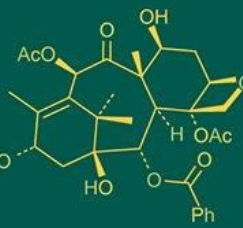
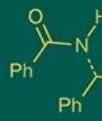


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Response of strawberry cv. winter dawn to plant growth regulators for growth, yield and quality under protected conditions

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Abstract

The present investigation "Response of Strawberry cv. Winter Dawn to Plant Growth Regulators for Growth, Yield, and Quality under Protected Conditions" was laid out in the naturally ventilated polyhouse at experimental field of the Department of Horticulture, Sam Higginbottom University of Agriculture, Technology and Sciences, Naini, Prayagraj (UP), during 2024-2025. This experiment was laid out in randomized block design and the study consists of ten treatments (9+1) including control and these treatments are replicated thrice. The treatments were, T₀ (control), T₁ (Gibberellic acid @ 50 ppm), T₂ (Gibberellic acid @ 75 ppm), T₃ (Gibberellic acid @ 100 ppm), T₄ (Paclobutrazol @ 25 ppm), T₅ (Paclobutrazol @ 50 ppm), T₆ (Paclobutrazol @ 75 ppm), T₇ (Triacontanol @ 30 ppm), T₈ (Triacontanol @ 40 ppm), T₉ (Triacontanol @ 50 ppm). From our experimental findings it is concluded that the treatment T₁ (GA₃ @ 50 ppm) performed best in terms of vegetative parameters. The treatment T₂ (GA₃ @ 75 ppm) performed best in terms of number of runners and earliness in flowering. However, the treatment T₇ (Triacontanol @ 30 ppm) was found best for other yield parameters, and the treatment T₃ (GA₃ @ 100 ppm) was found to be best in terms of TSS. The treatment (Triacontanol @ 30 ppm) was best for acidity and total sugar content. Moreover, treatment T₆ (Paclobutrazol @ 75 ppm) was found to be best for vitamin C.

Keywords: Strawberry, plant growth regulators, flowering, fruiting, yield parameters

Introduction

Strawberry (*Fragaria x ananassa* Duch.) belongs to family Rosaceae. The origin of the cultivated Strawberry can be traced to the hybridization of two wild species, *Fragaria cheloensis* Duch. from South America and *Fragaria Virginiana* Duch. from North America during the 18th century. The chromosome number of Strawberry is $2n = 2x = 56$. This is an octaploid species. It holds a prominent place among small fruits due to its short cropping period, high market demand, and economic profitability. Strawberry is a highly nutritious fruit, valued not only for its sensory appeal but for its rich nutrient profile. Strawberries are mainly composed of about 91% water making them an ideal choice for hydration and weight management. Strawberries are a good source of dietary fibre (2.0 g/100 g), which supports digestive health. In addition to this, strawberries are rich in bioactive compounds such as anthocyanins, ellagic acid, and other polyphenols which contributes to strong antioxidant and anti-inflammatory properties. The application of Plant Growth Regulators like GA₃ can effectively promote vegetative growth by stimulating cell elongation and division, resulting in increased plant height, larger leaves and overall canopy development. Paclobutrazol acts as a growth retardant by inhibiting gibberellin biosynthesis, resulting in more compact plant, while it significantly alters plants metabolic and physiological processes. Triacontanol, a naturally occurring plant stimulant, enhances physiological efficiency by stimulating photosynthesis, enzymatic activity and nutrient uptake. It enhances overall plant vigor, increases fruit number by increasing biomass and improves both yield and quality attributes, including color, taste and sweetness. It is also known to increase chlorophyll content and improve stomatal conduction which affects photosynthetic efficiency and energy availability for fruit development.

Materials and Methods

Climatic Conditions and Geographical Location at the Experimental Site

The experimental site is located at a latitude of 25.57° North and longitude of 81.51° East, with an altitude of 98 meters above the mean sea level. The region is characterized by extremely hot summers and fairly cold winters. Temperatures can rise upto 46-48 °C and it may occasionally drop to 4-5°. The relative humidity fluctuates between 20% and 94%, and the area receives an average rainfall of approximately 1013.4 mm.

Experimental Details

Studies on response of strawberry to plant growth regulators for growth, yield and quality under Protected Conditions was conducted on cv. Winter Dawn during 2024-2025 in the naturally ventilated polyhouse of Horticulture Research Field of the Department of Horticulture, Naini Agricultural Institute, SHUATS, Prayagraj, (Uttar Pradesh). The experiment was laid out in RBD with ten treatments (9+1) control and these are mentioned as T₀: Control, T₁: Gibberellic acid @ 50 ppm, T₂: Gibberellic acid @ 75 ppm, T₃: Gibberellic acid @ 100 ppm, T₄: Paclobutrazol @ 25 ppm, T₅: Paclobutrazol @ 50 ppm, T₆: Paclobutrazol @ 75 ppm, T₇: Triaccontanol @ 30 ppm, T₈: Triaccontanol @ 40 ppm, T₉: Triaccontanol @ 50 ppm. The runners were transplanted on 30th Nov. 2024 in the naturally ventilated polyhouse. The last harvesting was performed on 17th March 2025.

Results and Discussions

Response of Strawberry cv. Winter Dawn to Plant Growth Regulators on Plant height, Number of leaves and Number of runners under Protected Conditions

Plant Height (cm)

The maximum plant height 26.81 cm was recorded with the treatment T₁ (Gibberellic acid @ 50 ppm) and it was followed by T₂ (Gibberellic acid @ 75 ppm) with 26.66 cm. The minimum plant height was recorded under the treatment T₈ (Triaccontanol @ 40 ppm). This increase in height of the plant with the application of GA₃ @ 50 ppm during the research period has got the support of Swamy (2013) in Strawberry, Sakamoto *et al.*, (2004) [15] in rice, Weaver and McCune (1959) [16] in grapes, Amin *et al.*, (2008) [17] in papaya. The increased plant height in strawberry may be due to modifying gene expression related to cell wall loosening and expansion enabling cells to elongate more rapidly (Sponsel and Hedden, 2004) [18].

Number of leaves per plant

Maximum number of leaves (27.17) per plant was recorded in treatment T₁ (Gibberellic acid @ 50 ppm), followed by T₈ (Triaccontanol @ 40 ppm) with (26.05), while as the minimum number of leaves (20.80) was observed with treatment T₃ (Gibberellic acid @ 100 ppm). The increase in number of leaves may be due to enhanced chlorophyll content and accelerated meristematic activity. These observations are in close agreement with the findings of (Kumar *et al.*, 2012) [19], in tomato, (Panse *et al.*, 2013) [20] in brinjal, 9 Meena *et al.*, 2015) [21] in okra.

Number of runners per plant

At last harvest the maximum number of runners (2.67) was recorded in treatment T₂ (Gibberellic acid @ 75 ppm), the

minimum number of runners recorded was (0.87) in treatment T₄ (Paclobutrazol @ 25 ppm). However, no runners were produced in treatments T₅ (Paclobutrazol @ 50 ppm), T₆ (Paclobutrazol @ 75 ppm), T₇ (Triaccontanol @ 30 ppm), T₈ (Triaccontanol @ 40 ppm), T₉ (Triaccontanol @ 50 ppm). Highest number of runners are produced due to the promotion of cell elongation and enhanced activity of the apical meristem. This hormonal stimulation promotes the outgrowth of lateral buds into runners instead of flowering shoots. The results were further supported by (Rajesh *et al.*, 2012) [22].

Response of Strawberry cv. Winter Dawn to Plant Growth Regulators on First flower appearance (days), Number of flowers per plant, Duration of Harvesting (days), Polar Diameter (mm), Radial Diameter (mm), Number of Fruits Per Plant, Fruit Weight (g), Yield Per Plant (g) under protected conditions.

First Flower Appearance

Minimum days taken to first flower appearance (48.00) was noted with treatment T₂ (Gibberellic acid @ 75 ppm), maximum number of days to flower appearance (63.67) was found with treatment T₆ (Paclobutrazol @ 75 ppm). These findings have got the support from (Paroussi *et al.*, 2022) [23], and (Kumar *et al.*, 2014) [24]. Minimum number of days required to produce first flower is due to that GA₃ increases the activity of hydrolytic enzymes, like amylases, enhancing sugar mobilization to growing points, thus supplying energy for floral initiation.

Number of Flowers per Plant

The maximum number of flowers (31.27) was seen in treatment T₂ (Gibberellic acid @ 75 ppm), then followed by treatment T₃ (Gibberellic acid @ 100 ppm) as (27.92). The minimum number of flowers per plant was recorded in treatment T₀ (Control) with 16.35. The maximum number of flower production may be due to the effect of plant growth regulators that encourages rapid growth of plant tissues by promoting cell elongation, shoot growth and floral initiation. By stimulating stem elongation and leaf expansion, GA₃ improves overall plant vigor, which supports a higher capacity for flower production. These results were also in obtained by (Thakur *et al.*, 2017) [25].

Duration of Harvesting

The maximum duration of harvesting (29.00) was recorded in treatment T₇ (Triaccontanol @ 30 ppm), followed by (28.33) in treatment T₉ (Triaccontanol @ 50 ppm). The minimum duration of harvesting was seen in treatment T₅ (Paclobutrazol @ 50 ppm) with (23.67). These results have got the support from (Pang *et al.*, 2020) [26]. The results showed that foliar application of triaccontanol significantly extended the harvesting period by enhancing photosynthetic activity, improving nutrient assimilation, and promoting hormonal balance, especially of auxins and cytokinins (Kumar *et al.*, 2013) [27].

Polar Diameter (mm)

The maximum polar diameter of (47.15 mm) was recorded in treatment T₇ (Triaccontanol @ 30 ppm), followed by (42.14 mm) in treatment T₉ (Triaccontanol @ 50 ppm). The minimum polar diameter was seen in treatment T₃ (Gibberellic acid @ 100 ppm) with 32.75 mm.

Radial Diameter (mm)

The maximum radial diameter (29.10 mm) was recorded in treatment T₇ (Triacantanol @ 30 ppm), closely followed by (23.23 mm) in treatment T₉ (Triacantanol @ 50 ppm). However, the minimum radial diameter was found in treatment T₃ (Gibberellic acid @ 100 ppm) with (11.15mm). The increased dimensions in strawberry are due to enhanced physiological and biochemical processes essential for fruit development, by boosting photosynthesis and chlorophyll content. Triacantanol also improves nutrient uptake and translocation, supplies essential elements that supports the fruit enlargement. These results have found the support from Choudhary, Ashima (2023) ^[28] and similar to those of Khunte *et al.*, (2014) ^[29].

Number of Fruits per Plant

The maximum number of fruits per plant (25.08) was found in treatment T₇ (Triacantanol @ 30 ppm), which is followed by (22.67) in treatment T₈ (Triacantanol @ 40 ppm). Whereas, the minimum number of fruits per plant (13.75) was recorded in treatment T₁ (Gibberellic acid @ 50 ppm). These results are consistent with those of Rani *et al.*, (2005) in strawberry, Singh *et al.*, (2016) ^[31]. (Sharma and Singh, 2009) ^[3], reported that the increased number of fruits are due to enhanced photosynthetic efficiency, which results in more

production of carbohydrates and energy needed for flower initiation and fruit development.

Fruit Weight (g): The maximum fruit weight of (28.40 g) was recorded in treatment T₇ (Triacantanol @ 30 ppm), followed by (25.53 g) in treatment T₈ (Triacantanol @ 40 ppm). However, the minimum fruit weight (14.02 g) was found in treatment T₀ (control). The increased fruit weight in strawberry is due to the increased levels of natural growth hormones, promoting rapid cell division and enlargement in fruit tissues, increasing fruit size and weight. These results are in close context with Mehta *et al.*, (2012) ^[32]. Triacantanol could promote fruit development by up-regulating factors related to fruit ripening related growth and development in strawberry Pang *et al.*, (2020) ^[26].

Fruit Yield per Plant (g)

The maximum fruit yield per plant (314.90 g) was found to be in treatment T₇ (Triacantanol @ 30 ppm), which was followed by (296.43 g) in treatment T₈ (Triacantanol @ 40 ppm). The minimum fruit yield was seen in treatment T₀ (control) with (146.05 g). The increase in fruit yield per plant is due to enhanced photosynthetic efficiency by increasing chlorophyll content, which boosts carbohydrate production and translocation to the Verma *et al.*, (2020) ^[33].

Table 1: Response of Strawberry cv. Winter Dawn to Plant Growth Regulators for Plant height (cm), Number of leaves per plant, number of runners per plant under Protected Conditions

Treatment	Plant height (cm)	Number of leaves per plant	Number of runners per plant
	90 DAP	90 DAP	90 DAP
T ₀	19.71	23.45	1.33
T ₁	26.81	27.17	1.06
T ₂	26.66	24.01	2.67
T ₃	23.93	20.80	1.50
T ₄	19.13	25.88	0.87
T ₅	21.06	24.63	0.00
T ₆	17.76	21.28	0.00
T ₇	21.10	25.35	0.00
T ₈	15.94	26.05	0.00
T ₉	18.73	23.80	0.00
F test	S	S	S
SEm	1.58	0.43	0.45
CD (5%)	4.70	1.29	1.33
CV	12.98	3.10	104.70

Table 2: Response of Strawberry cv. Winter Dawn to Plant Growth Regulators for days taken to first flower, number of flowers per plant, duration of harvesting, polar diameter, radial diameter under protected conditions

Treatment	First flower Initiation (days)	Number of flowers per plant	Duration of harvesting	Polar diameter (mm)	Radial diameter (mm)
T ₀	61.00	16.35	26.00	37.40	22.90
T ₁	53.67	24.03	25.67	37.90	23.03
T ₂	48.00	31.27	24.00	41.45	13.75
T ₃	51.67	27.92	26.00	32.75	11.15
T ₄	59.33	24.63	24.33	38.40	19.97
T ₅	57.67	21.03	23.67	37.27	20.80
T ₆	63.67	20.30	24.00	37.43	17.77
T ₇	54.00	28.23	29.00	47.15	29.10
T ₈	56.00	24.07	25.33	37.39	21.18
T ₉	59.67	23.70	28.33	42.14	23.23
F test	S	S	S	S	S
SEm	0.99	0.89	0.75	0.77	0.31
CD (5%)	2.95	2.66	2.23	2.29	0.91
CV	3.04	6.49	5.08	3.42	2.61

Table 3: Response of Strawberry cv. Winter Dawn to Plant Growth Regulators for fruits per plant, average fruit weight (g), fruit yield per plant under protected conditions

Treatment	Number of fruits per plant	Average fruit weight	Fruit Yield Per Plant (200 m ²)	B:C ratio
T ₀	18.92	14.02	146.05	1.95
T ₁	13.75	18.40	236.52	3.44
T ₂	20.17	19.20	233.11	4.15
T ₃	20.47	21.33	224.27	4.05
T ₄	17.97	19.83	221.60	3.57
T ₅	15.17	23.43	225.07	3.50
T ₆	16.33	22.98	211.41	3.41
T ₇	25.08	28.40	314.90	6.63
T ₈	22.67	25.53	296.43	5.12
T ₉	22.12	23.80	272.93	4.44
F test	S	S	S	
SEm	1.22	0.32	0.74	
CD (5%)	3.63	0.95	2.20	
CV	10.87	2.54	0.54	

Response of Strawberry cv. Winter Dawn to Plant Growth Regulators for determination of TSS (° Brix), Acidity, Total sugar, Ascorbic acid, pH under protected conditions

TSS (° Brix)

The TSS was found maximum in treatment T₃ (Gibberellic acid @ 100 ppm) with 9.27 °Brix, followed by 8.03 in treatment T₇ (Triacantanol @ 40 ppm). Whereas, the minimum TSS 3.10 was recorded in treatment T₅ (paclobutrazol @ 50 ppm). The observed rise in TSS may be attributed to the breakdown of cell walls as suggested by (Anitha *et al.*, 2005) [34], along with a reduction in respiration and an increase in dry matter due to water loss. The reduction in TSS levels could be due to sugar dilution caused by water spraying during the first ripening phase. This has got the support from (Khatoun *et al.*, 2021) [35].

Titration Acidity (%)

The maximum acidity (%) was found highest in treatment T₇ (Triacantanol @ 30 ppm) with 1.70%, closely followed by 1.30%, in treatment T₄ (Paclobutrazol @ 25 ppm). The minimum acidity (%) 0.50% was found to be in the fruits with treatment T₁ (Gibberellic acid @ 50 ppm). The reduction in titration acidity is likely due to reduced respiration and slower accumulation of organic acids, this result has got the support from (Sharma *et al.*, 2018) [36], and in contrast to increasing acidity may be attributed to enhanced metabolic activity and organic acid biosynthesis during early fruit development and has got the support from (Singh *et al.*, 2016) [37].

Total Sugar (%)

The maximum sugar percentage (8.40) was found in treatment T₇ (Triacantanol @ 30 ppm), followed by (8.27) in treatment T₈ (Triacantanol @ 40 ppm) and the minimum 6.27) was recorded in treatment T₁ (Gibberellic acid @ 50 ppm). These results have got the support from (Singh *et al.*, 2017) [38] and (Mandal *et al.*, 2020) [39]. They reported that the respective increase in total sugar is attributed to enhanced photosynthesis, chlorophyll content, and activity of sugar metabolizing enzymes.

Ascorbic acid

The maximum ascorbic acid content (4.87) was found in treatment T₆ (Paclobutrazol @ 75 ppm), then followed by (4.07) in treatment T₂ (Gibberellic acid @ 75 ppm). Whereas, the minimum ascorbic acid content was found in treatment T₈ (Triacantanol @ 40 ppm) with (2.46). This finding correlates with the findings of (Kumar and Singh, 2019) [40].

pH

The maximum pH of 5.49 was found in the fruits of treatment T₄ (Paclobutrazol @ 25 ppm), followed by 5.22 found with treatment T₉ (Triacantanol @ 50 ppm). The minimum pH was found in treatment T₁ (Gibberellic acid @ 50 ppm) which is (3.00). The respective increase in pH is due to slowed synthesis of organic acids like citric acid and malic acid, which are responsible for the sour taste and low pH in fruits. As same was reported by (Sharma *et al.*, 2018) [36].

Table 4: Response of Strawberry cv. Winter Dawn to Plant Growth Regulators for TSS (° Brix, Acidity, Total sugar, Ascorbic acid, and pH under protected conditions

Treatment	TSS	Acidity (%)	Total sugar	Ascorbic acid	pH
T ₀	7.90	0.67	7.30	3.47	3.53
T ₁	5.97	0.50	6.27	3.80	3.00
T ₂	6.10	1.23	7.13	4.07	3.13
T ₃	9.27	0.83	7.27	2.87	3.47
T ₄	3.78	1.30	6.53	3.57	5.49
T ₅	3.10	0.90	6.50	3.23	3.65
T ₆	4.20	0.57	7.10	4.87	3.07
T ₇	8.03	1.07	8.40	3.90	4.90
T ₈	3.93	0.77	8.27	2.46	4.70
T ₉	5.57	0.80	7.43	3.32	5.22
F test	S	S	S	S	S
SEm	0.38	0.23	0.42	0.34	0.47
CD (5%)	1.13	0.69	1.26	1.00	1.39
CV	11.34	43.22	10.26	16.71	20.04

Conclusion

According to our experimental results it is concluded that the treatment T₁ (Gibberellic acid @ 50 ppm) performed best in terms of plant height and number of leaves. However, treatment T₂ (Gibberellic acid @ 75 ppm) had the maximum number of runners, earliness in flowering and number of flowers. The maximum duration of harvesting was seen in treatment T₇ (Triacantanol @ 30 ppm) and it was also found best for other yield parameters.

The treatment T₃ (Gibberellic acid @ 100 ppm) was found to be effective in terms of TSS° Brix. While as, the treatment T₇ (Triacantanol @ 30 ppm) was found best for acidity and total sugar content. Moreover, treatment T₆ (Paclobutrazol @ 75 ppm) showed the best performance for Vitamin C content.

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