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Effect of Growth Regulators on Growth and Quality of Strawberry cv. Sweet Sensation Grown in Pot Culture

D. Panda[1] and S. Mondal[2]

Dept. of Crop Physiology, Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal (731 235), India

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Corresponding debasishpanda007@gmail.com

0000-0002-4185-8375

ABSTRACT

A pot culture experiment was conducted at Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal, India during the *rabi* season (October, 2018–March, 2019) to study the effect of growth regulators such as 28-Homobrassinolide and Triacontanol on growth and yield of strawberry cv. Sweet Sensation. The treatments consisted of seven levels of growth regulators including control viz. control, 0.5 ppm, 1 ppm and 2 ppm of 28-Homobrassinolide and 2ppm, 5 ppm and 10 ppm of Triacontanol. The effect of growth regulators was studied on different morpho-physiological parameters and biochemical and quality parameters such as chlorophyll content of leaves, ascorbic acid, titratable acidity and TSS of fruit. The results revealed that the foliar application of 0.5 ppm of 28-Homobrassinolide produced the maximum plant height, number of leaves plant^{-1}, petiole length, canopy spread, leaf area plant^{-1}, crown diameter, shoot dry weight and root dry weight, RWC, number of flowers plant^{-1}, number of fruits plant^{-1}, percent fruit set, fruit length and fruit diameter, chlorophyll content of leaves, whereas the treatment of 1 ppm of 28-Homobrassinolide recorded maximum plant height, petiole length. However, the minimum value of the morphological, biochemical, yield and quality parameters were recorded in control (foliar spray of water). Hence form present study it may be confirmed that foliar application of 28-Homobrassinolide @ 0.5 ppm and 1 ppm significantly improved the growth, yield, and quality attributes of strawberry.

KEYWORDS: Growth, Homobrassinolide, quality, RWC, strawberry, Triacontanol, yield

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1. INTRODUCTION

Strawberry is one of the most widely grown soft fruits around the world. It is grown in both humid and dry climates in plains and hills up to a height of 3000 m (Singh et al., 2008). Temperatures between 22 and 25°C during day and 7 to 13°C at night are suitable for growing of strawberry (De and Bhattacharjee, 2012). The cultivated strawberry is a hybrid between two octoploid species, *Fragaria chiloensis* Duch. and *Fragaria virginiana* Duch. (Bowling, 2000). Strawberries were previously only grown in temperate areas of India, it is now-a-days widely grown throughout the India owing to tolerance of new cultivars to a wide range of climatic conditions and the standardisation of new agro-techniques (Sharma and Sharma, 2004). It is grown on 6,000 ha of land and yield 4.3 thousand tonne for both domestic and international markets (Anonymous, 2018, Saha et al., 2019) mostly in Maharashtra, Punjab, Haryana, Himachal Pradesh, Jammu & Kashmir, and West Bengal. The lack of required fruit quality and size is hurting the marketing and financial success of strawberries grown in West Bengal's Gangetic alluvial zone. Strawberry is a rich source of iron and antioxidants, vitamin C and vitamin A, minerals with lovely aroma as well as the anti-cancerous molecule ellagic acid (Wange and Kzlogoz, 1998; El-Beltagi et al., 2022; Sharma and Singh, 1990).

Among the phytohormones, auxin and abscisic acid (ABA) are known to play significant role in development and ripening of the non-climacteric fruit of strawberry. However, the role of other phytohormones is not well known in fruit development and ripening (Symons et al., 2012). Brassinosteroids play important roles in plant growth and development such as promotion of seed germination, cell division and elongation, root growth, photomorphogenesis, xylem differentiation, organogenesis, reproductive development, metabolism, and immunity of plants (Gudesblat and Russinova, 2011; Zhu et al., 2015; Zhou et al., 2015; Wei and Li, 2016; Ali, 2017; Nolan et al., 2020; Ahammed et al., 2020; Zu et al., 2019; Li and He, 2020; Hwang et al., 2021; Xiong et al., 2022). Brassinosteroids are also known to ameliorate abiotic stress tolerance in plants (Tanveer et al., 2019; Arfan et al., 2019; Fang et al., 2019; Khan et al., 2019; Planas-Riverola et al., 2019; Wang et al., 2020; Sheikhi et al., 2023). Foliar application of Brassinosteroids was found to significantly improved yield and quality parameters of strawberry (Salazar et al., 2016; Khatoon et al., 2020; Zahedipour-Sheshglani and Asghari, 2020). Triacontanol is broad spectrum plant growth regulator with multi-faceted role in plant growth and development (Mao and Yan, 2004; Islam et al., 2020). Application of triacontanol was found to increase the yield of many crops such as rice, wheat, corn, tomato, cucumber, lettuce, carrot, soybean (Pang et al., 2020). Triacontanol is known to enhance enzymatic activity, absorption of water and minerals, chlorophyll content and net photosynthetic rate and promote carbon-nitrogen metabolism in plants. Triacontanol mediated improvements in growth, yield, photosynthesis, protein synthesis, water and nutrients intake, nitrogen fixation, and enzyme activity in diverse crops was reported by Trevisan et al. (2020), Bhandari et al. (2021), Verma et al. (2022) and Sarwar et al. (2022). Triacontanol improves growth by alleviation of various abiotic stresses in plants (Li et al., 2016; Perveen et al., 2017; Asadi Karam and Keramat, 2017; Sarwar, 2017; Chandra and Roychoudhury, 2020; Zaid et al., 2020; Sarwar et al., 2021; El-Beltagi et al., 2022). Triacontanol was found to promotes the fruit development and retards fruit senescence in strawberry (Pang et al., 2020). Therefore, the investigation was aimed on improving the productivity of strawberry through the foliar applications of 28-Homobrassinolide and Triacontanol.

2. MATERIALS AND METHODS

The present investigation was carried out during *rabi* season (October, 2018–March, 2019) at the Institute of Agriculture, Visva-Bharati, Sriniketan to study the effect of growth regulators such as 28-Homobrassinolide and Triacontanol on growth and quality of strawberry (*Fragaria×ananassa* Duch.) cv. Sweet sensation grown in pot culture. The experiment was laid out in Completely Randomized Design (CRD), with 7 treatments replicated thrice in earthen pots of 12'' inner diameter and 9'' height. The place of experiment is situated at 23°39' North latitude and 87°42' East longitude and an average altitude of 58.9 m above mean sea level in western part of South Bengal under sub-humid, sub-tropical belt. The texture of the soil used in the experimental pots was sandy loam with medium in available P_2O_5 (12.5 kg ha^{-1}) and available K_2O (164.2 kg ha^{-1}) and low in available N (137.5 kg ha^{-1}). Two plants of one month old were planted pot^{-1} in the first week of November. The paddy straw mulch was used on the top of the soil of the pot at the time of planting. The seven treatments included T_1: Control (foliar spray of water), T_2: 28-Homobrassinolide @ 0.5 ppm, T_3: 28-Homobrassinolide @ 1 ppm, T_4- 28-Homobrassinolide @ 2 ppm, T_5: Triacontanol @ 2 ppm, T_6: Triacontanol @ 5 ppm, T_7: Triacontanol @ 10 ppm were imposed for three times at 10, 20 and 30 days after planting (DAP). The pot soil was prepared by mixing well decomposed farmyard manure and soil @ 1:1. 50% of N: P: K @ 100:80:100 kg ha^{-1} were applied to the pots as the basal dose at 7 days before planting and remaining 50% was applied 15 days after planting. The quality parameters of strawberry such as TSS (%), titratable acidity and ascorbic acid content (mg 100 g^{-1}) was studied of ripened fruits at harvest. The chlorophyll content of strawberry leaves was measured adopting the method of Hiscox and Israelstam (1979), using Dimethyl sulfoxide (DMSO). Carotenoids content of leaves was calculated according to the method of Lichtenthaler and Wellburn (1983). The chlorophyll as well as carotenoids content were estimated by using the formula given by Arnon (1949) and expressed as mg g^{-1} of fresh leaf. The total soluble solids (TSS) of fruits were measured by using hand refractometer. Ascorbic acid content of fruits was estimated by titration method (Rangana, 1979). The titratable acidity strawberry was measured by macerating 10 g of fruit sample in distilled water (Raja et al., 2018). The pulp was filtered through muslin cloth, made up to 10 ml with distilled water, and 5 ml of the filtrate was titrated against standard NaOH using phenolphthalein indicator. The amount was given as a percentage of malic acid. Titratable acidity is determined using a method described by The Association of Official Analytical Chemists (Anonymous, 2012). The experiment was concluded at the last date of harvest, when two plants of each treatment were uprooted from the soil. The number of leaves, leaf area plant^{-1}, crown diameter was counted and dry mass of shoot and roots was determined after drying plant in hot air oven at of 65°C until constant mass was obtained. The length and diameter of each fruit was measured by Vernier calliper Statistical inference of the data was obtained following the analysis of variance (ANOVA) for Completely Randomized Design (CRD) (Gomez and Gomez, 1984). The data recorded were tabulated and statistically analysed to differentiate the superiority of treatment means using critical difference (CD) by MS-EXCEL software.

3. RESULTS AND DISCUSSION

3.1. *Effect on plant height*

The effect of growth regulators on the height of strawberry plant was studied on the last date of harvest during 2018–19 (Table 1). Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) significantly influenced the plant height. Foliar application of 1 ppm of 28-Homobrassinolide recorded significantly higher plant height over control and other treatments except 0.5 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. However, the plant height was recorded maximum in plants treated with 1 ppm of 28-Homobrassinolide (18.30 cm) followed by that of 0.5 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The plant height recorded from the application of 1 ppm of 28-Homobrassinolide was found to be at par with that of 0.5 ppm of 28-Homobrassinolide (17.40 cm) and 5 ppm of Triacontanol (17.07 cm). The role of Brassinosteroids in plant cell elongation and cell division may be the cause of the increased plant height that results from their application (Gudesblat and Russinova, 2011, Wei and Li, 2016). This result also corroborates the finding of Bera et al. (2014) and Ghosh et al. (2020a). Foliar application of triacontanol (5 ppm) also significantly increased the plant height of strawberry. Similar results were also found by El-Beltagi et al. (2022). This may be attributed to the Triacontanol mediated improvements in growth, photosynthesis, nitrogen fixation, protein synthesis, water and nutrient uptake and enzyme activities in plants (Katel et al., 2022).

3.2. *Effect on number of leaves plant^{-1}*

The effect of growth regulators on the number of leaves plant^{-1} of strawberry was studied on the last date of harvest during 2018–19 (Table 1). Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) significantly influenced the number of leaves. Foliar application of 0.5 ppm of 28-Homobrassinolide recorded significantly higher number of leaves over control and other treatments except 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The maximum number of leaves plant^{-1} was recorded from the application of 0.5 ppm of 28-Homobrassinolide (15.43) followed by that of 1 ppm of 28-Homobrassinolide (15.10) and 5 ppm of Triacontanol (14.50). The number of leaves plant^{-1} recorded from the application of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The function of Brassinosteroids in plant cell elongation and cell division may be the cause of the increased number of leaves caused by their application (Gudesblat and Russinova, 2011, Wei and Li, 2016). Khatoon et al. (2021) also reported increase in number of leaves plant^{-1} of strawberry by application of Homobrassinolide. This result also corroborates the finding of Eskandari and Eskandari (2013). Foliar application of triacontanol (5 ppm) also significantly increased the leaf numbers of strawberry. Similar results were also found by Baba et al. (2017). This may be attributed to the Triacontanol mediated improvements in growth, water and nutrient uptake and enzyme activities in plants (Katel et al., 2022).

3.3. *Effect on petiole length*

Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) significantly influenced the petiole length (Table 1). Petiole length of leaves recorded from foliar application of 1 ppm of 28-Homobrassinolide was found to be significantly higher than control and other treatments except 0.5 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The maximum petiole length was recorded from the application of 1 ppm of 28-Homobrassinolide (15.37 cm) followed by that of 0.5 ppm of 28-Homobrassinolide (14.13 cm) and 5 ppm of Triacontanol (13.47 cm). The petiole length recorded from the application of 1 ppm of 28-Homobrassinolide was found

Table 1: Effect of growth regulators on the growth attributes of strawberry

Treatments	Plant height (cm)	No. of leaves plants^{-1}	Petiole length (cm)	Plant spread (cm)	Leaf area plant^{-1} (cm^2)	Crown diameter (cm)	Shoot dry weight (g)	Root dry weight (g)
T_1	14.33	12.37	11.70	28.17	594.63	1.30	2.47	2.83
T_2	17.40	15.43	14.13	37.23	817.13	1.70	3.53	4.20
T_3	18.30	15.10	15.37	35.13	780.67	1.63	3.30	4.07
T_4	16.17	13.83	12.53	31.70	702.57	1.37	2.83	3.10
T_5	15.37	13.13	12.17	30.13	677.60	1.33	2.70	3.13
T_6	17.07	14.50	13.47	32.73	729.67	1.57	3.17	3.87
T_7	14.80	12.67	11.93	28.40	606.30	1.43	2.57	2.97
SEm±	0.68	0.54	0.74	1.96	30.85	0.07	0.23	0.28
CD (p=0.05)	1.99	1.58	2.20	5.77	90.98	0.22	0.68	0.82

T_1: Control (foliar spray of water); T_2: 28-Homobrassinolide @ 0.5 ppm; T_3: 28-Homobrassinolide @ 1 ppm; T_4: 28-Homobrassinolide @ 2 ppm; T_5: Triacontanol @ 2 ppm; T_6: Triacontanol @ 5 ppm; T_7: Triacontanol @ 10 ppm were applied thrice at 10, 20 and 30 days after planting (DAP)

to be at par with that of 0.5 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The function of Brassinosteroids in plant cell elongation and cell division may be the cause of the increased petiole length of leaves caused by their application (Gudesblat and Russinova, 2011, Wei and Li, 2016, Ghosh et al., 2020a). Ono et al. (2000) also reported increase in petiole length of Tabebuia alba by application of Brassinolide. This result also corroborates the finding of Kozuka (2010). Foliar application of triacontanol (5 ppm) also significantly increased the petiole length of strawberry. Similar results were also found by Bhattacharya and Rao (1996). This may be attributed to the Triacontanol mediated improvements in growth, photosynthesis, nitrogen fixation, protein synthesis, water and nutrient uptake and enzyme activities in plants (Katel et al., 2022).

3.4. Effect on plant spread

The effect of growth regulators on the plant spread of strawberry was studied on the last date of harvest during 2018–19 (Table 1). Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) significantly influenced the plant spread of strawberry. Foliar application of 0.5 ppm of 28-Homobrassinolide recorded significantly higher plant spread over control and other treatments except 1 and 2 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. However, the maximum plant spread was recorded from the treatment of 0.5 ppm of 28-Homobrassinolide (37.23 cm) followed by that of 1 ppm of 28-Homobrassinolide (35.13 cm) and 5 ppm of Triacontanol (32.73 cm). The plant spread of strawberry recorded from the treatment of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1 and 2 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The function of Brassinosteroids in plant cell elongation and cell division may be the cause of the increased plant spread or canopy growth caused by their application (Gudesblat and Russinova, 2011, Wei and Li, 2016, Ghosh et al., 2020a). Furio et al. (2022) also reported increase in canopy growth of strawberry by application of Homobrassinolide. Foliar application of triacontanol (5 ppm) also significantly increased the leaf numbers of strawberry. Similar results were also found by Gora et al. (2021). This may be attributed to the Triacontanol mediated improvements in growth, photosynthesis, water and nutrient uptake and enzyme activities in plants (Katel et al., 2022).

3.5. Effect on leaf area plant^{-1}

The effect of growth regulators on the leaf area plant^{-1} of strawberry was studied on the last date of harvest during 2018–19 (Table 1). Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) significantly influenced the leaf area plant^{-1}. Foliar application of 0.5 ppm of 28-Homobrassinolide recorded significantly higher leaf area plant^{-1} over control and other treatments except 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The maximum leaf area plant^{-1} was recorded from the application of 0.5 ppm of 28-Homobrassinolide (817.13 cm^2) followed by that of 1 ppm of 28-Homobrassinolide (780.67 cm^2) and 5 ppm of Triacontanol (729.67 cm^2). The leaf area plant^{-1} recorded from the application of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The function of Brassinosteroids in plant cell elongation and cell division may be the cause of the increased leaf area caused by their application (Gudesblat and Russinova, 2011, Wei and Li, 2016, Ghosh et al., 2020a). Ali et al. (2022) also reported increase in leaf area of strawberry by application of Brassinosteroids (24-Epibrassinolide). This result also corroborates the finding of Furio et al. (2019) and Anjum et al. (2011). Foliar application of triacontanol (5 ppm) also significantly increased the leaf area of strawberry. Similar results were also found by Roberts and Hooley (1988). This may be attributed to the Triacontanol mediated improvements in growth, water and nutrient uptake and enzyme activities in plants (Katel et al., 2022).

3.6. *Effect on crown diameter*

The effect of growth regulators on the crown diameter of strawberry plant was studied during 2018–19 (Table 1). Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) significantly influenced the crown diameter. Foliar application of 0.5 ppm of 28-Homobrassinolide recorded significantly higher crown diameter over control and other treatments except 1 ppm of 28-Homobrassinolide. Among different treatments of growth regulators, the maximum crown diameter of strawberry plant was recorded from the application of 0.5 ppm of 28-Homobrassinolide (1.70 cm) followed by that of 1 ppm of 28-Homobrassinolide (1.63 cm) and 5 ppm of Triacontanol (1.57 cm). The crown diameter of plant recorded from the application of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1 ppm of 28-Homobrassinolide. The function of Brassinosteroids in plant cell elongation and cell division may be the cause of the increased crown diameter caused by their application (Gudesblat and Russinova, 2011, Wei and Li, 2016, Ghosh et al., 2020a). Furio et al. (2022) also reported increase in crown diameter of strawberry plant by application of Homobrassinolide. Foliar application of triacontanol (5 ppm) also significantly increased the crown diameter of strawberry. This may be attributed to the Triacontanol mediated improvements in growth, water and nutrient uptake and enzyme activities in plants (Katel et al., 2022).

3.7. *Effect on shoot and root dry weight*

The effect of growth regulators on the shoot and root dry weight of strawberry was studied on the last date of harvest during 2018–19 (Table 1). Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) significantly influenced the shoot and root weight of strawberry plants. Foliar application of 0.5 ppm of 28-Homobrassinolide recorded significantly higher shoot and root dry weight over control and other treatments except 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. However, the maximum shoot and root dry weight was recorded from the application of 0.5 ppm of 28-Homobrassinolide (3.53 g and 4.70 g, respectively) followed by that of 1 ppm of 28-Homobrassinolide (3.30 g and 4.07 g, respectively) and 5 ppm of Triacontanol (3.17 g and 3.87 g, respectively). The shoot and root dry weight recorded from the application of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The function of Brassinosteroids in plant cell elongation and cell division may be the cause of the increased biomass production of strawberry caused by their application (Gudesblat and Russinova, 2011, Wei and Li, 2016, Ghosh et al., 2020a). Furio et al. (2022) also reported increase in plant dry weight of strawberry by application of Homobrassinolide. This result also corroborates the finding of Ali et al. (2022). Foliar application of triacontanol (5 ppm) also significantly increased the shoot and root dry weight of strawberry plant. Similar results were also found by Roberts and Hooley (1988). This may be attributed to the Triacontanol mediated improvements in growth, water and nutrient uptake and enzyme activities in plants (Katel et al., 2022).

3.8. *Effect on chlorophyll and carotenoids content of leaves*

The treatments of growth regulators (28-Homobrassinolide and Triacontanol) increased the pigment (chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids) content of leaf measured at last date of harvest (Table 2). The treatment of 0.5 ppm 28-Homobrassinolide recorded significantly higher chlorophyll a content over control and other treatments except 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol, whereas chlorophyll b and total chlorophyll content recorded from 0.5 ppm of 28-Homobrassinolide was significantly higher than other treatments except 1 ppm of 28-Homobrassinolide The carotenoids content of leaves recorded from 0.5 ppm of 28-Homobrassinolide was found to be significantly higher than all other treatments The maximum value of chlorophyll a (1.805 mg g^{-1}), chlorophyll b (0.842 mg g^{-1}), total chlorophyll (2.647 mg g^{-1}) and carotenoids content (0.363 mg g^{-1}) was recorded from the treatment 0.5ppm of 28-Homobrassinolide by that of 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The chlorophyll a, chlorophyll b and total chlorophyll content of leaves recorded from the application of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1 ppm of 28-Homobrassinolide. However the treatments 0.5 ppm was statistically at par with 5 ppm of Triacontanol in terms of chlorophyll a content strawberry leaf. Increased chlorophyll content of leaves by treatment of brassinosteroids may be attributed to its role in elevation of enzyme synthesis associated with chlorophyll biosynthesis and activation of specific genes through regulation of transcription and/or translation (Kalinich et al., 1985, Mandava, 1988, Ali et al., 2006). This result also validates the finding of Fariduddin et al. (2004), Ali et al. (2006) and

Table 2: Effect of growth regulators on the chlorophyll and carotenoids content of strawberry leaves

Treatments	Chlorophyll a (mg g^{-1} fresh wt.)	Chlorophyll b (mg g^{-1} fresh wt.)	Total chlorophyll (mg g^{-1} fresh wt.)	Carotenoids (mg g^{-1} fresh wt.)	RWC (%)
T_1	1.445	0.623	2.067	0.277	67.59
T_2	1.805	0.842	2.647	0.363	84.04
T_3	1.744	0.760	2.503	0.342	81.58
T_4	1.567	0.695	2.261	0.310	76.50
T_5	1.513	0.653	2.166	0.319	73.24
T_6	1.617	0.721	2.338	0.341	79.31
T_7	1.570	0.602	2.171	0.287	70.77
SEm±	0.070	0.038	0.054	0.007	1.30
CD (p=0.05)	0.206	0.113	0.160	0.020	3.84

Alyemeni et al. (2013) and Ghosh et al. (2020b). Sarwar et al. (2022) also reported increase in chlorophyll content of hot pepper by application of Triacontanol.

3.9. Effect on relative water content of leaves

Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) was found to increase the relative water content of strawberry leaves significantly (Table 2). RWC of leaves was increase significantly by foliar application of 1 ppm of 28-Homobrassinolide over control and other treatments except 0.5 ppm of 28-Homobrassinolide. The maximum RWC of leaves were recorded from the application of 0.5 ppm of 28-Homobrassinolide (84.04%) followed by that of 1 ppm of 28-Homobrassinolide (81.58%) and 5 ppm of Triacontanol (79.31%). The RWC recorded from the application of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1 ppm of 28-Homobrassinolide. Sairam (1994) and Yuan et al. (2010) also reported increase in RWC by application brassinosteroid. This result also corroborates the findings of and Ali et al. (2006). Increased RWC by application of brassinosteroids may be attributed to its role in increasing uptake of water by the treated plants (Sairam, 1994, Ghosh et al., 2020b). Foliar application of triacontanol (5 ppm) also significantly increased the RWC of strawberry leaves. Similar results were also found by Ostrowska et al. (2021). This may be attributed to the Triacontanol mediated improvements water and nutrient uptake in plants (Katel et al., 2022).

3.10. Effect on number of flowers plant^{-1}

The effect of growth regulators on the number of flowers plant^{-1} of strawberry was studied as cumulative value of number of flowers till the last date of harvest during 2018–19 (Table 3). Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) significantly influenced the number of flowers. Foliar application of 0.5 ppm of 28-Homobrassinolide recorded significantly higher number of flowers over control and other treatments except 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. However, the number of flowers plant^{-1} was recorded maximum in plants treated with 0.5 ppm of 28-Homobrassinolide (18.0) followed by that of 1 ppm of 28-Homobrassinolide (17.7) and 5 ppm of Triacontanol (17.1). The number of flowers plant^{-1} recorded from the application of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The function of Brassinosteroids in plant cell division, cell expansion and flowering may be the cause of the increased number of flowers caused by their application (Gudesblat and Russinova, 2011, Wei and Li, 2016, Clouse, 2011). Similar results were found by Pipattanawong et al. (1996) and Hayat et al. (2012). Foliar application of triacontanol (5 ppm) also significantly increased the number of flowers of strawberry. This result also corroborates the findings of Baba et al. (2017) and Pang et al. (2020). This may be attributed to the Triacontanol mediated improvements in growth, water and nutrient uptake and enzyme activities in plants (Katel et al., 2022).

3.11. Effect on number of fruits plant^{-1}

The effect of growth regulators on the number of fruits plant^{-1} of strawberry was studied as cumulative value of number of fruits till the last date of harvest during 2018–19 (Table 3). Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) significantly influenced the number of fruits. Foliar application of 0.5 ppm of 28-Homobrassinolide recorded significantly higher number of fruits over control and other treatments except 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. However, the number of fruits plant^{-1} was recorded maximum in plants treated with 0.5 ppm of 28-Homobrassinolide (14.5) followed by that of 1 ppm of 28-Homobrassinolide (14.0) and 5 ppm of Triacontanol (13.2). The number of fruits plant^{-1} recorded from the application of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1

Table 3: Effect of growth regulators on the yield and quality attributes of strawberry

Treat-ments	No. of flowers plant^{-1}	No. of fruits plants^{-1}	Fruit set percentage	Fruit length (mm)	Fruit diameter (mm)	Fruit weight (g)	Fruit yield (g plant^{-1})	TSS (°Brix)	Titratable Acidity (%)	Ascorbic acid content (mg 100 g^{-1})
T_1	15.7	11.2	71.3	27.43	23.23	16.57	184.98	6.8	0.86	54.7
T_2	18.0	14.5	80.7	39.57	31.53	18.50	268.33	9.1	0.67	67.5
T_3	17.7	14.0	79.2	38.63	29.40	18.17	254.23	8.7	0.70	64.4
T_4	16.8	12.5	74.3	32.23	25.67	17.70	221.60	7.9	0.78	58.6
T_5	16.2	11.8	73.2	30.20	24.77	17.20	203.47	7.7	0.81	56.9
T_6	17.2	13.2	76.9	37.47	28.67	18.07	237.80	8.2	0.75	61.7
T_7	15.8	11.5	72.6	28.67	24.30	16.83	193.43	7.2	0.83	56.5
SEm±	0.5	0.4	2.1	1.96	1.31	0.38	8.18	0.3	0.02	2.16
CD (p=0.05)	1.4	1.1	6.1	5.78	3.87	1.12	24.13	0.9	0.07	6.36

ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The function of Brassinosteroids in plant cell division, cell expansion, plant reproductive development and fertilization may be the cause of the increased number of fruits caused by their application (Gudesblat and Russinova, 2011, Wei and Li, 2016, Clouse, 2011, Li and He, 2020, Tepkaew et al., 2022). Pipattanawong et al. (1996) reported increase in number of fruits plant^{-1} of strawberry by application of Homobrassinolide. Similar results were found by Hayat et al. (2012) and Ghosh et al. (2020a). Foliar application of triacontanol (5 ppm) also significantly increased the number of fruits of strawberry. Similar results were also found by Baba et al. (2017) and Pang et al. (2020). This may be attributed to the Triacontanol mediated improvements in growth, water and nutrient uptake and enzyme activities in plants (Katel et al., 2022).

3.12. Effect on fruit setting %

The effect of growth regulators on the fruit setting % of strawberry was studied the last date of harvest during 2018–19 (Table 3). Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) significantly influenced the fruit setting percentage of strawberry. Foliar application of 0.5 ppm of 28-Homobrassinolide recorded significantly higher fruit setting percentage over control and other treatments except 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The maximum fruit setting% was recorded from the application of 0.5 ppm of 28-Homobrassinolide (80.7%) followed by that of 1 ppm of 28-Homobrassinolide (79.2%) and 5 ppm of Triacontanol (76.9%). The fruit setting percentage recorded from the application of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The function of Brassinosteroids in plant cell division, cell expansion, plant reproductive development and fertilization may be the cause of the increased fruit setting caused by their application (Gudesblat and Russinova, 2011, Wei and Li, 2016, Clouse, 2011, Li and He, 2020, Tepkaew et al., 2022). This result also corroborates the finding of Mostafa and Kotb (2018). Foliar application of triacontanol (5 ppm) also significantly increased the fruit setting percentage of strawberry. Similar results were also found by Baba et al. (2017) and Abubakar et al. (2013). This may be attributed to the Triacontanol mediated improvements in growth, water and nutrient uptake and enzyme activities in plants (Katel et al., 2022).

3.12. Effect on fruit length and diameter

The effect of growth regulators on the fruit length and diameter of strawberry was studied at harvest during 2018–19 (Table 3). Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) significantly influenced the morphological parameters of fruits such as fruit length and diameter. Foliar application of 0.5 ppm of 28-Homobrassinolide increased the length and breadth of fruits significantly over control and other treatments except 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The maximum length and diameter of fruits was recorded from the application of 0.5 ppm of 28-Homobrassinolide (39.57 mm and 31.53 mm) followed by that of 1 ppm of 28-Homobrassinolide (38.63 mm and 29.40 mm respectively) and 5 ppm of Triacontanol (37.47 mm and 28.67 mm respectively). The length and diameter of fruit recorded from the application of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The function of Brassinosteroids in plant cell division, cell expansion, plant reproductive development and fertilization may be the cause of the increased fruit growth caused by their application (Gudesblat and Russinova, 2011, Wei and

Li, 2016, Clouse, 2011, Li and He, 2020, Ghosh et al., 2020a, Tepkaew et al., 2022). This result also corroborates the finding of Mostafa and Kotb (2018). Foliar application of triacontanol (5 ppm) also significantly increased the length and diameter of strawberry fruit. Similar results were also found by Sharma et al. (2011) and Dhall et al. (2004). This may be attributed to the Triacontanol mediated improvements in growth, photosynthesis, protein synthesis, water and nutrient uptake and enzyme activities in plants (Katel et al., 2022).

3.13. Effect on fruit weight

The effect of growth regulators on the fruit weight of strawberry was studied at harvest during 2018–19 (Table 3). Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) significantly influenced the weight of strawberry fruit. Foliar application of 0.5 ppm of 28-Homobrassinolide increased the fruit weight significantly over control and other treatments except 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. However, the fruit weight was recorded maximum in plants treated with 0.5 ppm of 28-Homobrassinolide (18.50 g) followed by that of 1 ppm of 28-Homobrassinolide (18.17 g) and 5 ppm of Triacontanol (18.07 g). The fruit weight of strawberry recorded from the application of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. The function of Brassinosteroids in plant cell division, cell expansion, plant reproductive development and fertilization may be the cause of the increased fruit weight caused by their application (Gudesblat and Russinova, 2011, Wei and Li, 2016, Clouse, 2011, Li and He, 2020, Tepkaew et al., 2022). This result also corroborates the finding of Mostafa and Kotb (2018) and Ghosh et al. (2022). Foliar application of triacontanol (5 ppm) also significantly increased the weight of strawberry fruit. Similar results were also found by Sharma et al. (2011) and Dhall et al. (2004). This may be attributed to the Triacontanol mediated improvements in growth, photosynthesis, protein synthesis, water and nutrient uptake and enzyme activities in plants (Katel et al., 2022).

3.14. Effect on fruit yield plant^{-1}

The effect of growth regulators on the fruit yield plant^{-1} of strawberry was studied was studied as cumulative value of fruit yield in different pickings till the last date of harvest during 2018–19 (Table 1). Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) significantly influenced the fruit yield plant^{-1}. Foliar application of 0.5 ppm of 28-Homobrassinolide recorded significantly higher fruit yield over control and other treatments except 1 ppm of 28-Homobrassinolide. However, the maximum fruit plant^{-1} was recorded from the application of 0.5 ppm of 28-Homobrassinolide (268.33 g) followed by that of 1 ppm of 28-Homobrassinolide (254.23 g) and 5 ppm of Triacontanol (237.80 g). The fruit yield plant^{-1} recorded from the application of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1 ppm of 28-Homobrassinolide. The function of Brassinosteroids in plant cell division, cell expansion, plant reproductive development and fertilization may be the cause of the increased fruit yield plant^{-1} caused by their application (Gudesblat and Russinova, 2011, Wei and Li, 2016, Clouse, 2011, Li and He, 2020, Tepkaew et al., 2022). Khatoon et al. (2021) also reported increase in fruit yield of strawberry by application of Homobrassinolide. This result also corroborates the finding of Hayat et al. (2000). Foliar application of triacontanol (5 ppm) also significantly increased the fruit yield of strawberry. Similar results were also found by Dhall et al. (2004), Kumar et al. (2012), Baba et al. (2017) and El-Beltagi et al. (2022). This may be attributed to the Triacontanol mediated improvements in growth, water and nutrient uptake and enzyme activities in plants (Katel et al., 2022).

3.15. Effect on fruit quality

The effect of growth regulators on the quality parameters of strawberry fruits such as total soluble solids (%), titratable acidity (%) and ascorbic acid content was studied at harvest during 2018–19 (Table 3). Foliar application of growth regulators (28-Homobrassinolide and Triacontanol) significantly improved TSS percentage and ascorbic acid content of fruits, but reduced the titratable acidity (%) of fruit as compared to control. Foliar application of 0.5 ppm of 28-Homobrassinolide recorded significantly higher TSS percentage and ascorbic acid content of fruit over control and other treatments except 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. However, the TSS percentage and ascorbic acid content of fruit were recorded maximum in plants treated with 0.5 ppm of 28-Homobrassinolide (9.1 Brix and 67.5 mg 100 g^{-1} respectively) followed by that of 1 ppm of 28-Homobrassinolide (8.7 Brix and 64.4 mg 100 g^{-1}) and 5 ppm of Triacontanol (8.2 Brix and 61.7 mg 100 g^{-1}). The value of these quality parameters recorded from the application of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol. Increased total soluble solids (%) and ascorbic acid content of fruits by application of Brassinosteroids may be attributed to its involvement in ripening and fruit quality development of climacteric and non-climacteric fruits (Sharma, 2021). Sridhara et al. (2021) and Aly et al. (2021) also reported increase in TSS percentage and Ascorbic acid content of fruit by application of Homobrassinolide. This result also corroborates the finding of Mohammadrezakhani et al. (2016). Foliar application of triacontanol (5 ppm) also significantly increased these fruit quality parameters of strawberry. Similar results were also found by El-Beltagi et al. (2022). This may be attributed to the role of Triacontanol in metabolic processes of plants including cell division and expansion, photosynthesis, and the activity of several enzymes (Perveen et al., 2011, Sarwar et al., 2019, El-Beltagi et al., 2022). The minimum titratable acidity (0.67%) was recorded from the treatment of 0.5 ppm 28-homobrassinolide. Lower acidity in fruits. Lower acidity in fruits might be due to higher accumulation of sugars, better translocation of sugars into fruit tissues and conversion of organic acids into sugars (Kumar et al., 2015, Saha et al., 2019). Mostafa and Kotb (2018) also reported decrease in fruit by application of Homobrassinolide. The titratable acidity of strawberry fruit recorded from the treatment of 0.5 ppm of 28-Homobrassinolide was found to be at par with that of 1 ppm of 28-Homobrassinolide and 5 ppm of Triacontanol.

3.16. Correlation between fruit yield and biochemical and quality parameters

Simple linear correlation between fruit yield plant^{-1} and biochemical and quality parameters such as pigment content (chlorophyll and carotenoids content) and RWC of leaves, ascorbic acid content TSS%, titratable acidity of strawberry fruits recorded during *rabi* 2018–19 are shown in Figures 1, 2, 3, 4, 5 and 6. The result revealed highly significant (p<0.01) positive correlation between fruit yield plant^{-1} and total chlorophyll content and carotenoids content of leaves. This indicates a very vital role of these pigments in photosynthesis and fruit yield of chilli. Jogi et al. (2013) also reported of the positive correlation between chlorophyll content of leaves and fruit yield of chilli. Increase in yield can be attributed to increase in assimilation of dry matter by higher rate of photosynthesis by application of growth regulators such as 28-Homobrassinolide and Triacontanol. There was strong positive correlation (p<0.01) between relative water content of leaves and fruit yield of strawberry. The fruit yield plant^{-1} showed a strong positive correlation

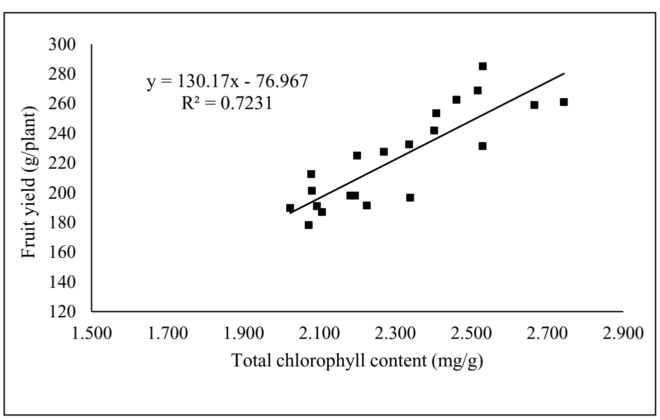

Figure 1: Correlation between total chlorophyll content of leaves and fruit yield plant^{-1} of strawberry

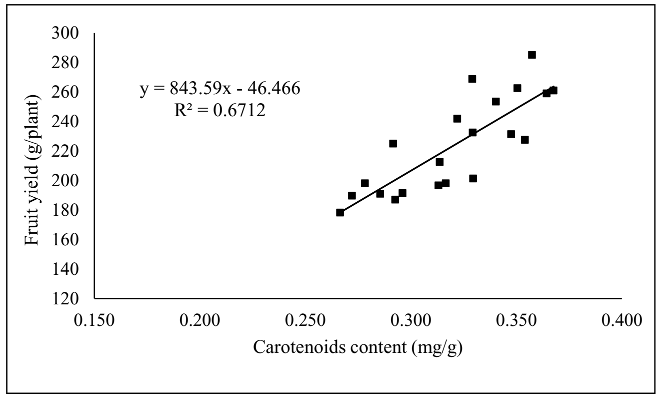

Figure 2: Correlation between carotenoids content of leaves and fruit yield plant^{-1} of strawberry

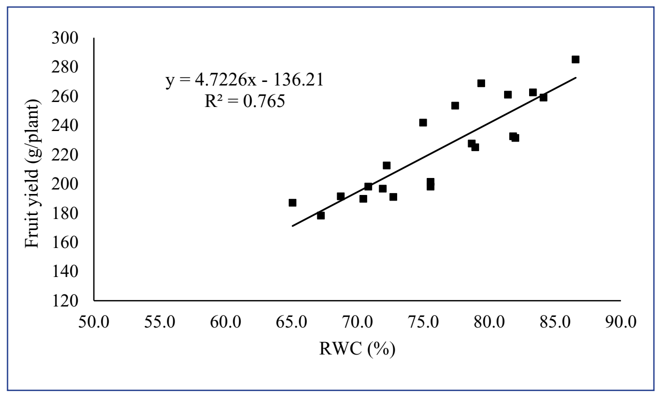

Figure 3: Correlation between relative water content of leaves and fruit yield plant^{-1} of strawberry

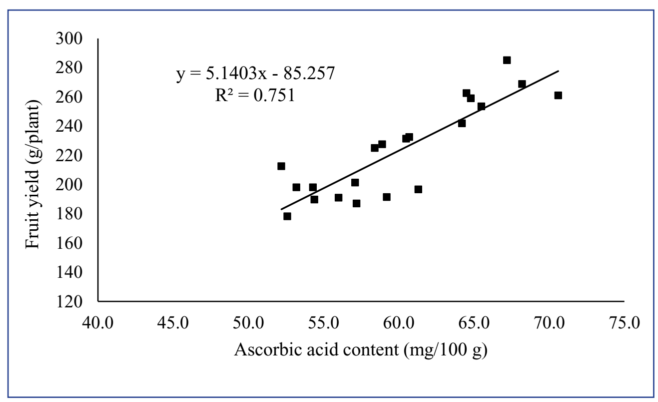

Figure 4: Correlation between ascorbic acid content of fruits and fruit yield plant^{-1} of strawberry

(p<0.01) with ascorbic acid content of fruits. The fruit yield plant^{-1} was found to have a strong positive correlation (p<0.01) with TSS (°Brix) of fruits. However, the titratable acidity (%) of fruit showed a significant (p<0.01) negative correlation with fruit yield. The total chlorophyll content of leaves accounted for 72.31% variability in fruit yield of strawberry (Figure 1). Similarly, carotenoids content of leaves accounted for 67.12% variability (Figure 2). The relative water content of leaves also accounted for 76.5%

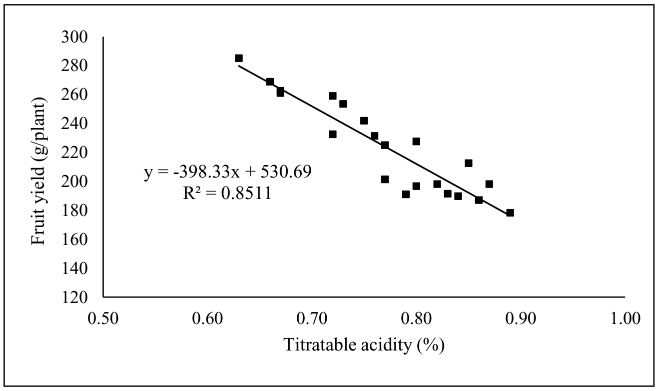

Figure 5: Correlation between titratable acidity of fruits and fruit yield plant^{-1} of strawberry

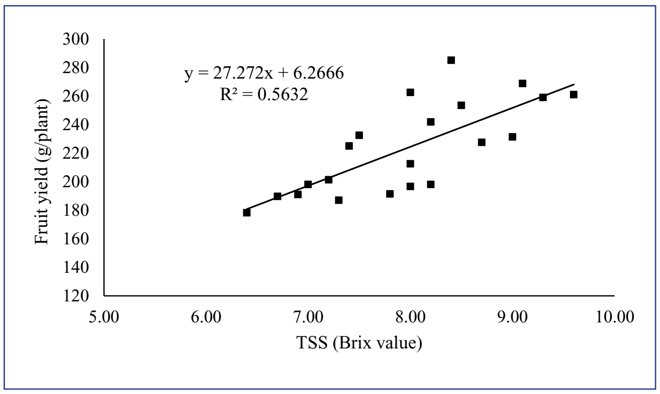

Figure 6: Correlation between total soluble solids of fruits and fruit yield plant^{-1} of strawberry

variability in fruit yield (Figure 3). Ascorbic acid content (Figure 4), titratable acidity (Figure 5) and total soluble solids content (Figure 6) of strawberry fruits accounted for 75.1%, 85.11% and 56.32% variability respectively in the fruit yield Hence, increasing total chlorophyll and carotenoids content of leaves, ascorbic acid content, titratable acidity and TSS content of fruits has direct effect for increasing the fruit yield of strawberry.

Beneficial effect of these growth regulators as manifested by higher fruit yield was found to be positively correlated with total chlorophyll and carotenoids content of leaves, ascorbic acid content and total soluble solids of fruits. The positive and significant correlation coefficient between fruit yield and chlorophyll and carotenoids content and RWC of leaves, ascorbic acid content and total soluble solids of fruits explains the true relationship between theses parameters and direct selection through these traits can be effective for crop improvement since these characters had high correlation.

4. CONCLUSION

The foliar application of 0.5 ppm of 28-Homobrassinolide was proved best among the treatments on growth and biochemical parameters of strawberry resulting higher fruit yield. Strong positive correlation was observed between yield and total chlorophyll content, relative water content of leaves and other quality parameters of fruits.

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