22.39 ^e	24.22 ^d	26.17 ^h	5.02 ^f	6.22 ^e	6.22 ^e	6.16 ^f	4.67 ^e	5.33 ^d	6.67 ^e	7.00 ^e	24.33 ^e
V ₁ T ₁	19.92 ^d	30.67 ^c	31.67 ^b	31.61 ^f	5.41 ^e	7.11 ^d	7.00 ^d	7.22 ^d	5.33 ^d	6.33 ^c	7.67 ^d	8.33 ^d	33.22 ^c
V ₁ T ₂	22.28 ^c	33.28 ^a	32.22 ^b	34.88 ^c	5.86 ^b	8.61 ^a	7.61 ^b	7.94 ^a	6.00 ^b	7.00 ^a	8.67 ^b	8.67 ^c	36.78 ^b
V ₁ T ₃	22.17 ^c	30.66 ^c	32.17 ^b	32.61 ^e	5.52 ^d	7.50 ^c	7.00 ^d	7.33 ^c	5.33 ^d	6.33 ^c	8.00 ^c	8.67 ^c	33.67 ^c
V ₂ T ₀	19.08 ^e	26.66 ^d	27.94 ^c	29.72 ^g	5.56 ^d	6.44 ^e	6.89 ^d	7.05 ^e	5.33 ^d	5.33 ^d	7.67 ^d	8.33 ^d	28.55 ^d
V ₂ T ₁	22.14 ^c	31.44 ^c	32.11 ^b	33.83 ^d	5.70 ^c	7.22 ^d	7.44 ^c	7.33 ^c	5.67 ^c	6.67 ^b	8.67 ^b	8.33 ^d	34.33 ^c
V ₂ T ₂	25.47 ^a	33.39 ^a	34.72 ^a	37.22 ^a	6.61 ^a	8.61 ^a	7.94 ^a	8.00 ^a	6.33 ^a	7.00 ^a	9.33 ^a	11.00 ^a	38.44 ^a
V ₂ T ₃	23.67 ^b	32.66 ^b	32.77 ^b	35.66 ^b	6.58 ^a	7.94 ^b	7.44 ^c	7.67 ^b	6.33 ^a	7.00 ^a	8.67 ^b	10.00 ^b	36.05 ^b
LSD _{0.05}	0.48	0.43	0.99	0.43	0.16	0.19	0.12	0.18	0.16	0.18	0.13	0.27	0.85

3.3. Number of leaves/plant

The number of leaves per plant showed a clear increase over time across all treatments in Table 1. At 35, 50, 65, and 80 DAT the leaf number of the plants was measured. The number of leaves per plant responded significantly to the varieties. The number of leaves per plant gradually increased up to 65 DAT, then slowly increased by 80 DAT. The results indicate that the highest number of leaves (9.42) was recorded on the heart beet (V2) variety at 80 DAT, and the lowest value (5.33) was recorded on the red baby (V1) variety at 35 DAT. The number of leaves per plant was significantly affected by the application of gibberellic acid (GA₃) at 35, 50, 65, and 80 days after transplanting. The treatment T2 (200 ppm GA₃) consistently produced the highest number of leaves throughout the growth stages, with the maximum (9.83) recorded at 80 DAT. In contrast, the lowest number of leaves (5.00) was recorded in the control treatment (T0) at 35 DAT. At 35 DAT, the lowest count was observed in V1T0 (4.67 leaves), while V2T2 and V2T3 had the highest (6.33 leaves). By 50 DAT, leaf numbers ranged from 5.33 in V1T0 to 7.00 in V2T2. At 65 DAT, V2T2 reached 9.33 leaves, the highest among all treatments, whereas V1T0 had only 6.67. At 80 DAT, V2T2 (Heart Beet × 200 ppm GA₃) maintained the highest leaf count (11.00), followed by V2T3 (10.00), and V1T0 remained the lowest (7.00). This pattern indicates that GA₃ application, especially at T2, promoted greater leaf production in both varieties. GA₃ application significantly enhanced plant growth by increasing number of leaves per plant, even under drought stress (Azab, 2018).

3.4. Plant height

Gibberellic acid (GA₃) application significantly enhanced plant height in Table 1. In both beetroot varieties, with the

tallest plants observed at 200 ppm (V2T2, 37.22 cm) and 300 ppm (V2T3, 35.66 cm) at 80 DAT, compared to the untreated controls (V1T0, 24.33 cm; V2T0, 28.55 cm), demonstrating that GA₃ effectively promotes stem elongation and higher concentrations generally resulted in greater height, with Heart Beet (V2) responding more prominently than Red Baby (V1). The tallest plants were recorded in V2T2 (Heart Beet with 200 ppm GA₃, 37.22 cm), followed by V2T3 (35.66 cm), while the shortest was in V1T0 (Red Baby control, 24.33 cm). Overall, Heart Beet (V2) responded more strongly to GA₃ than Red Baby (V1). Previous study supported that 150 ppm GA₃ significantly increased shoot length in rice seedlings, indicating its effectiveness in promoting plant height (Chauhan et al., 2019).

3.5. Anthocyanin Content

Anthocyanin accumulation in beetroot leaves varied with GA₃ treatment and variety (Table 3). The highest anthocyanin content at 35 DAT was recorded in Red Baby treated with 100 ppm GA₃ (V1T1, 0.055 μmol m⁻²), while the lowest was observed in Heart Beet treated with 200 ppm GA₃ (V2T2, 0.015 μmol m⁻²) (Figure 1.). In general, moderate GA₃ concentrations (100-200 ppm) enhanced anthocyanin levels during early stages, whereas higher concentrations (300 ppm) or no GA₃ resulted in lower content. Anthocyanin accumulation in beetroot varied significantly with both varietal differences and GA₃ concentrations across growth stages. Red Baby (V1) consistently exhibited higher anthocyanin concentrations (0.041, 0.037, 0.031, and 0.032 μmol m⁻² at 35, 50, 65, and 80 DAT, respectively) compared to Heart Beet (V2) (0.031, 0.031, 0.026, and 0.030 μmol m⁻²). Among the treatments, 100 ppm GA₃ (T1) produced the highest anthocyanin levels at 35 and 50 DAT (0.049 and 0.047 μmol m⁻²), whereas 300 ppm GA₃ (T3) recorded the lowest values (0.030, 0.028, 0.027, and 0.027 μmol m⁻²),

indicating a concentration-dependent decline at higher GA₃ levels. GA₃ enhances anthocyanin accumulation especially when applied shortly before harvest (Taheri-Shiva et al., 2014).

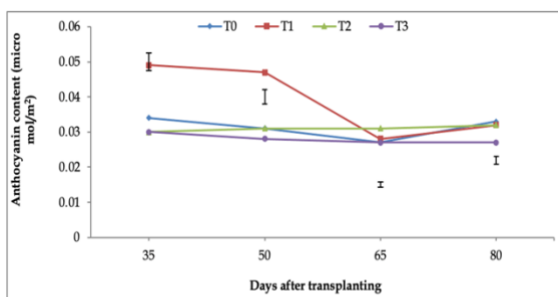


Figure 1. Effects of gibberellic acid (GA₃) on anthocyanin content at different days after planting of beetroot. The vertical bars represent LSD at 1% level of probability. Here, T₀= Control, T₁=100 ppm (GA₃), T₂=200 ppm (GA₃), T₃= 300 ppm (GA₃).

3.6. Root length

Root length of beetroot was significantly influenced by the interaction of GA₃ application and variety in Table 2. The longest roots were observed in V2T2 (Heart Beet × 200 ppm GA₃) at 4.83 cm, followed by V1T2 (Red Baby × 200 ppm GA₃) at 4.75 cm and V2T3 (Heart Beet × 300 ppm GA₃) at 4.55 cm. Moderate root lengths were recorded in V1T3 (4.28 cm) and V2T1 (3.94 cm), while the shortest roots were found in the controls V1T0 (3.55 cm) and V2T0 (3.78 cm). Overall, 200 ppm GA₃ promoted maximum root elongation in both varieties, with Heart Beet consistently showing slightly higher root lengths than Red Baby at corresponding GA₃ levels. The differences among the treatment combinations were statistically significant at both 5% and 1% levels (LSD_{0.05} = 0.08, LSD_{0.01} = 0.11). Foliar application of GA₃ enhanced root length in sugar beet, with higher concentrations showing greater increases (Leilah and Khan, 2021). In recent studies, an optimal concentration of GA₃ that maximized root length (Patel et al., 2015) and GA₃ treatment increased root length in okra plants under both normal and saline (NaCl) conditions. (Teama et al., 2023).

3.7. Root diameter

There was a significant variation in root diameter depending on the different concentration of GA₃ used (Table 2). Heart Beet treated with 200 ppm GA₃ (V2T2) produced the thickest roots (5.02 cm), followed by V2T3 (4.25 cm) and Red Baby with 200 ppm GA₃ (V1T2, 4.11 cm). In contrast, the lowest root diameter was observed in Red Baby without GA₃ application (V1T0, 2.86 cm). Overall, GA₃ application increased root diameter in both varieties, with Heart Beet showing a greater response than Red Baby. The researchers found that GA₃ application significantly increased root diameter, with the highest value observed at a concentration of 50 mg/L. This enhancement in root diameter was attributed to the hormone's role in promoting cell division and elongation within the root tissues (Leilah and Khan, 2021).

3.8. Root Weight Plant⁻¹

Application of GA₃ significantly affected the weight of both varieties (Table 2). The highest root weight (58.17 g) was recorded in V2T2, while the lowest was in V1T0 (33.11 g). Treatments receiving 200 ppm and 300 ppm GA₃ produced significantly heavier roots compared to the

untreated control. Heart Beet consistently showed higher root weight than Red Baby under the same GA₃ treatments. Researcher observed that GA₃ increased root weight in sugar beet by enhancing root growth, especially at 160–240 mg L⁻¹ applied at 60 days after planting (Leilah and Khan, 2021). Seed treatment with gibberellic acid (GA₃), especially at 150 mg L⁻¹, increases root weight in sugar beet by improving growth and physiological traits under water stress (Azab, 2018).

Table 2. Effect of gibberellic acid on yield and yield-contributing characters of Beetroot

Treatment combination	Root length (cm)	Root diameter (cm)	Average root weight (g)
V ₁ T ₀	3.55 ^f	2.86 ^e	33.11 ^e
V ₁ T ₁	3.83 ^e	3.68 ^c	42.28 ^c
V ₁ T ₂	4.75 ^a	4.11 ^b	49.44 ^b
V ₁ T ₃	4.28 ^c	3.80 ^c	47.50 ^b
V ₂ T ₀	3.78 ^e	3.52 ^d	36.77 ^d
V ₂ T ₁	3.94 ^d	4.21 ^b	47.22 ^b
V ₂ T ₂	4.83 ^a	5.02 ^a	58.17 ^a
V ₂ T ₃	4.55 ^b	4.25 ^b	49.33 ^b
LSD _{0.05}	0.08	0.17	1.78

3.9. Total Soluble solids (TSS Brix %)

TSS values were influenced by both GA₃ application and variety (Table 3). At harvest, the highest TSS (21.00% Brix) was recorded in Red Baby with 100 ppm GA₃ (V1T1), whereas the lowest TSS (15.00% Brix) was observed in Red Baby without GA₃ (V1T0). Moderate GA₃ treatments generally increased TSS compared to untreated controls, indicating improved sugar accumulation. Between the varieties, Red Baby (V1) showed the highest TSS value (17.50 °Brix), while Heart Beet (V2) recorded slightly lower TSS (17.00 °Brix). Among the treatments, 100 ppm GA₃ (T1) produced the highest TSS (19.50 °Brix), followed by T2 and T3 (17.00 °Brix), while the lowest was observed in the control (T0) with 15.50 °Brix, showing a significant difference at the 1% level. Studies stated that GA₃ seed pre-soaking and GA₃ improved sucrose content in sugar beet, implying a potential increase in TSS (Azab, 2018).

3.10. Weight loss (%)

Weight loss of beetroot during storage was significantly affected by GA₃ application and variety (Table 3). At 8 days of storage, the highest weight loss (44.80%) was recorded in Red Baby without GA₃ (V1T0), while the lowest weight loss (32.26%) was observed in Red Baby treated with 200 ppm GA₃ (V1T2). Overall, GA₃ application reduced weight loss in both varieties compared to untreated controls, indicating improved shelf-life quality. Heart Beet (V2) showed slightly lower weight loss than Red Baby under similar GA₃ treatments. Between the varieties, Heart Beet (V2) exhibited lower weight loss (36.68%) compared to Red Baby (V1) (38.15%) at 8 days after storage. Among the treatments, 200 ppm GA₃ (T2) showed the minimum weight loss (33.34%), followed by T3 (35.46%), T1 (38.68%), and the highest in the control (T0) with 42.17%. GA₃ application

improved yield and preserved the quality of minimally processed lettuce and rocket during 21 days of cold storage at 4°C (Miceli et al., 2019).

Table 3. Effect of gibberellic acid on postharvest quality

Interaction effect	Shelf life quality		Anthocyanin Content							TSS (%brix)
	Initial weight (g)	Weight loss (%) at different days after storage				Anthocyanin content (μmol m ⁻²) at different days after transplanting				
		2	4	6	8	35	50	65	80	
V ₁ T ₀	184.00	13.60 ^a	23.20 ^a	38.40 ^a	44.80 ^a	0.037 ^b	0.026 ^c	0.030 ^b	0.032 ^a	15.00 ^e
V ₁ T ₁	177.00	11.76 ^c	20.92 ^b	34.64 ^b	39.87 ^b	0.055 ^a	0.051 ^a	0.029 ^b	0.034 ^a	21.00 ^a
V ₁ T ₂	227.00	7.47 ^a	15.73 ^d	29.22 ^c	32.26 ^a	0.045 ^b	0.045 ^b	0.035 ^a	0.029 ^a	17.00 ^c
V ₁ T ₃	308.00	10.33 ^e	18.06 ^c	30.99 ^c	35.67 ^d	0.025 ^b	0.025 ^c	0.031 ^b	0.034 ^a	17.00 ^c
V ₂ T ₀	153.00	12.43 ^b	20.90 ^b	34.46 ^b	39.55 ^b	0.032 ^b	0.035 ^c	0.025 ^b	0.033 ^a	16.00 ^d
V ₂ T ₁	125.00	11.01 ^d	18.48 ^c	32.07 ^c	37.50 ^c	0.042 ^b	0.042 ^b	0.026 ^b	0.031 ^a	18.00 ^b
V ₂ T ₂	248.00	8.47 ^f	15.26 ^d	27.42 ^c	34.42 ^d	0.015 ^c	0.017 ^d	0.028 ^b	0.035 ^a	17.00 ^c
V ₂ T ₃	171.00	8.77 ^f	17.54 ^c	30.84 ^c	35.24 ^d	0.034 ^b	0.031 ^c	0.023 ^b	0.020 ^b	17.00 ^c
LSD _{0.05}		0.45	0.68	1.66	1.31	0.006	0.005	0.0016	0.0023	0.38

4. Conclusion

Based on the experimental results, it can be concluded that gibberellic acid (GA₃) had a substantial impact on the growth, yield, and quality of beetroot. Among the different levels, plants treated with GA₃ @ 200 ppm showed the greatest improvements in leaf growth, root diameter and root weight (58.17 g), while also reducing post-harvest weight loss. Therefore, GA₃ at 200 ppm can be recommended as the optimal concentration for enhancing both productivity and quality in beetroot cultivation.

Conflict of interest

The authors declare no conflict of interest.

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