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Influence of plant growth regulators on vegetative, flowering and physical attributes of strawberry cv. Winter Dawn

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ABSTRACT

The present investigation was carried out to evaluate the influence of different plant growth regulators (PGRs) on vegetative growth, flowering behavior, and physical attributes of strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under field conditions. Treatments consisted of foliar application of GA_3 (25 and 50 ppm), NAA (25 and 50 ppm), Cycocel (500 and 750 ppm), and BA (30 and 50 ppm), along with an untreated control. Results revealed that GA_3 at 50 ppm significantly enhanced vegetative parameters including number of leaves (52.21), plant height (28.01 cm), and plant spread (36.10 cm) and petiole length (12.29 cm). Similarly, early flowering (52.84 days to first flower), maximum number of flowers (19.27), early fruit set (55.00 days), and highest fruit number per plant (16.90) were also recorded with GA_3 50 ppm. Yield attributes such as berry weight (14.76 g), berry length (41.02 mm), berry width (27.59 mm), and fruit yield per plant (249.89 g) were significantly superior under GA_3 50 ppm, followed by GA_3 25 ppm. Among other treatments, NAA 25 ppm and Cycocel 500 ppm also improved yield and fruiting characteristics compared with control. It can be concluded that foliar application of GA_3 50 ppm proved most effective in improving vegetative growth, earliness, yield, and berry quality of strawberry cv. Winter Dawn, thereby contributing towards sustainable food production and promoting a low-carbon economy through enhanced resource efficiency in horticultural systems.

Keywords: *Cycocel, Gibberellic acid (GA_3), Naphthalene acetic acid (NAA), Plant growth regulators, Strawberry*

Introduction

The strawberry, or *Fragaria* × *ananassa* Duch.is a low-yield crop of great value in the Rosaceae family. Originating from North American species, *Fragaria chiloensis* and *Fragaria verginiana* in France in the 17th century, the cultivated cultivars are octaploid (2n = 56) in nature (Nayyer *et al*., 2024). It is a rich source of vitamin C, phenolics, and antioxidants that contribute to its functional and medicinal properties, making it a crop of both economic and nutritional significance (Qaderi *et al*., 2023). In India and other subtropical regions, strawberry production is often constrained by poor vegetative growth, delayed flowering, low fruit set, and small berry size, all of which lead to reduced yield and inferior market quality. Since these traits are largely regulated by endogenous hormonal balance, manipulation of physiological processes through the exogenous application of plant growth regulators (PGRs) offers a promising approach for improving productivity and fruit quality.

Plant growth regulators are synthetic or naturally occurring organic compounds which, even at very low concentrations, regulate growth and developmental processes such as cell division, cell elongation, flowering, fruit set, and senescence (Rademacher, 2015). Their targetedapplication allows growers to direct plant resources toward desired outcomes such as enhanced vegetative vigor, increased flower and fruit number, or improved fruit quality attributes. Consequently, PGRs have been widely studied as tools for enhancing the commercial performance of strawberries under diverse production systems.

Among the commonly used PGRs, gibberellins (GA_3) are well known for their role in stimulating stem and petiole elongation, leaf expansion, and overall vegetative growth. Application of GA_3 has been shown to accelerate floral initiation, reduce the number of days to first flower and fruit set, and enhance berry weight and yield in strawberry and other rosaceous fruit crops (Paroussi *et al.,* 2002). (NAA) is a synthetic auxin, that can bring changes in the phenotype of plants and affects growth either by enhancing or by stimulating the natural growth regulatory system from seed germination to senescence. It stimulates cell elongation, cell division in the cambium, differentiation of phloem and xylem and induces flowering and fruiting. (Lanuchila and Deepanshu, 2022).

Growth retardants like chlormequat chloride (CCC or Cycocel) act by inhibiting gibberellin biosynthesis, thereby restricting excessive vegetative elongation and promoting compact plant architecture. Such regulation often results in increased crown branching and improved reproductive efficiency, although higher concentrations may adversely affect yield (Rademacher, 2000). Cytokinins such as benzyladenine (BA) promote cell division, delay senescence, and improve nutrient mobilization. In strawberries, BA has been associated with enhanced vegetative vigor and higher flower or runner initiation, though its effectiveness varies with concentration and cultivar (Aremu *et al*., 2020; Dale *et al*., 1996).

Given the importance of hormonal regulation in strawberry growth and development, the present study was undertaken to investigate the influence of foliar application of GA_3, NAA, Cycocel, and BA on vegetative growth, flowering behavior, and physical fruit attributes of strawberry cv. Winter Dawn under subtropical conditions.

Materials and Methods

Plant materials

The experiment was carried out at Instructional Farm-3, Integral University, Lucknow, Uttar Pradesh, India, over two consecutive seasons (2023–24 and 2024–25). Strawberry runners of cv. Winter Dawn were procured from Dr. Y. S. Parmar University of Horticulture and Forestry, Himachal Pradesh. The runners were planted at a spacing of 45 × 30 cm during the second fortnight of October, preferably in the evening. Following planting, irrigation was applied immediately and repeated every three days until the plants were well established.

Treatments details

The experiment consist of nine treatments with three replication using a randomized complete block design (RCBD). The details of treatments listed below.

S. No	Treatments
T_0	Control (Normal water)
T_1	GA_3 25 ppm
T_2	GA_3 50 ppm
T_3	NAA 25 ppm
T_4	NAA 50 ppm
T_5	Cycocel 500 ppm
T_6	Cycocel 750 ppm
T_7	BA 30 ppm
T_8	BA 50 ppm

*All the PGRs were applied thrice

Experimental details

Data were recorded for various vegetative, flowering, fruiting, yield, and quality traits. Plant height (cm) and plant spread (cm) were measured using a meter scale and expressed in centimeters. The total number of leaves per plant was determined by counting fully expanded leaves from five randomly selected plants. The number of days to first flowering was calculated as the interval between the date of planting and the opening of the first flower. Similarly, the days to first fruit set were recorded from the date of flower opening to the initiation of fruit set. The number of flowers per plant, number of fruits per plant, and total fruits per plant were recorded from five randomly selected plants.

Statistical Analysis

The ANOVA was conducted using SPSS software (version 22.0 for Windows). Mean comparisons were performed using the Tukey HSD test, with significance determined at ($p \leq 0.05$)

Results and Discussion

Vegetative parameters

The pooled analysis of two years data (Table 1) revealed significant differences among the treatments for vegetative parameters of strawberry cv. Winter Dawn under the influence of various plant growth regulators (PGRs).

The maximum number of leaves per plant (52.21) was observed with GA_3 50 ppm, followed by GA_3 25 ppm (51.01), which were significantly superior to the control (34.16). Similarly, plant height was highest with GA_3 50 ppm (28.01 cm), followed by GA_3 25 ppm (25.88 cm), compared to the control (17.73 cm). Plant spread was significantly affected, with the highest value (36.10 cm) observed under the GA_3 50 ppm treatment. In terms of petiole length, GA_3 50 ppm also showed superiority (12.29 cm), whereas the control recorded the lowest value (7.12 cm).

The results indicate that the application of plant growth regulators exerted a profound effect on the vegetative growth of strawberry plants. Gibberellic acid (GA), particularly at 50 ppm, proved to be the most effective in enhancing vegetative parameters such as the number of leaves, plant height, plant spread, and petiole length. GA_3 is well-known for stimulating cell elongation, breaking dormancy, and promoting leaf expansion, which explains the observed enhancement in vegetative growth (Paroussi *et al.,* 2002). Enhanced photosynthetic efficiency due to increased leaf area under GA treatment might have contributed to greater assimilate availability, thereby improving plant vigor (Katel *et al.,* 2022). These findings are in accordance with those of Guttridge and Thompson (1959) and Pathak and Singh (1976).

Flowering parameters

The pooled analysis of two years' data (Table 2) revealed significant differences among the treatments for flowering parameters of strawberry cv. Winter Dawn under the influence of various plant growth regulators (PGRs). The earliest flowering was recorded in plants treated with GA_3 50 ppm, which produced the first flower in (52.84 days), followed closely by GA_3 25 ppm (54.50 days). These values were significantly lower than the control (63.67 days), indicating a strong promotive effect of gibberellic acid on flowering initiation. Similarly, NAA at 50 ppm and 25 ppm also reduced the days to first flowering compared to control, whereas BA and Cycocel treatments had a moderate effect.

In terms of flower number per plant, GA_3 50 ppm recorded the highest (19.27), followed by GA_3 25 ppm (19.04), which were significantly higher than the control (13.97). NAA 25 ppm (14.84) and Cycocel 500 ppm (16.00) also improved flower production over control. Conversely, BA treatments were comparatively less effective in increasing flower number.

The days taken to first fruit set followed a similar trend, with GA_3 50 ppm showing the earliest fruit set (55.00 days), followed by GA_3 25 ppm (56.50 days), compared to control (65.83 days). The highest number of fruits per plant was also observed with GA_3 50 ppm (16.90), followed by GA_3 25 ppm (16.30), whereas the control produced only (12.17) fruits per plant.

Table 1. Influence of PGRs on vegetative parameters of strawberry (means pooled of two years).

Treatment	Number of leaves/plant	Plant height (cm)	Plant spread (cm)	Petiole length (cm)
Control	34.16	17.73	23.12	7.12
GA_3 25 ppm	51.01	25.88	33.27	11.66
GA_3 50 ppm	52.21	28.01	36.10	12.29
NAA 25 ppm	41.31	25.06	31.02	10.06
NAA 50 ppm	39.89	24.06	30.68	8.50
Cycocel 500 ppm	47.97	24.22	31.30	9.33
Cycocel 750 ppm	37.05	23.47	30.07	8.92
BA 30 ppm	39.88	24.28	30.61	9.67
BA 50 ppm	43.33	23.21	30.93	9.30
SEm±	1.37	0.72	0.74	0.28
Tukey HSD ($P \leq 0.05$)	4.10	2.14	2.22	0.83

Early flowering in strawberry can be attributed to the balanced supply of nutrients facilitated by growth regulators such as GA and NAA, which stimulate cell division, elongation, and floral bud initiation, thereby reducing flowering duration (Singh and Singh, 2006; Tripathi and Shukla, 2006; Singh and Tripathi, 2010). The increase in flower number may result from accelerated inflorescence differentiation and higher carbohydrate accumulation through enhanced photosynthesis, compelling the plant to allocate assimilates toward reproductive growth (Kaur *et al*., 2018; Sood *et al*., 2018). Greater photosynthetic activity, supported by larger leaf area and hormonal stimulation, also contributed to early fruit set (Prasad *et al*., 2012; Palei *et al*., 2016). GA further promotes fruit set through its action on both pollen and ovary tissues, possibly by activating enzymatic systems that release active hormones from stored pools (Singh and Singh, 2009; Kumar and Tripathi, 2006). Thus, PGR application enhances flowering and fruiting in strawberry by improving photosynthetic efficiency, assimilate partitioning, and endogenous hormonal activity.

Yield parameters

The results presented in Table 3 indicate that the yield attributes of strawberry, namely berry weight, berry length, berry width, and fruit yield per plant, were markedly influenced by the application of different plant growth regulators (PGRs).

The maximum berry weight (14.76 g) was recorded under GA_3 at 50 ppm, which was at par with GA_3 at 25 ppm (14.48 g), whereas the minimum berry weight (9.07 g) was observed in the control (9.07 g). Similarly, berry length was highest (41.02 mm) with GA_3 at 50 ppm, followed by GA_3 at 25 ppm (39.97 mm), while the lowest length (22.22 mm) was obtained under control. Berry width also showed significant variation, with the maximum width (27.59 mm) recorded with GA_3 50 ppm,

Table 2. Influence of PGRs on flowering parameters of strawberry (means pooled of two years).

Treatment	Days taken to produce first flower	Number of flowers/ plant	Days taken to first fruit set	Number of fruits per plant
Control	63.67	13.97	65.83	12.17
GA_3 25 ppm	54.50	19.04	56.50	16.30
GA_3 50 ppm	52.84	19.27	55.00	16.90
NAA 25 ppm	59.34	16.40	63.00	15.14
NAA 50 ppm	56.00	14.84	58.34	13.90
Cycocel 500 ppm	60.17	16.00	62.34	15.67
Cycocel 750 ppm	58.00	16.17	59.67	14.87
BA 30 ppm	56.34	15.10	58.34	15.10
BA 50 ppm	57.84	14.90	59.67	14.80
SEm±	2.13	0.51	2.52	0.45
Tukey HSD ($P \leq 0.05$)	6.40	1.53	6.43	1.34

Table 3. Influence of PGRs on yield parameters of strawberry (means pooled of two years).

Treatment	Berry weight (g)	Berry length (mm)	Berry width (mm)	Fruits yield per plant (g)
Control	9.07	22.22	18.83	110.75
GA_3 25 ppm	14.48	39.97	27.12	236.31
GA_3 50 ppm	14.76	41.02	27.59	249.89
NAA 25 ppm	11.31	36.37	25.18	171.47
NAA 50 ppm	12.58	33.17	24.89	174.96
Cycocel 500 ppm	11.20	37.70	25.13	175.77
Cycocel 750 ppm	13.01	38.16	23.19	193.55
BA 30 ppm	12.33	35.62	22.36	186.68
BA 50 ppm	11.66	35.99	23.73	172.97
SEm±	0.37	1.06	0.76	11.24
Tukey HSD($P \leq 0.05$)	1.10	3.16	2.26	33.70

closely followed by GA_3 25 ppm (27.12 mm). The minimum berry width (18.83 mm) was observed in the control. Regarding fruit yield per plant, GA_3 at 50 ppm resulted in the highest yield (249.89 g), which was statistically superior to all other treatments, followed by GA_3 25 ppm (236.31 g). The lowest yield (110.75 g) was recorded under control.

Exogenous application of gibberellic acid (GA_3) enhanced fruit growth and size by promoting cell elongation, expansion, and improved assimilate supply through increased vegetative growth and photosynthetic efficiency. Treatment with GA_3 at 50 ppm resulted in maximum fruit weight, size, and yield, likely due to enhanced source–sink activity. The increase in fruit length and width may be attributed to higher carbohydrate accumulation and stimulation of cell division and elongation, leading to greater dry matter deposition. Consequently, yield per plant increased as a cumulative effect of improved fruit set, size, and weight. These results corroborate earlier findings by Lopez *et al*., (1989); Singh and Singh (2006); Kumar and Tripathi (2006); Singh and Tripathi (2010); Prasad *et al*., (2013); Rajbahar *et al*., (2015); Dubey *et al*., (2017), and Kaur *et al*., (2018).

Correlation analysis

The correlation matrix illustrates the relationship among various vegetative, flowering, and fruiting parameters of the studied crop. The color scale ranges from -1 (strong negative correlation) to +1 (strong positive correlation), with green shades representing positive associations and brown shades indicating negative associations.

A strong positive correlation was observed among most growth and yield attributes. Plant height exhibited a high correlation with plant spread (r = 0.98), number of fruits per plant (r = 0.93), berry width (r = 0.93), and fruit yield per plant (r = 0.91). Similarly, petiole length showed strong

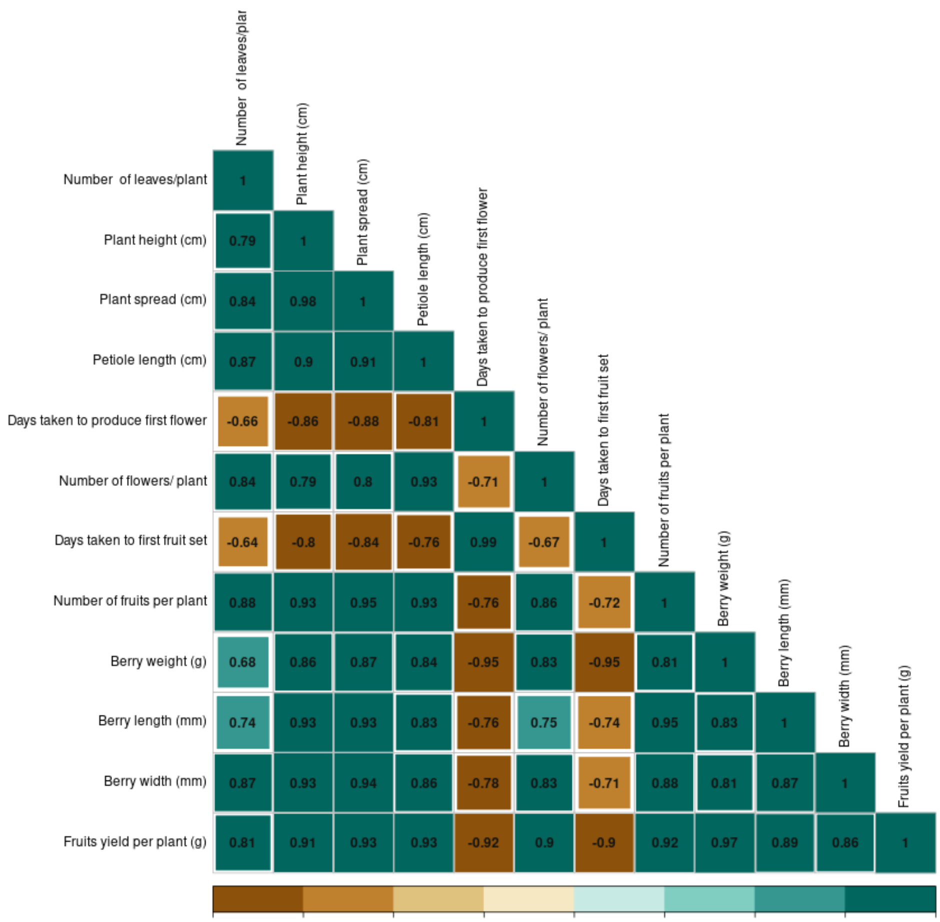

Fig. 2. Pearson correlation heat map for strawberry parameters

positive associations with the number of flowers per plant (r = 0.93) and number of fruits per plant (r = 0.93). Conversely, days taken to produce the first flower showed a significant negative correlation with most growth and yield parameters, particularly with plant height (r = -0.86), plant spread (r = -0.88), and fruit yield per plant (r = -0.92), suggesting that delayed flowering adversely affects overall productivity.

Overall, the correlation pattern indicates that vegetative vigor (height, spread, and leaf number) and early flowering are critical determinants of higher fruit yield in the variety.

Conclusion

The present investigation demonstrated that foliar application of plant growth regulators had a significant influence on the growth, flowering, and fruiting behaviour of strawberry cv. Winter Dawn under subtropical conditions. Among the treatments, GA_3 at 50 ppm proved to be the most effective in enhancing vegetative parameters such as plant height, number of leaves, plant spread, and petiole length. It also promoted early flowering, increased flower number, number of fruits/plant, and improved fruit yield per plant. The yield attributes, including berry weight, length, and width, were maximized under GA_3 at 50 ppm, resulting in superior overall yield.

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Conflict of interest: None

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