

Assessment of effect of different doses of GA₃ on strawberry under different environmental conditions

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Abstract

Background: Strawberry (*Fragaria* × *ananassa*) production in subtropical regions is often constrained by unfavorable environmental conditions, particularly excessive solar radiation and temperature. The use of shade and plant growth regulators such as gibberellic acid (GA₃) may improve vegetative growth, yield, and fruit quality. However, information on the combined effects of agro-shade and GA₃ application on strawberry production under subtropical conditions of Bangladesh remains limited. Therefore, this study was conducted to evaluate the effects of different GA₃ doses under ambient and agro-shade conditions on the growth, yield, and fruit quality of strawberry.

Materials and Methods: The experiment was conducted at the Horticulture Research Field of the Bangladesh Institute of Nuclear Agriculture from October 2025 to March 2026. The experiment comprised two factors: growing conditions, including ambient and agro-shade conditions with 55% sunlight absorption, and four GA₃ concentrations (0, 50, 100, and 200 ppm). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Healthy and disease-free daughter plants of strawberry cultivar Rabi-1 were used as planting materials. GA₃ was applied as foliar spray twice at 15-day intervals after transplanting. Growth, yield, and fruit quality parameters were recorded and analyzed statistically to determine the effects of growing conditions and GA₃ treatments.

Results: Growing conditions significantly influenced most growth, yield, and quality attributes. Plants grown under agro-shade conditions exhibited greater plant height, number of leaves, canopy spread, survivability, number of fruits per plant, individual fruit weight, and total yield than those grown under ambient conditions. Conversely, fruits produced under ambient conditions showed superior quality attributes, including higher total soluble solids, vitamin C, titratable acidity, reducing sugar, non-reducing sugar, total sugar, and juice content. Among the GA₃ treatments, 100 ppm GA₃ produced the best overall performance, resulting in the highest plant height, leaf number, canopy spread, survivability, fruit number, individual fruit weight, yield per plot, and yield per hectare. It also improved most fruit quality attributes compared with the control and other GA₃ concentrations. In contrast, 200 ppm GA₃ resulted in comparatively lower performance for most measured traits. The combined treatment of agro-shade with 100 ppm GA₃ was the most effective for enhancing vegetative growth and yield.

Conclusion: The findings demonstrate that agro-shade conditions combined with an appropriate GA₃ concentration can substantially improve strawberry growth and productivity under subtropical conditions. Among the tested treatments, 100 ppm GA₃ under agro-shade conditions provided the best overall performance and may be recommended for maximizing strawberry growth and yield in Bangladesh. However, ambient conditions may be preferable when the primary objective is to enhance specific fruit-quality attributes.

Keywords: Strawberry, Gibberellic acid (GA₃), Plant growth regulator, Agro-shade condition, Ambient condition, Growth performance, Fruit yield, Fruit quality, Survivability.

Date of Submission: 28-09-2026

Date of Acceptance: 07-10-2026

I. Introduction

Strawberry (*Fragaria* × *ananassa* Duch.) is one of the most economically important berry crops worldwide because of its exceptional nutritional quality, attractive appearance, pleasant flavor, and high market value. The fruit is widely appreciated as a rich source of vitamin C, folates, dietary fiber, anthocyanins, flavonoids, ellagic acid, and other phenolic compounds with antioxidant properties. Regular strawberry consumption has been reduced oxidative stress and inflammation and may contribute to lowering the risk of cardiovascular diseases, type 2 diabetes, and certain types of cancer (Giampieri et al., 2012; Basu et al., 2014; Giampieri et al., 2017). Growing consumer interest in healthy and functional foods has contributed to a steady increase in global

strawberry production, which exceeded 10 million tonnes in 2023, with China, the United States, Türkiye, Egypt, Mexico, and Spain among the major producers (FAO, 2025).

Strawberry is highly sensitive to environmental conditions, particularly temperature, solar radiation, relative humidity, and soil moisture. Optimum growth and reproductive development generally occur under moderate temperatures of approximately 18–25°C and favorable moisture conditions (Hernández-Martínez et al., 2023; Menzel, 2024; Bisht et al., 2024). Although strawberry is native to temperate regions, its commercial cultivation has expanded into several subtropical countries through the development of improved cultivars and the adoption of appropriate crop management practices (da Silva et al., 2023; Ullah et al., 2026). In Bangladesh, strawberry cultivation was introduced by the Bangladesh Agricultural Research Institute during the early 2000s, and since then the crop has gained considerable attention among farmers because of its high economic return, short production cycle, and increasing consumer demand (Khatun et al., 2022). Despite its potential, strawberry cultivation in Bangladesh faces several challenges because of unfavorable environmental conditions during the growing season, including high temperature, fluctuating humidity, excessive rainfall during crop establishment, and irregular solar radiation, all of which adversely affect vegetative growth, flowering, fruit set, fruit quality, and marketable yield (BARI, 2020; Hancock, 2020; Wang et al., 2023). These constraints may become more severe under climate change, emphasizing the need for environmentally adaptive production practices.

Protected cultivation techniques, including net houses, agro-shades, and shade-net structures, have emerged as effective approaches for improving strawberry production under suboptimal environmental conditions. Previous studies have demonstrated that protected cultivation can modify the crop microclimate by reducing excessive solar radiation and wind speed, increasing relative humidity, and maintaining more favorable air and soil temperatures, and promotes greater vegetative growth, and increased fruit yield compared with open-field cultivation. In addition, the moderated microenvironment reduces abiotic stress during the critical establishment stage and extends the productive period of the crop (Mahmood et al., 2018; Hernández-Martínez et al., 2023; Doust et al., 2023; Ono et al., 2024; Yang et al., 2026). Nevertheless, responses in fruit quality attributes, such as total soluble solids, vitamin C, and sugar accumulation, may vary depending on the degree of shading, cultivar, and prevailing climatic conditions. Therefore, optimizing the growing environment remains an important prerequisite for achieving a balance between high fruit yield and superior fruit quality under subtropical production systems (Liu et al., 2023; Zhu et al., 2023; Doust et al., 2023; Yang et al., 2026).

In addition to environmental modification, plant growth regulators can be used to manipulate strawberry growth and productivity. Gibberellic acid (GA₃) is one of the most extensively studied hormones because of its ability to stimulate stem elongation, leaf expansion, flowering, and fruit growth (Li et al., 2024). In strawberry, GA₃ promotes vegetative vigor by enhancing leaf area development, also influences floral initiation, fruit set, berry enlargement, and fruit maturation, thereby improving both yield and commercial fruit quality (Rimy et al., 2024; Palei et al., 2024; Kamboj et al., 2024). However, the physiological response to exogenous GA₃ is concentration-dependent, and excessive application may disrupt endogenous hormonal balance, stimulate excessive vegetative growth at the expense of reproductive development, and ultimately reduce fruit yield and quality (Rademacher, 2015; Li et al., 2024). Numerous studies have demonstrated the beneficial effects of moderate GA₃ concentrations on strawberry production under different growing environments. These findings indicate that identifying an optimum GA₃ concentration suitable for specific environmental conditions is essential for maximizing strawberry productivity and fruit quality under subtropical cultivation systems (Katel et al., 2022; Li et al., 2024; Palei et al., 2024; Cai et al., 2024; Kamboj et al., 2024).

Despite considerable progress in strawberry production research, most previous studies have evaluated the effects of protected cultivation or plant growth regulators independently, with relatively limited attention given to their combined influence under subtropical environmental conditions. Furthermore, few studies have simultaneously assessed plant establishment, growth dynamics, yield components, and comprehensive fruit quality attributes under contrasting cultivation environments using locally adapted strawberry cultivars. Consequently, growers still lack clear recommendations regarding the most effective combination of growing environment and GA₃ concentration for maximizing strawberry productivity while maintaining desirable fruit quality under subtropical conditions.

Based on the established roles of protected cultivation in moderating the crop microclimate and of gibberellic acid in promoting vegetative growth and reproductive development, it was hypothesized that cultivating strawberry under agro-shade conditions in combination with an optimum concentration of GA₃ would improve plant establishment, vegetative growth, fruit yield, and physicochemical quality compared with ambient cultivation or suboptimal GA₃ concentrations. Furthermore, it was expected that excessive GA₃ application would not confer additional benefits and might adversely affect plant performance due to hormonal imbalance and excessive vegetative growth. To test this hypothesis, the present study was conducted to (i) evaluate the effects of two different growing environments on the growth, survivability, yield, and physicochemical quality of strawberry, (ii) determine the optimum concentration of gibberellic acid (GA₃) for improving vegetative growth, fruit yield, and fruit quality of strawberry, (iii) assess the interactive effects of growing environment and GA₃ concentration on growth, yield attributes, and physicochemical quality parameters of strawberry, and (iv) to

identify the most suitable combination of growing environment and GA₃ concentration for maximizing strawberry productivity and fruit quality under the subtropical agroecological conditions of Bangladesh.

II. Materials and Methods

Experimental site: The experiment was conducted at the Horticulture Research Field of the Bangladesh Institute of Nuclear Agriculture (BINA) (24.75° N, 90.50° E), Mymensingh, Bangladesh, during the period from October 2025 to March 2026. The experimental site is situated in the Old Brahmaputra Floodplain (Agro-Ecological Zone 9), characterized by medium-high land with well-drained alluvial soil (pH 6.8) (BARC, 2018). The location of the experimental site is presented at Figure 1.

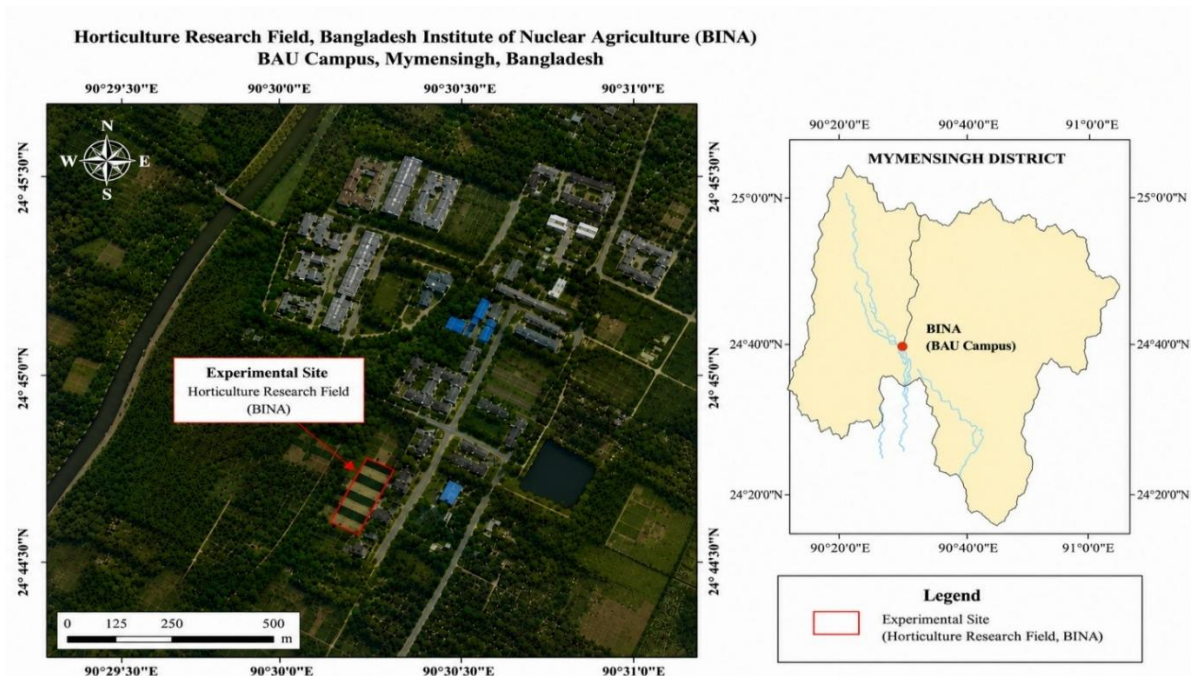


Figure 1. Location of the experimental site

Plant materials and treatments: About 35 days old healthy, disease-free daughter plants of strawberry (*Fragaria × ananassa* Duch.) cultivar Rabi-1 was collected from Rajshahi and transplanted into the experimental field. The experiment consisted of two factors: (i) growing environment and (ii) gibberellic acid (GA₃) concentration. Two growing environments were evaluated: ambient (open-field) and agro-shed (55% light interception). Four concentrations of GA₃ (0, 50, 100, and 200 ppm) were applied as foliar sprays to the roots and shoots at 15-day intervals after transplanting, with a total of two applications. Tween 80 was added as a surfactant to improve the adhesion, spreading, and uniform distribution of the GA₃ solution on the leaf surface.

Experimental design and crop management: The experiment was conducted in a two-factor Randomized Complete Block Design (RCBD) with three replications, following the experimental design principles described by Gomez and Gomez (1984). Twenty-four plots (1.0 × 1.0 m) were established, each containing twelve plants spaced at 25 cm × 30 cm. Distance between plot to plot was 50 cm. For land preparation, weeds and stubbles of previous crops were collected and removed manually from the plot. Fertilizers were applied at recommended doses (BARC, 2024). Full dose of cow dung (37 t ha⁻¹), MoP (333 kg ha⁻¹), TSP and Urea were applied at final land preparation and rest of MoP and Urea in two installments. Standard intercultural operations, including gap filling, irrigation, weed management, and pest control, were maintained uniformly throughout the growing period according to the recommended production practices for strawberry cultivation in Bangladesh (BARI, 2011). Strawberry plants were irrigated by water cane soon after transplanting and thereafter at two days interval up to 60 days. At the time of fruit setting, the crop was attacked by ant and fox. The insects were controlled mechanically and the total experimental field was covered by net. Harvesting was done by plot wise at different days after attaining maturity.

Experimental site weather data: The monthly average meteorological conditions prevailing during the experimental period are presented in Table no 1. The experiment was conducted under typical winter climatic conditions of Mymensingh, characterized by a gradual decline in temperature from October to January followed

by an increase from February onward, accompanied by low rainfall and moderate sunshine duration. The region experiences a subtropical climate with cool and dry winter conditions, which are favorable for strawberry cultivation (Hasan et al, 2024).

Table no 1: Distribution of monthly average air temperature, relative humidity, rainfall and sunshine hours of the experiment site during the period from October 2026 to March 2026

Month	Monthly average relative humidity (%)	Maximum (°C)	Minimum (°C)	Average (°C)	Monthly average rainfall (mm)	Monthly average sunshine (hrs)
October	68	30.8	23.6	27.2	179	235
November	55	28.7	18.2	23.4	18	170
December	50	25.8	13.5	19.6	0	160
January	60	24	11	17.5	5	165
February	55	27.5	14	22	20-100	180
March	50	32	22.6	25	15.5	200

Source: Weather Yard, Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh and Bangladesh Meteorological Department (2026).

Data collection: Three representative plants were randomly selected from each plot for recording observations. Plant height (cm), number of leaves per plant, runner per plant, and canopy spread (cm³) were measured at 45, 60, 75, and 90 days after transplanting (DAT). Canopy spread (canopy volume) was estimated using the equation: Canopy volume = $\frac{4}{3} a^2 b$, where a is half of the plant height and b is the average canopy radius measured along the north-south and east-west directions. Yield components including fruit number per plant, fruit length (cm), fruit diameter (cm), individual fruit weight (g), fruit number per plot, fruit yield per plot (kg), and estimated yield (ton per hectare) were recorded at harvest.

Fruit quality analysis: Fruit quality parameters were determined using established analytical procedures. Total soluble solids (TSS) were measured with a digital refractometer (Model N-1 a. Atago, Japan) following the procedure described by the Association of Official Analytical Chemists (AOAC, 2019). Ascorbic acid (vitamin C) content and titratable acidity (% Citric Acid) (TA) were determined according to the method of Ranganna (1979). pH of the fruit pulp was measured using a glam electrode pH meter (GLP 21, Crison, Bercelesona, EEC) following AOAC International (2019). Reducing sugar (RS), non-reducing sugar (NRS), and total sugar (TS) contents were determined using the Lane and Eynon (1923) titrimetric method, while juice content (JC) was calculated with the following formula: % juice in fruit pulp = $\frac{(FW-JW)}{(FW)} \times 100$, where, FW Fresh weight of fruit pulp and JW = Juice weight of fruit pulp.

Statistical analysis: The collected data were subjected to analysis of variance (ANOVA) appropriate for a two-factor Randomized Complete Block Design using MSTAT-C software. Treatment means were separated using the Least Significant Difference (LSD) test at the 5% probability level following the procedures described by Gomez and Gomez (1984).

III. Result

Effects of two different growing conditions

Effects of different growing conditions on vegetative growth

Growing conditions significantly influenced the vegetative growth of strawberry plants throughout the experimental period (Supplementary information: Table S1, Table S2; Table no 2). Figure 2 shows that plant height increased progressively from 45 to 90 DAT under both growing conditions. At 90 DAT, plants grown under the agro-shed attained a significantly greater height (20.94 cm) than those grown under ambient conditions (19.05 cm), representing a 9.9% increase (Figure 2A). Leaf production was enhanced under the agro-shed, with plants producing 18.52 leaves plant⁻¹ compared with 17.11 leaves plant⁻¹ under ambient conditions at 90 DAT (Figure 2B).

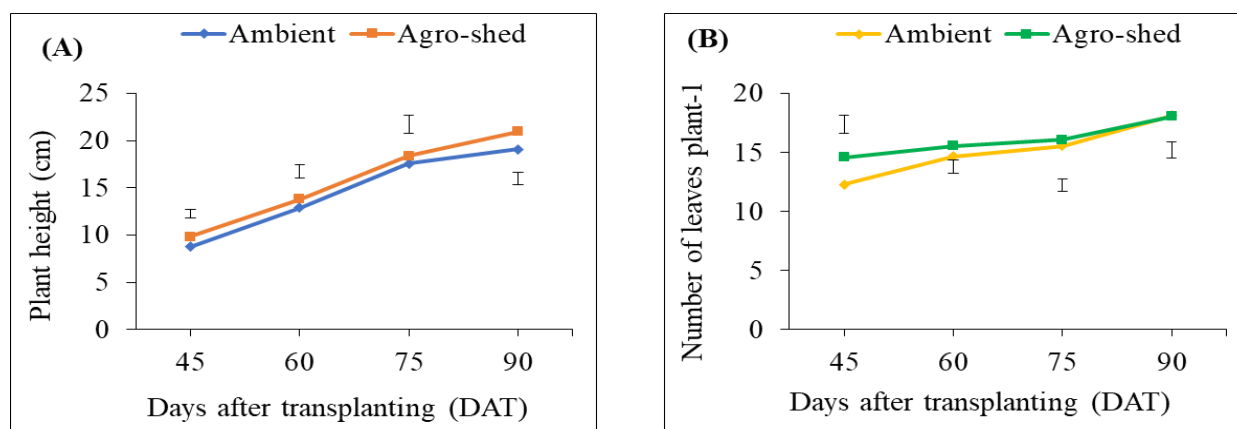


Figure 2. Effect of growing condition on plant height (A), and number of leaves plant⁻¹ (B) at different DAT.
Legend: Vertical bars represents standard error.

Table no 2 shows the effect of growing condition on growth and growth contributing characters of strawberry. At 90 DAT, canopy spread reached 1883.58 cm³ under the agro-shed, which was approximately 21.4% greater than that recorded under ambient conditions (1551.34 cm³). Likewise, runner production was consistently higher under protected cultivation. At 90 DAT, agro-shed-grown plants produced 2.75 runner plant⁻¹, whereas ambient-grown plants produced 2.38 runner plant⁻¹, corresponding to a 15.5% increase. Number of fruits plant⁻¹ as higher in agro shed condition (4.06 plant⁻¹) than in ambient condition (3.45 plant⁻¹).

Table no 2: Effect of growing condition on growth and growth contributing characters of strawberry

Growing condition	Canopy spread (cm ³)				Runner plant ⁻¹				Individual fruit plant ⁻¹			
	45 DAT	60 DAT	75 DAT	90 DAT	45 DAT	60 DAT	75 DAT	90 DAT	45 DAT	60 DAT	75 DAT	90 DAT
C ₁ (Ambient)	548.39 b	884.64 b	1228.95 b	1551.34 b	0.08 b	0.67 b	1.85 b	2.38 b	0.00	0.45 b	2.42 b	3.45 b
C ₂ (Agro-shed)	755.87 a	1212.24 a	1540.66 a	1883.58 a	0.17 a	1.03 a	2.25 a	2.75 a	0.00	0.92 a	2.64 a	4.06 a
LSD _{0.05}	35.02	34.43	46.76	66.53	0.02	0.10	0.09	0.10	-	0.07	0.11	0.18
Level of significance	**	**	**	**	**	**	**	**	-	**	**	**
CV (%)	6.13	3.75	3.86	4.42	22.25	13.74	5.26	4.36	-	12.37	5.01	5.63

** = Significant at 1% level of probability, NS = Not significant; DAT = Days after transplanting

Table no 3 shows that plant mortality and survivability in different strawberry was significantly ($p < 0.01$) influenced by growing condition. The highest plant mortality (20.29%) was found from ambient condition and agro shed condition exhibited the lowest (17.27%). Whereas, the highest survivability (82.72%) was found from agro shed condition and the lowest (79.70%) was found in ambient condition.

Table no 3: Effect of growing condition on percent survivability and mortality of strawberry

Growing condition	Mortality (%)	Survivability (%)
C ₁ (Ambient)	20.29 a	79.70 b
C ₂ (Agro-shed)	17.27 b	82.72 a
LSD _{0.05}	0.43	0.42
Level of significance	**	**
CV (%)	2.60	0.58

** = Significant at 1% level of probability

There was a significant ($p < 0.01$) variation on growing condition in respect of yield and yield contributing characters on different growing condition (Table no 4). The longest fruit length (3.54cm) was found in agro-shed condition whereas the shortest (3.41cm) was observed in agro-shed condition. The maximum average diameter (2.39 cm) was recorded from agro-shed condition and the minimum (2.22 cm) as was found from ambient condition. Fruit fresh weight was higher in agro-shed condition (15.85 g fruit⁻¹) than in ambient condition and the value is 14.71 g fruit⁻¹. Number of fruits per plot as higher in agro-shed condition (80.25 plot⁻¹) than in ambient condition (62.17 plot⁻¹). The highest fruit yield (1.34 kg plot⁻¹) found in agro-shed condition and the lowest (0.95 kg plot⁻¹) measured in ambient condition.

Table no 4: Effect of growing condition on yield and yield contributing characters of strawberry

Growing condition	Length of fruit (cm)	Diameter of fruit (cm)	Individual weight fruit ⁻¹ (g)	No. of fruits plant ⁻¹	No. of fruits plot ⁻¹	Yield plot ⁻¹ (kg)
C ₁ (Ambient)	3.41 b	2.22 b	14.71 b	6.06 b	62.17 b	0.95 b
C ₂ (Agro-shed)	3.54 a	2.39 a	15.85 a	7.56 a	80.25 a	1.34 a
LSD _{0.05}	0.05	0.05	0.31	1.09	10.33	0.16
Level of significance	**	**	**	**	**	**
CV (%)	1.69	2.42	2.30	18.23	16.57	16.31

** = Significant at 1% level of probability

The results in Table no 5, showed the presence of significant ($p < 0.01$) differences on brix percentage, vitamin C, RS, NRS, TS and JC of different growing condition. Strawberry from ambient condition contained more, brix percentage (9.97%), TA (0.75), Vitamin C (55.27 mg/100g), RS (3.23), TS (7.07), and NRS (3.83%), than agro-shed brix percentage (8.76%), TA (0.74), Vitamin C (53.99) RS (3.09), TS (6.83), and NRS (3.74%). However, no significant difference in TA was detected.

Table no 5: Effect of growing condition on % of brix, TA, vitamin C, pH, % of RS, %NRS, % of TS and % of JC of strawberry

Growing condition	% of Brix	TA	Vitamin C (mg/100g)	pH	% of RS	% of NRS	% of TS	% of JC
C ₁ (Ambient)	9.97 b	0.75	55.27 a	3.29 b	3.23 a	3.83 a	7.07 a	75.26 a
C ₂ (Agro-shed)	8.76a	0.74	54.24 b	3.35 a	3.09 b	3.74 b	6.83 b	74.75 b
LSD _{0.05}	0.16	0.01	0.23	0.03	0.03	0.01	0.03	0.06
Level of significance	**	NS	**	**	**	**	**	**
CV(%)	1.95	1.21	0.48	0.91	1.04	0.44	0.56	0.09

** = Significant at 1% level of probability, NS = Not significant

Effect of different doses of GA₃

Effect of different doses of GA₃ on vegetative growth

The variation in vegetative growth of strawberry was found to be significant due to the use of different doses of GA₃ throughout the experimental period (Supplementary information: Table S1, Table S2; Table no 6). At 45 DAT, 60 DAT, 75DAT and 90 DAT the highest plant height was measured 13.22 cm, 20.66 cm, 29.33 cm and 30.83 cm in 100 ppm GA₃ dose respectively. It was observed that the highest plant height (30.68 cm) was obtained in 100 ppm GA₃ and the lowest plant height (6.39 cm) was obtained in GA₃ dose 200 ppm. (Fig. 3A). The minimum number of leaves per plant (12.33 plant⁻¹) was in GA₃ dose 200 GA₃ at 90 days after transplanting and the maximum was in GA₃ dose 100 ppm. (Fig.3B)

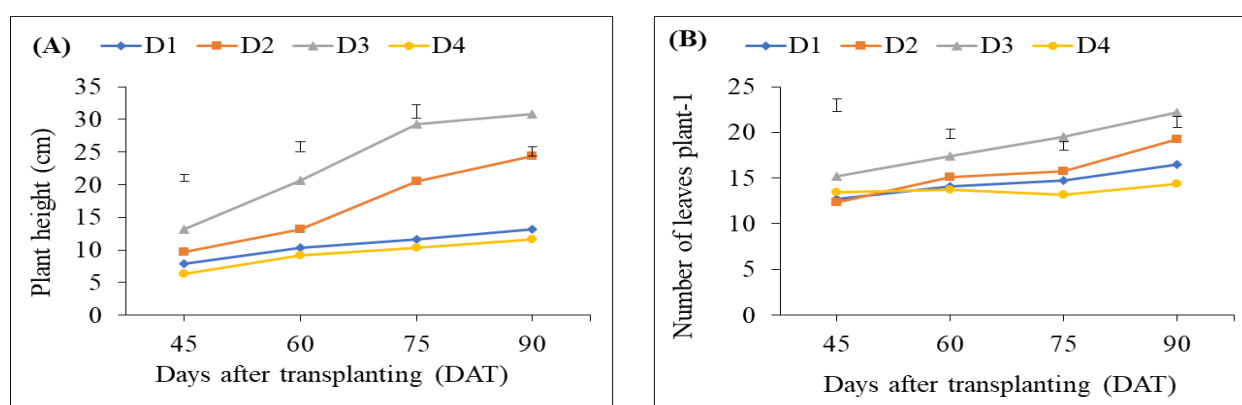


Figure 3. Effect of different doses of GA₃ on plant height (A), and leaves plant⁻¹ (B) at different DAT (Days after transplanting)

The highest canopy spread 2513.9 cm was recorded in GA₃ dose 100ppm at 90 DAT and the lowest canopy spread (396.78 cm²) was observed in GA₃ dose 200 ppm at 45 DAT. The maximum number of runner per plant was found in GA₃ dose 100 ppm is 3.59 at day 90, whereas the minimum number of runner plant⁻¹ was counted in GA₃ dose 200 is 1.44 at day 90 (Table no 6).

Table no 6: Effect of different doses of GA₃ on growth and growth contributing characters at different days after transplanting (DAT)

Level of GA ₃	Canopy spread (cm ²)				Runner plant ⁻¹			
	45 DAT	60 DAT	75 DAT	90 DAT	45 DAT	60 DAT	75 DAT	90 DAT
D ₁	615.83 c	1002.2 c	1240.2 c	1535.0 c	0.00 c	0.66 b	1.60 c	2.20 c
D ₂	716.97 b	1225.7 b	1547.5 b	1957.2 b	0.17 b	0.94a	1.99 b	3.01 b
D ₃	878.93a	1436.3a	1989.8a	2513.9a	0.33 a	1.11a	3.33 a	3.59 a
D ₄	396.78 d	529.5 d	761.7 d	863.8 d	0.00 c	0.66 b	1.28 d	1.44 d
LSD _{0.05}	49.52	48.69	66.12	94.09	0.05	0.14	0.18	0.19
Level of significance	**	**	**	**	**	**	**	**
CV (%)	6.13	3.75	3.86	4.42	22.25	13.74	5.26	4.36

** = Significant at 1% level of probability; D₁ = 0 ppm, D₃ = 100 ppm, D₂ = 50 ppm, D₄ = 200 ppm

Plant mortality and survivability was significantly ($p < 0.01$) influenced by GA₃ doses and the highest plant mortality (32.20%) was found in GA₃ dose 200 and GA₃ dose 100 exhibited the lowest (6.87%). Whereas, the highest survivability (93.12%) was found in GA₃ dose 100 ppm and the lowest (67.79%) was obtained in GA₃ dose 200 ppm shown in (Table no 7).

Table no 7: Effect of level of GA₃ on percent survivability and mortality of strawberry

Level of GA ₃	Mortality (%)	Survivability (%)
D ₁	21.88 b	78.11 c
D ₂	14.16 c	85.83 b
D ₃	6.87 d	93.12 a
D ₄	32.20 a	67.79 d
LSD _{0.05}	0.82	0.80
Level of significance	**	**
CV (%)	2.60	0.58

** = Significant at 1% level of probability; D₁ = 0 ppm, D₃ = 100 ppm, D₂ = 50 ppm, D₄ = 200 ppm

Effect of different doses of GA₃ on yield and yield contributing character

Table no 8 shows the significant ($p < 0.01$) effect of different doses of GA₃ on yield and yield contributing characters of strawberry. Fruit length was varied significantly among different GA₃ doses. The longest fruit length (3.82 cm) was found in GA₃ dose 100 ppm, the shortest (3.13 cm) was found in GA₃ dose 200 ppm. The maximum average diameter (2.8 cm) was recorded from GA₃ dose 100 ppm and the minimum diameter (1.9 cm) was measured from GA₃ dose 200 ppm. Fruit fresh weight was found higher in GA₃ dose 100 (18.08 g fruit⁻¹) and lower was obtained in GA₃ dose 200 ppm (12.41 g fruit⁻¹). Number of fruits plant was found highest in GA₃ dose 100 ppm (10.66 plant⁻¹) and lowest (4.05 plant⁻¹) found in GA₃ dose 200 ppm. Number of fruits plot⁻¹ was found maximum in GA₃ dose 100 (114.5 plot⁻¹) and minimum was obtained GA₃ dose 200 ppm (38.5 plot⁻¹). The highest fruit yield (2.08 kg plot⁻¹) found in GA₃ dose 100 ppm and lowest (0.46 kg plot⁻¹) found in GA₃ dose 200 ppm.

Table no 8: Effect of different doses of GA₃ on yield and yield contributing characters of strawberry

Level of GA ₃	Length of fruit (cm)	Diameter of fruit (cm)	Individual weight fruit ⁻¹ (g)	No. of fruits plant ⁻¹	No. of fruits plot ⁻¹	Yield plot ⁻¹ (kg)
D ₁	3.39 c	2.19 c	14.62 c	5.27 bc	55.33 c	0.81 c
D ₂	3.53 b	2.31 b	16.00 b	7.22 b	76.50 b	1.22 b
D ₃	3.82a	2.80a	18.08a	10.66a	114.50a	2.08a
D ₄	3.13 d	1.90 d	12.41 d	4.05 c	38.50 c	0.46 d
LSD _{0.05}	0.07	0.07	0.44	1.54	14.61	0.23
Level of significance	**	**	**	**	**	**
CV (%)	1.69	2.42	2.30	18.23	16.57	16.31

** = Significant at 1% level of probability; D₁ = 0 ppm, D₃ = 100 ppm, D₂ = 50 ppm, D₄ = 200 ppm

Fruit quality traits

Table no 9 shows the significant ($p < 0.01$) differences on fruit quality traits, as a result of different GA₃ doses. GA₃ dose of 100 ppm found maximum brix percentage (10.82%), TA (0.77), Vitamin C (58.32), pH (3.40), RS (3.41%), NRS (3.93%), TS (7.34%) and JC (77.36%). The minimum brix percentage (7.25%), TA (0.72), Vitamin C (52.56), pH (3.24), RS (3.02%), NRS (3.65%), TS (6.67%) and JC (73.42%) was obtained in GA₃ dose 200 ppm.

Table no 9: Effect of level of GA₃ on % of brix, TA, vitamin C, pH, % of RS, %NRS, % of TS and % of JC of strawberry

Level of GA ₃	% of Brix	TA	Vitamin C (mg/100g)	pH	% of RS	% of NRS	% of TS	% of JC
D ₁	9.13 c	0.73 c	53.27 c	3.27 c	3.07 c	3.73 c	6.80 c	74.06 c
D ₂	10.26 b	0.75 b	54.87 b	3.35 b	3.14 b	3.84 b	6.99 b	75.17 b
D ₃	10.82 a	0.77a	58.32 a	3.40a	3.41a	3.93a	7.34 a	77.36 a
D ₄	7.25 d	0.72 c	52.56 d	3.24 c	3.02 c	3.65 d	6.67 d	73.42 d
LSD _{0.05}	0.30	0.011	0.43	0.04	0.03	0.03	0.06	0.11
Level of significance	**	**	**	**	**	**	**	**
CV (%)	1.95	1.21	0.48	0.91	1.04	0.44	0.56	0.09

** = Significant at 1% level of probability; D₁= 0 ppm, D₃= 100 ppm, D₂= 50 ppm, D₄= 200 ppm

Interaction effect of growing condition and different doses of GA₃

Interaction effect on vegetative growth

The interaction effect between growing conditions and GA₃ doses on vegetative growth was found significant at 45, 60, 75 and 90 DAT (Table no 10; Table no 11). The maximum plant height (33.33 cm) was recorded at 90 DAT from the shed condition at GA₃ dose 100 ppm and the minimum (10.44 cm) was recorded from the ambient condition at GA₃ dose 200 ppm (Table no 10). At 90 DAT, the highest number of leaves plant⁻¹ (23.00 plant⁻¹) was counted in shed condition at GA₃ dose 100 ppm while 13.55 plant⁻¹ was observed in ambient condition at GA₃ dose 200ppm.

Table no 10: Combined effects of growing condition and different doses of GA₃ on plant height, and number of leaves plant⁻¹ at different days after transplanting

Treatment combination	Plant height (cm)				Number of leaves plant ⁻¹			
	45 DAT	60 DAT	75 DAT	90 DAT	45 DAT	60 DAT	75 DAT	90 DAT
C ₁ D ₁	7.67 e	9.55 ef	10.66 cd	12.33 d	11.10 b	13.33 cd	14.89 cd	15.44 e
C ₁ D ₂	9.11 cd	12.44 cd	19.97 b	25.11 c	11.16 b	14.66 bc	14.89 cd	18.44 cd
C ₁ D ₃	12.55 b	21.77 a	30.00 a	28.33 b	14.78 a	18.66a	21.22a	21.00 b
C ₁ D ₄	5.77 f	7.78 f	9.56 d	10.44 e	10.50 b	11.88 d	11.11 e	13.55 f
C ₂ D ₁	8.22 de	11.11 de	12.55 c	13.88 d	13.79 a	14.77 bc	14.66 d	17.22 d
C ₂ D ₂	10.22 c	13.78 c	21.11 b	23.66 c	14.17 a	15.55 b	16.55 bc	19.77 bc
C ₂ D ₃	13.89 a	19.55 b	28.66 a	33.33 a	15.66 a	16.22 b	17.77 b	23.00 a
C ₂ D ₄	7.00 ef	10.67 de	11.22 cd	12.88 d	14.17 a	15.55 b	15.33 cd	14.11 ef
LSD _{0.05}	1.29	1.87	2.54	1.78	2.10	1.18	1.03	1.74
Level of significance	**	**	**	**	**	**	**	**
CV (%)	4.81	4.86	4.90	3.10	5.54	4.47	3.71	3.39

** = Significant at 1% level of probability, * = Significant at 5% level of probability; C₁= Ambient, C₂= Agro-shed, D₁= 0 ppm, D₃= 100 ppm, D₂= 50 ppm, D₄= 200 ppm

At 90 DAT, the highest canopy spread (2645 cm³) was recorded from the combination of agro-shed condition at GA₃ dose 100 ppm and lowest (757.9 cm³) one was found from ambient condition at GA₃ doses 200 ppm. At day 90, the maximum number of runner plant⁻¹ (3.89) was found from shed condition at GA₃ dose 100 ppm and the minimum (1.32) was found in ambient at GA₃ dose 200 ppm. (Table no 11).

Table no 11: Combined effects of growing condition and different doses of GA₃ on canopy spread at different days after transplanting (DAT)

Treatment combination	Canopy spread (cm ³)				Runner plant ⁻¹			
	45 DAT	60 DAT	75 DAT	90 DAT	45 DAT	60 DAT	75 DAT	90 DAT
C ₁ D ₁	448.30 d	740.7 d	1027.0 d	1251.7 e	0.00 c	0.66 cd	1.31de	2.08 d
C ₁ D ₂	585.63 c	1000.7 c	1338.8 c	1813.1 d	0.33 b	0.77 bc	1.87 c	2.81 c
C ₁ D ₃	798.89 b	1326.5 b	1863.2 b	2382.6 b	0.00 c	0.77 bc	3.10 b	3.30 b
C ₁ D ₄	360.73 d	470.6 f	686.8 e	757.9 f	0.00 c	0.44 d	1.11 e	1.32 e
C ₂ D ₁	783.37 b	1263.7 b	1453.3 c	1818.3 d	0.00 c	0.66 cd	1.89 c	2.33 d
C ₂ D ₂	848.30ab	1450.7a	1756.2 b	2101.2 c	0.00 c	1.11ab	2.11 c	3.22 b
C ₂ D ₃	958.97a	1546.2a	2116.4a	2645.2a	0.67 a	1.44a	3.55 a	3.89a
C ₂ D ₄	432.83 d	588.4 e	836.7 e	969.6 f	0.00 c	0.89 bc	1.44 d	1.55 e

Assessment of effect of different doses of GA₃ on strawberry under different environmental conditions

LSD _{0.05}	70.03	68.86	93.51	133.06	0.08	0.20	0.31	0.32
Level of significance	**	**	**	**	**	**	**	**
CV(%)	6.13	3.75	3.86	4.42	22.25	13.74	5.26	4.36

** = Significant at 1% level of probability; C₁= Ambient, C₂= Agro-shed, D₁= 0 ppm, D₃= 100 ppm, D₂= 50 ppm, D₄= 200 ppm

Table no 12 shows the significant ($p < 0.01$) variation due to growing condition and different GA₃ doses of percent mortality and survivability. The highest plant mortality (34.33%) may found in ambient condition at GA₃ dose 200 ppm and agro-shed condition at GA₃ dose 100 ppm exhibited the lowest (6.17%). The highest survivability (93.83%) was found from agro-shed condition at GA₃ dose 100 ppm and the lowest (65.66%) was found in ambient at GA₃ dose 200 ppm.

Table no 12: Combined effects of growing condition and different doses of GA₃ on percent survivability and mortality

Treatment combination	Mortality (%)	Survivability (%)
C ₁ D ₁	23.44 c	76.55 f
C ₁ D ₂	15.83 e	84.16 d
C ₁ D ₃	7.58 g	92.41 b
C ₁ D ₄	34.33a	65.66 h
C ₂ D ₁	20.33 d	79.66 e
C ₂ D ₂	12.50 f	87.50 c
C ₂ D ₃	6.17 h	93.83a
C ₂ D ₄	30.08 b	69.91 g
LSD _{0.05}	1.41	1.37
Level of significance	**	**
CV (%)	2.60	0.58

** = Significant at 1% level of probability; C₁= Ambient, C₂= Agro-shed, D₁= 0 ppm, D₃= 100 ppm, D₂= 50 ppm, D₄= 200 ppm

The interaction effect on yield and yield contributing character

Growing conditions and GA₃ doses had significant ($p < 0.01$) interaction effects on yield and yield contributing characters of strawberry (Table no 13). The maximum fruit length (3.9 cm) was obtained in agro-shed condition at GA₃ dose 100 ppm and the minimum (3.08 cm) was found in ambient condition from GA₃ doses 200 ppm combination. The maximum average diameter (2.86 cm) was recorded from agro-shed condition at GA₃ dose 100 ppm and the minimum (1.85 cm) was found from ambient condition from GA₃ doses 200 ppm. Highest weight (18.66 g) was found in agro-shed condition at GA₃ dose 100 ppm and the lowest (11.75) was found in ambient condition at GA₃ dose 200 ppm. The highest number of fruits plant⁻¹ (12.22) was observed from agro-shed condition at GA₃ dose 100 ppm and the lowest (4.11) was observed in ambient condition at GA₃ doses 200 ppm. Number of fruits per plot was found maximum in agro shed condition at GA₃ dose 100 ppm (136) and minimum in ambient condition from GA₃ dose 200 ppm (39.33). The highest fruit yield plot⁻¹ was obtained from shed condition at GA₃ dose 100 ppm (2.53 kg plot⁻¹) and minimum was found in ambient condition from GA₃ doses 200 ppm (0.46 kg plot⁻¹).

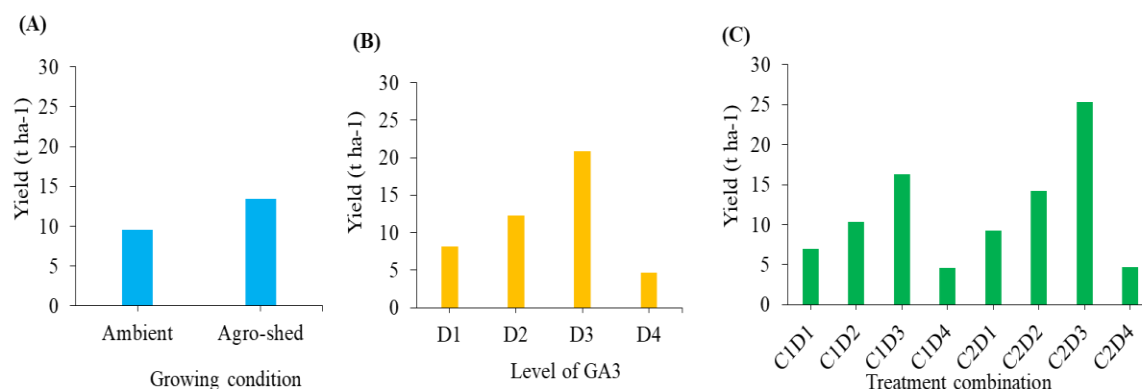
Table no 13: Combined effects of growing condition and level of GA₃ on yield and yield contributing characters

Treatment combination	Length of fruit (cm)	Diameter of fruit (cm)	Individual weight fruit ⁻¹ (g)	No. of fruits plant ⁻¹	No. of fruits plot ⁻¹	Yield plot ⁻¹ (kg)
C ₁ D ₁	3.35 de	2.10 de	14.08 e	4.66 cd	49.67 c	0.70 de
C ₁ D ₂	3.45 cd	2.18 cd	15.50 cd	6.33 bcd	66.67 bc	1.03 cd
C ₁ D ₃	3.75ab	2.75a	17.50 b	9.11ab	93.00 b	1.62 b
C ₁ D ₄	3.08 f	1.85 f	11.75 f	4.11 d	39.33 c	0.46 e
C ₂ D ₁	3.44 cd	2.29 bc	15.16 d	5.89 bcd	61.00 bc	0.92 cde
C ₂ D ₂	3.60 bc	2.44 b	16.50 bc	8.11 bc	86.33 b	1.42 bc
C ₂ D ₃	3.90a	2.86a	18.66a	12.22a	136.00a	2.53a
C ₂ D ₄	3.19 ef	1.95 ef	13.08 e	4.00 d	37.67 c	0.46 e
LSD _{0.05}	0.10	0.10	0.62	2.17	20.66	0.33
Level of significance	**	**	**	**	**	**
CV(%)	1.69	2.42	2.30	18.23	16.57	16.31

** = Significant at 1% level of probability; C₁= Ambient, C₂= Agro-shed, D₁= 0 ppm, D₃= 100 ppm, D₂= 50 ppm, D₄= 200 ppm

Yield (t ha⁻¹)

The variation due to growing condition, different GA₃ doses, and interactions between growing conditions and GA₃ doses was significant in respect of fruit yield (Table S3). The maximum fruit yield (13.40 t ha⁻¹) was obtained in agro-shed condition (Supplementary Figure S2) and the minimum fruit yield (9.55 t ha⁻¹) was found in ambient condition (Figure S1) (Figure 4A). The maximum fruit yield (20.82 tha⁻¹) was obtained in GA₃ dose 100 and the minimum fruit yield (4.64 tha⁻¹) was found in GA₃ dose 200 (Figure 4B). The maximum fruit yield (25.38 tha⁻¹) was obtained in agro shed condition at GA₃ dose 100 ppm and the minimum fruit yield (4.60 tha⁻¹) was found in ambient condition from GA₃ doses 200 ppm combination (Figure 4C).



C₁= Ambient, C₂= Agro-shed, D₁= 0 ppm, D₃= 100 ppm, D₂= 50 ppm, D₄= 200 ppm

Figure 4. Effect of growing condition (A), doses of GA₃ (B), and interactions between growing conditions and GA₃ doses (C) on yield.

Fruit quality traits

Table no 14 shows that the interaction between growing condition and GA₃ concentration had a highly significant effect ($p < 0.01$) on all evaluated fruit quality traits. The highest values of TA (0.78%), vitamin C (59.46 mg/100 g), RS (3.52%), NRS (3.98%), TS (7.50%), and JC (77.87%) were recorded under ambient condition with 100 ppm GA₃ (C1D3). In contrast, the lowest values were observed under agro-shed with 200 ppm GA₃, where TA, vitamin C, RS, NRS, TS, and JC were 0.72%, 52.14 mg/100 g, 2.91%, 3.61%, 6.53%, and 73.38%, respectively. The highest Brix (11.62%), and pH (3.43) was recorded under agro-shed with 100 ppm GA₃, whereas the lowest value (7.06%), and (3.21), respectively occurred under ambient condition with 200 ppm GA₃.

Table no 14: Combined effects of growing condition and level of GA₃ on % of brix, TA, vitamin C, pH, % of RS, %NRS, % of TS and % of JC of strawberry

Treatment combination	% of Brix	TA	Vitamin C (mg/100g)	pH	% of RS	% of NRS	% of TS	% of JC
C ₁ D ₁	8.36 d	0.73 cd	53.35 e	3.25 cd	3.11 cd	3.78 c	6.89 d	74.22 e
C ₁ D ₂	9.59 c	0.75 bc	55.28 c	3.33 bc	3.18 c	3.88 b	7.06 c	75.48 c
C ₁ D ₃	10.03 c	0.78 a	59.46 a	3.37ab	3.52 a	3.98 a	7.50 a	77.87 a
C ₁ D ₄	7.06 e	0.73 cd	52.98 e	3.21 d	3.13 c	3.68 d	6.82 de	73.47 g
C ₂ D ₁	9.90 c	0.73 cd	53.20 e	3.30 bc	3.03 d	3.68 d	6.71 e	73.90 f
C ₂ D ₂	10.93 b	0.75 bc	54.47 d	3.36ab	3.11 cd	3.79 c	6.91 d	74.87 d
C ₂ D ₃	11.62a	0.77ab	57.18 b	3.43a	3.30 b	3.88 b	7.18 b	76.85 b
C ₂ D ₄	7.43 e	0.72 d	52.14 f	3.27 cd	2.91 e	3.61 e	6.53 f	73.38 g
LSD _{0.05}	0.52	0.016	0.74	0.05	0.09	0.05	0.11	0.20
Level of significance	**	**	**	**	**	**	**	**
CV (%)	1.95	1.21	0.48	0.91	1.04	0.44	0.56	0.09

** = Significant at 1% level of probability; C₁= Ambient, C₂= Agro-shed, D₁= 0 ppm, D₃= 100 ppm, D₂= 50 ppm, D₄= 200 ppm

IV. Discussion

The superior vegetative performance under the agro-shed was primarily attributed to the creation of a more favorable microclimate that reduced environmental stress during crop growth (Menzel, 2025). In the present study, agro-shed cultivation increased plant height by approximately 10%, canopy spread by 21%, runner production by 16%, and leaf number by 8% compared with ambient conditions, reflecting enhanced vegetative vigor. Mahmood et al. (2018) reported that shading and insect-proof screen structures reduce solar radiation by

15–39%, decrease wind speed by 50–87%, increase relative humidity by 2–21%, and lower crop evapotranspiration by 17–50%, thereby improving photosynthetic efficiency, reducing transpiration losses, and increasing assimilate accumulation. Similar mechanisms have been reported to promote canopy development and runner formation in strawberry (Menzel, 2022; Yang et al., 2026). The response of strawberry to GA₃ was highly dependent on concentration. From the study, 100 ppm treatment consistently produced the greatest plant height, canopy spread, runner production, fruit number, and fruit weight. These improvements are attributed to the role of gibberellins in promoting cell expansion, vascular development, flowering regulation, and assimilate transport toward reproductive sinks (Li et al., 2024; Cai et al., 2024). Similar findings have been reported in strawberry, where GA₃ concentrations (75–125 ppm) improved vegetative growth, flowering, berry size, soluble solids, and yield (Palei et al., 2024; Singh et al., 2026). Singh et al. (2026) reported that foliar application of 100 ppm GA₃ significantly enhanced strawberry growth by increasing plant height (21.40 cm), flowers (19.67 plant⁻¹), fruit number (18.65 plant⁻¹), and size (39.40 mm length and 24.47 mm breadth). Increasing the GA₃ concentration to 200 ppm reduced growth attributes, indicating that high gibberellin levels may disrupt endogenous hormonal homeostasis and source–sink relationships by stimulating excessive vegetative growth, accelerating respiration, and reducing carbohydrate partitioning to reproductive organs (Katel et al., 2022; Ughareja & Pandya, 2023). The combination of agro-shed and 100 ppm GA₃ produced the highest plant height, canopy spread, fruit number, whereas ambient conditions combined with 200 ppm GA₃ resulted in the poorest performance. This synergistic response indicates that protected cultivation provided favorable temperature, humidity, and soil moisture conditions, allowing plants to utilize GA₃ more efficiently for vegetative and reproductive growth (Yang et al., 2026; Salwa et al., 2026).

In the present study, agro-shed cultivation improved plant establishment by reducing mortality from under ambient conditions and increasing survivability. Similarly, application of 100 ppm GA₃ markedly enhanced plant establishment, reducing mortality. The combined effect of agro-shed cultivation and 100 ppm GA₃ produced the highest survivability (93.83%) and the lowest mortality (6.17%), whereas ambient conditions combined with 200 ppm GA₃ resulted in the poorest establishment. During the establishment period (October), the experimental site experienced a relatively high average maximum air temperature (30.8°C) accompanied by 179 mm rainfall, conditions that could have imposed heat and transient moisture stress under ambient cultivation. In contrast, the agro-shed likely moderated these environmental fluctuations, resulting in better plant establishment and survival. This interpretation is consistent with FAO (2023), which reported that protected cultivation reduces abiotic stress during crop establishment, and with Torres-Quezada et al. (2025), who demonstrated that exposure to elevated temperatures during the first 8–12 days after transplanting impairs plant water status, thereby reducing establishment, survivability, and subsequent yield.

The higher fruit yield under agro-shed cultivation was associated with improved plant establishment, greater canopy development, and enhanced yield components. From the study, plants grown under the agro-shed produced 40% higher fruit yield than those under ambient, indicating that the yield advantage resulted from the cumulative improvement of vegetative growth, photosynthetic capacity, and reproductive performance rather than from any single yield component (Taiz et al., 2015; Hernández-Martínez et al., 2023; Katel et al., 2022). Previous studies have reported 20–40% increases in strawberry yield under protected cultivation due to improved microclimate regulation and more efficient water use (Biswas et al., 2024; Menzel, 2025). The yield under 100 ppm GA₃ was approximately 4.52 times that under 200 ppm GA₃. Similarly, Lamba et al. (2024) found that 100 ppm GA₃ increased strawberry fruit yield by 31.7% over the untreated control. The significant interaction between yield and GA₃ application demonstrated that the response of strawberry to exogenous GA₃ depended strongly on the surrounding microclimate. The combination of agro-shed and 100 ppm GA₃ produced the highest fruit yield.

Although agro-shed cultivation substantially increased fruit yield, some biochemical quality attributes were slightly higher under ambient conditions. In the present study, fruits grown under ambient conditions contained greater vitamin C, TS, and JC, likely because higher natural irradiance enhanced photosynthetic carbon assimilation and antioxidant metabolism, promoting the accumulation of carbohydrates and ascorbic acid (Giampieri et al., 2012; Zushi et al., 2020). Similar responses have been reported in open-field strawberries, which contained 16.3% higher total soluble solids and 23.7% higher vitamin C than greenhouse-grown fruits (Doust et al., 2023). Likewise, Guiamba et al. (2023) showed that improving the light environment increased photosynthetic rate by 28.9%, total soluble solids by 11.6%, and vitamin C content by 17.8%, emphasizing the importance of light availability for fruit quality. Regardless of the growing environment, 100 ppm GA₃ produced the highest fruit quality, increasing total soluble solids (% of Brix), TA, vitamin C, pH, RS, NRS, TS, and JC. These findings agree with Singh et al. (2026), who reported that 100 ppm GA₃ increased total soluble solids to 11.02 °Brix and TS to 6.16%, demonstrating that an optimum GA₃ concentration enhances fruit quality by improving assimilate translocation and sink strength. In contrast, 200 ppm GA₃ reduced most quality attributes, indicating that excessive GA₃ may disrupt assimilate partitioning and normal fruit ripening, thereby limiting the accumulation of sugars and other quality-related metabolites (Gundogdu et al., 2017; Gao et al., 2025). The interaction effect further demonstrated that ambient cultivation with 100 ppm GA₃ produced the highest vitamin C, RS, NRS, TS, and JC, whereas agro-shed cultivation with 100 ppm GA₃ resulted in the highest total soluble solids (% of Brix) and pH.

From a practical perspective, the present findings demonstrate that integrating protected cultivation with 100 ppm GA₃ concentration represents an effective strategy for increasing strawberry productivity under subtropical climatic conditions. The combination of these two management practices produced the highest fruit yield (25.38 t ha⁻¹) together with superior vegetative performance and plant survivability, indicating a clear synergistic effect between microclimate modification and hormonal regulation. These findings are particularly relevant in the context of climate variability, where increasing temperatures and erratic rainfall frequently reduce strawberry productivity in subtropical regions. Furthermore, the effectiveness of plant growth regulators depends on the applied concentration and timing, as moderate GA₃ doses generally stimulate reproductive development, fruit set, yield, and quality, whereas suboptimal or excessive concentrations may disturb hormonal regulation and reduce crop performance (Gomasta et al., 2024; Ahmed et al., 2022; Ali et al., 2022). Future research should evaluate the economic feasibility of this technology under farmers' conditions, investigate cultivar-specific responses to protected cultivation and growth regulator application, and assess long-term effects on fruit nutritional quality, water-use efficiency, and production sustainability under projected climate change scenarios.

V. Conclusion

The present study demonstrated that both the growing environment and exogenous application of gibberellic acid (GA₃) significantly influenced the growth, survivability, yield, and fruit quality of strawberry under the subtropical conditions of Bangladesh. Cultivation under the agro-shade environment created a more favorable microclimate that enhanced vegetative growth, plant establishment, fruit size, fruit number, and overall yield compared with ambient conditions. In contrast, ambient cultivation generally produced fruits with superior quality attributes, including higher total soluble solids, vitamin C, total sugars, and juice content. Among the GA₃ treatments, the application of 100 ppm consistently produced the best performance by significantly improving vegetative growth, canopy development, survivability, fruit yield, and physicochemical characteristics, whereas the highest concentration (200 ppm) adversely affected plant growth and productivity. The interaction between agro-shade cultivation and 100 ppm GA₃ was the most effective treatment for maximizing strawberry growth and yield, producing the highest fruit yield, superior vegetative performance, and maximum plant survivability. However, the interaction of the ambient growing condition with 100 ppm GA₃ resulted in the highest fruit quality, characterized by greater vitamin C, total sugar, and juice content, indicating that open-field conditions combined with the optimum GA₃ concentration favored the accumulation of desirable biochemical constituents. Therefore, while agro-shade cultivation with 100 ppm GA₃ is recommended for maximizing commercial strawberry production and yield, ambient cultivation with 100 ppm GA₃ may be preferred when premium fruit quality is the primary production objective. Further multi-location and multi-season studies involving different strawberry cultivars are recommended to validate these findings and assess their economic feasibility for commercial strawberry production in Bangladesh.

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