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Impact of Plant Growth Regulators on Growth, Fruit Yield and Quality of Strawberry (*Fragaria ananassa* Duch.) cv. Winter Dawn

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The present study aimed to investigate the impact of plant growth regulators on the growth, yield, and quality of strawberry (Fragaria × ananassa Duch) cv. Winter Dawn. A total of ten treatments were examined, including control (Water Spray), individual treatments of NAA (Naphthalene Acetic Acid) and GA3(Gibberellic Acid) and BA(6-benzvladenine). The experiment was conducted under controlled conditions, and various parameters related to vegetative growth, quality, and yield were evaluated.

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The results demonstrated that treatment T9, combination BA (6-benzyladenine) 75ppm exhibited superior vegetative growth characteristics. Plants treated with T9 displayed increased plant height, Number of leaves, plant spread, petiole length, chlorophyll content, and early onset of flowering and first fruiting. Moreover, T9 also demonstrated remarkable performance in terms of fruit production, with a higher number of fruits, flowers, and excellent fruit set, and TSS, Acidity (%), and Ascorbic acid.

These findings highlight the beneficial impact of plant growth regulators on the growth, yield, and quality of strawberry plants. The combined application of BA (6-benzyladenine) 75ppm (T9) resulted in superior vegetative growth. These results suggest that the incorporation of Plant growth regulators in strawberry cultivation practices can be a promising approach to optimize both yield and fruit quality. Further studies are warranted to understand the underlying mechanisms and optimize the application dosage and timing of these bio inputs for sustainable strawberry production.

Keywords: Naphthalene acetic acid; gibberellic acid; BA(6-Benzyladenine); winter dawn.

1. INTRODUCTION

"Strawberry is one of the most delicious, attractive, nutritious and refreshing soft fruits of the world. The cultivated strawberry (Fragaria x ananassa) is a hybrid of two native American sp; *F. chiloensis* and *F. virginiana*. Strawberries are good source of natural anti-oxidant. Owing to its medicinal properties (anticarcinogenic, antidiabetic and antioxidant), strawberry is gaining popularity among all age group consumers. Strawberries are good source of natural anti-oxidant. In India, it is mainly grown in Maharashtra and in hills of Himachal Pradesh, J&K and Uttarakhand, Uttar Pradesh and Haryana" [1]. "Strawberry usually grows in temperate zones, and it is classified as a short-day plant based on its behaviour and eco system. Strawberry is a temperate plant that can be grown in both farmlands and mountains, but the fruit results are better on the hills. For best progress and growth, the strawberry needed a day temperature of 22°C and a night temperature of 7°C to 13°C. Frost and winter injuries decreased yield. Strawberry might cultivate in particular land, extending from thick clay to light sand and gravel. Strawberry plants, on the other hand, grow on sandy loam soil with a pH of 5.5 to 6.5. It is a heavy conveyor crop that produces more" (Yadav et al*.,* 2018). "The main objective of the strawberry growers is to produce a fruit with appealing appearance (size, color and shape) not necessary accompanied by the same appealing tasteful characteristics. In order for the farmers to achieve such fruit growth enhancement, they often use plant growth regulating compoun, ds [2-4]. Plant growth regulators (PGRS) have proven their role in augmenting yield and quality in many fruits. Some of plant bioregulators are synthesized endogenously, but occasionally they are needed to get supplemented exogenously for additional stimulus for short duration crop like strawberry, which require quick response for increased growth, fruit set and yield. Use of plant bioregulators plays an important role in vegetative growth, flowering, yield and quality. Use of GA3 in strawberry has been reported in early flowering, increased duration of flowering, harvesting and yield. It increases yield and quality of fruits, helps in cell elongation and cell enlargement, increases vegetative growth and minimizes time of maturity and increases fruit set. Application of NAA increases fruit size and delays ripening and increases anthocyanin accumulation in strawberry fruits. It also increases duration of flowering, improves yield and quality of fruits. BA, as a plant growth regulator enhances the size and shape of fruits, lateral bud break and lateral shoot growth, leading to improved branching in fruit trees and flowering. BA increases fruit size and delay chlorophyll breakdown and fruit ageing. BA also decreases loss in firmness, delay ethylene production, decreases respiration rate and induces mechanical resistance which reduces senescence rate after harvest" [1] "In India, strawberry fruit crop is still grown in open areas using a paddy straw mulching strategy by poor or marginal farmers, and it accounts for a large part of the national annual strawberry cultivable land. According to scientific findings, the strawberry plant responded positively to the application of a growth regulator" (Sharma and Sharma, 2004). "Because of their suitability for treatment at a lower cost, naphthalene acetic acid (NAA) and gibberellins (GA3) have been widely investigated in present agricultural systems [5-7]. In many

fruits, the role of these plant growth regulators has been explored" (Bist et al., 2018). Premature flowering, enhanced flowering time, collecting, and yield have all been observed with the use of GA3 in strawberries. It boosts fruit output and quality, promotes cell elongation and expansion, helps to improve vegetative growth, reduces the period to maturity, and boosts fruit set (Sharma and Singh, 2009). In strawberry fruits, NAA promotes growth parameters, slows ripening, and enhances anthocyanin accumulation. It furthermore enhances the blooming period and improve fruit output and quality (Mir et al*.,* 2004) [2,8-10].

2. MATERIALS AND METHODS

The experiment was conducted during 2023-2024 at experimental filed of department of horticulture, Naini Agricultural Institute, Sam Higginbottom University of Agriculture Technology and Sciences, Prayagraj to experiment the impact of plant growth regulators on growth, yield, and quality of strawberry. The practical was carryout in a randomized block design with seven treatments consisted of control (no application of plant growth regulators), GA3 (25, 50, 75 ppm), NAA (25, 50, 75 ppm), and BA (25, 50, 75 ppm). All the treatment were replicated thrice. All the runners are equal and vigour transplanted during morning hours at a 30cm x 30cm. Daily watering was done for first week with drip irrigation and gap filling was done after first week of transplanted. After the transplant, the plant growth regulators were sprayed at 30, 60, and 90 days [11-15]. In each replication, the observation was noted in three randomly selected plants. According to A.O.A.C (1990), the quality of the fruits was tested during harvest using a standard method and procedure, and the results were statistically analysed. Randomized Block Design was used to set up the experiment, and ten treatments were reproduced three times. The ten treatments consist of (Water spray) T0, NAA (Naphthalene Acetic Acid) 25 ppm T1, NAA (Naphthalene Acetic Acid) 50 ppm T2, NAA (Naphthalene Acetic Acid) 75ppm T3, GA3 (Gibberellic Acid) 25ppm T4, GA3 (Gibberellic Acid) 50ppm T5, GA3 (Gibberellic Acid) 75ppm T6, BA(6-benzyladenine) 25ppm T7, BA(6-benzyladenine) 50ppm T8, BA(6-benzyladenine) 75ppm T9. All the doses of NAA, GA3, BA combination was applied at the time of planting and during flowering initiation and observations were recorded on plant height (cm), number of leaves per plant, plant spread (cm), petiole length (cm), Days to first flowering, number of flowers per plant, number of fruits per plant, diameters of fruits, fruits length, fruit weight, fruit set, TSS, acidity, ascorbic acid. The statistical procedure for agricultural research states that an analysis of variance will be performed on the data's mean values. Randomized Block Design. A method and algorithms were used to compute different statistical parameters. The Analysis of Variance (ANNOVA) method was used to compare the means of the attributes [16-20].

2.1 Vegetative Characters

2.1.1 Plant Height (cm)

The height of plants was measured by using a measuring scale from crown level of plants to the apex of primary leave at was recorded at 30, 60 and 90 DAP and results were expressed in cm.

List 1. Treatment details

Treatment	Treatment Details
T0	Control
T1	NAA (Naphthalene Acetic Acid) 25ppm
T2	NAA (Naphthalene Acetic Acid) 50ppm
T3	NAA (Naphthalene Acetic Acid) 75ppm
T4	GA3 (Gibberellic Acid) 25ppm
T5	GA3 (Gibberellic Acid) 50ppm
T6	GA3 (Gibberellic Acid) 75ppm
T7	BA (6-benzyladenine) 25ppm
T8	BA (6-benzyladenine) 50ppm
T9	BA (6-benzyladenine) 75ppm

ABBREVIATIONS

C.D. = Critical Difference
F = Fertilizer
F test S = F Test Significant
S = Spacing
SE (d) = Standard Error of Difference

2.1.2 Plant Spread (cm)

The spread of the tagged plants was recorded at 30, 60 and 90 DAP in east-west and north-south direction separately with the help of a meter scale and the average for each direction was calculated [21-25].

2.1.3 Petiole length (cm)

The petiole is the stalk of the entire leaf, but for the operation of this key this feature is applied also to the leaflet stalk of compound leaves. It is measured at 30, 60 and 90. Their average was calculated and subjected to statistical analysis.

2.1.4 Numbers of leaves per plant

Total number of leaves was counted from tagged plants in each replication at 30, 60 and 90 DAP and expressed as average number of leaves per plant.

2.2 Floral Characters

2.2.1 Days to first flowering

It was recorded after planting when 5-6 plants in each replication started to flower. The average number of days from planting date was calculated to make the observation.

2.2.2 No of flowers/plants

The total number of flowers per plant was recorded on the five tagged plants. The number of flowers was counted from first flower initiation after planting till last harvesting and the value was expressed as number of flowers per plant.

2.3 Fruit and Yield Attributes

2.3.1 Number of fruits per plant

It was recorded after planting when 5-6 plants in each replication started to fruiting. The average number of days from planting date was calculated to make the observation.

2.3.2 Number of fruits/plants

The number of fruits per plant was recorded on the same three tagged plants on which fruit set was studied. The number of fruits reaching harvestable maturity was counted at each harvest and the value was expressed as number of fruits per plant.

2.3.3 Length – diameter of the fruit (cm)

The length diameter ratio is the ratio of the flighted length of the fruit to its outside diameter of the fruit. The ratio calculation is calculated by dividing the flighted length of the fruit by its nominal diameter.

2.3.4 Fruit weight (g)

Selected fruit were harvested from each replication to measure the fruit weight. The weight was measured on electronic balance and average berry weight was calculated and expressed in grams (g).

2.3.5 Fruit length (mm)

Fruit length of 10 fruits from each treatment was taken with the help of digital vernier caliper. The average length was then worked out to record the data.

2.3.6 Fruit set (%)

For each stem, calculate the percent fruit set as follows: divide the number of fruits by the number of blossoms, then multiply by 100.

2.4 Quality Parameters

2.4.1 Total soluble solid (°Brix)

Total soluble solids (TSS) were recorded with the help of digital refractometer. Fully ripe fruits of each treatment were taken and few (2-3) drops of juice from 5 fruits were taken separately and dropped over the prism of the refractometer. The value as observed was averaged to record the TSS (°Brix).

2.4.2 Ascorbic acid (mg/100g of fresh fruits)

Ascorbic acid content was estimated by grinding 5-gram fruit pulp with 30 per cent metaphosphoric acid as buffer. The extract was filtered with muslin cloth and appropriate volume was made. A suitable aliquot was titrated against 2-6. dichlorophenol dye solution till light pink colour appeared. The result was calculated with help of following formula and expressed as milligram ascorbic acid per 100 gram of fruit pulp. (AOAC 1975)

2.4.3 Acidity (%)

Titratable acidity (% malic acid) was measured by using a standard procedure of Hortwitz (1980)

with a slight modification. For this, a known weight of the fruit sample was crushed and taken in a 100ml volumetric flask and the volume was made up by adding distilled water. Add filtration, 10 ml of the filtrate was taken in a separate conical flask and titrated against 0.1 N sodium hydroxide (NaOH) using phenolphthalein dye as an indicator. The end point was determined by the appearance of a faint pink colour. Titratable acidity was calculated by using the formula given below:

Titrable acidity (%) = Titre volume × Normality of alkali × volume made up × Equivalent weight of acid X 100 / Volume of aliquot sample × weight of sample × 1000

3. RESULTS AND DISCUSSION

Plant height, petiole length, number of leaves and plant spread all showed in the data (Table 1). Result on different PGR (NAA, GA3, BA) combination indicated that T9 {BA(6-benzyladenine) 75ppm} recorded maximum plant height (cm) of 12.56cm (30DAT), 13.22cm (60 DAT), 14.16cm (90 DAT) whereas minimum plant height (cm) of 5.95cm (30DAT), 7.54cm (60 DAT), 9.12cm (90 DAT) was recorded in T_0 (Control), recorded maximum number of leaves per plant of 4.80 (30DAT), 12.93 (60DAT), 16.33 (90DAT) whereas minimum number of leaves per plant of 2.67 (30DAT), 7.56 (60DAT), 10.54 (90DAT) was recorded in T_0 (Control). recorded maximum plant spread of 16.26cm (30DAT), 21.52cm (60DAT), 32.54cm (90DAT) whereas minimum plant spread of 6.54cm (30DAT), 10.86cm (60DAT), 18.56cm (90DAT) was recorded in T_0 (Control). recorded maximum petiole length (cm) of 8.50cm (30DAT), 10.00cm (60DAT), 12.04cm (90DAT) whereas minimum petiole length of 3.31cm (30DAT), 4.72cm (60DAT), 5.98cm (90DAT) was recorded in T_0 (Control). "When no of runners found best in treatment T9. The number of fruits, flowers, and fruit productivity all significantly increased after BA application, according to their observations of plant height, leaf count, leaf area, and fruit productivity. The evidence of, who also discovered that the application of BA greatly improves plant height, leaf area, fruit setting percentage, and the number of runners is consistent with the study's findings as well". (Qureshi et al., 2013).

Days to first flowering, number of flowers per plant, number of fruits per plant, diameters of fruit, length of fruit, fruit weight, fruit set (%) all showed in the data (Table 2). Result on different PGR (NNA, GA3, BA) combination indicated that T9 {BA(6-benzyladenine) 75ppm} recorded maximum days to first flowering 62.91 whereas minimum days to first flowering 48.66 recorded in T0 (control), and recorded maximum number of flowers per plant of 1.60 (60DAT), 4.96 (70DAT), 13.45 (80DAT) whereas minimum number of flowers per plant of 0.87 (60DAT), 2.83 (70DAT), 4.76 (80DAT) was recorded in T0 (Control). recorded maximum number of fruits per plant of 1.26 (75DAT), 4.47 (85DAT), 7.13 (95DAT) whereas minimum number of fruits per plant of 0.54 (75DAT), 2.30 (85DAT), 4.32 (95DAT) was recorded in T0 (Control), and recorded maximum diameters of fruit (cm) 3.98 cm whereas minimum diameters of fruits 2.97 cm recorded in T0 (control), and recorded maximum length of fruit 60.66 mm whereas minimum length of fruits 37.10 mm recorded in T0 (control),

Table 1. Impact of plant growth regulators on plant height (cm), Number of leaves per plant, plant spread(cm), petiole length(cm) at (30,60,90 DAT)

	Plant Height (cm)			Number of Leaves			Plant Spread (cm)			Petiole Length (cm)		
Notation	**30 Days**	**60 Days**	**90 Days**	**30 Days**	**60 Days**	**90 Days**	**30 Days**	**60 Days**	**90 Days**	**30 Days**	**60 Days**	**90 Days**
T0	5.95	7.54	9.12	2.67	7.56	10.54	6.54	10.86	18.56	3.31	4.72	5.98
T1	8.09	9.92	11.83	3.80	10.00	12.60	11.88	18.28	28.86	4.36	6.57	8.79
T2	9.06	9.20	10.99	3.20	11.40	13.40	12.28	17.54	28.84	4.77	6.74	8.89
T3	9.30	10.19	11.22	3.86	10.33	12.33	13.06	17.82	29.12	4.29	5.61	7.77
T4	10.31	10.20	12.04	3.66	11.20	13.93	14.15	19.13	30.20	4.80	6.20	8.36
T5	9.27	10.41	12.31	3.77	10.53	13.20	14.03	18.45	29.00	5.16	6.49	7.66
T6	7.43	11.40	11.41	3.73	10.80	14.00	11.94	17.14	27.63	4.57	5.98	8.02
T7	8.40	9.25	13.05	3.93	11.06	13.80	13.12	17.96	28.98	6.17	7.37	8.39
T8	7.60	11.75	13.43	4.00	11.53	14.13	11.80	19.31	26.69	7.52	9.38	11.54
T9	12.56	13.22	14.16	4.80	12.93	16.33	16.26	21.52	32.54	8.50	10.00	12.04
Sed	**0.23**	**0.20**	**0.20**	**0.24**	**0.45**	**0.62**	**0.33**	**0.47**	**0.833**	**0.38**	**0.37**	**0.37**
CD	**0.69**	**0.61**	**0.59**	**0.50**	**0.95**	**1.31**	**0.71**	**1.01**	**1.76**	**0.81**	**0.79**	**0.79**
F-Test	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**

Table 2. Impact of plant growth regulators on Days of first flowering, Number of flowers per plant at 60 days,70 days,80 days, Number of fruits per plant at 75 days,85 days,95 days, Diameters of fruit (cm), Length of fruit (mm), Fruits weight (g), Fruit set (%)

	Days to First Flowering	Number of Flower/Plants			Number of Fruits/Plants			Diameters of Fruit	Length of Fruit	Fruit Weight	Fruit Set
Notation	**Days**	**60 Days**	**70 Days**	**80 Days**	**75 Days**	**85 Days**	**95 Days**	**(cm)**	**(mm)**	**(g)**	**(%)**
T0	62.91	0.87	2.83	4.76	0.54	2.30	4.32	2.97	37.10	11.13	63.80
T1	58.08	1.13	4.33	6.80	0.86	3.93	5.87	3.20	38.60	16.55	63.83
T2	56.58	1.20	4.20	6.46	1.06	3.73	5.93	3.23	38.80	17.63	66.33
T3	55.25	1.46	4.53	6.93	1.00	3.80	6.13	3.30	40.80	19.22	77.93
T4	55.16	1.26	4.80	7.13	0.73	4.13	6.60	3.26	41.50	19.79	80.86
T5	54.83	1.33	4.39	9.85	0.66	3.66	6.73	3.39	51.50	20.48	75
T6	55.25	1.40	4.66	10.45	1.13	4.21	6.20	3.53	52.33	20.73	81.66
T7	52.72	1.35	4.85	11.32	0.98	3.76	5.45	3.76	51.83	24.39	76.66
T8	50.50	1.54	4.79	11.67	1.20	4.36	6.80	3.81	54.50	28.41	82
T9	48.66	1.60	4.96	13.45	1.26	4.47	7.13	3.98	60.66	31.55	83.10
Sed	**0.61**	**0.22**	**0.35**	**1.87**	**0.22**	**0.36**	**0.41**	**0.30**	**1.12**	**0.38**	**5.04**
CD	**0.82**	**---**	**1.46**	**3.35**	**----**	**1.34**	**1.57**	**0.91**	**2.37**	**1.14**	**10.6**
F-Test	**S**	**NS**	**S**	**S**	**NS**	**S**	**S**	**S**	**S**	**S**	**S**

Table 3. Impact of plant growth regulators on Number of fruits per plant, TSS, Acidity (%), Ascorbic acid % (mg/100g)

	Number of Fruits Per Plant	TSS (Total Solid Soluble)	Acidity	ASCORBIC ACID
Notation	**No.**	**(%)**	**(%)**	**%(mm/100g)**
T0	8.66	5.33	0.6	51.30
T1	11	8.33	0.6	53.83
T2	11.33	8.33	0.83	53.83
T3	13	8.50	0.90	54.50
T4	14	7.67	0.86	54.83
T5	11	7.83	1.03	56.16
T6	12	8.50	0.86	56.83
T7	12.66	9.50	0.80	56
T8	14	9.50	1.06	57.16
T9	16.66	10.17	1.33	58.66
Sed	**0.90**	**0.63**	**0.19**	**0.56**
CD	**1.89**	**1.32**	**NA**	**1.19**
F-Test	**S**	**S**	**S**	**S**

and recorded maximum fruit weight 31.55 g whereas minimum fruit weight 11.13 g recorded in T0 (control). “In foliar spray with BA, additional biomass may be able to generate extra metabolites during photosynthesis, which eventually sank into the producing fruits and generated berry with the most weight. In strawberries, the use of BA has been observed to boost berry weight” (Sharma and Singh, 2009). “A higher number of marketable fruits were produced as a result of the exogenous application of BA, which also indirectly affected the benzylidene metabolism and increased the fruit yield. It has also been previously documented that applying BA increases fruit yield in strawberry” (Rathod et al., 2021).

Number of fruits per plant, TSS (Total Solid Soluble), Acidity (%), Ascorbic acid (Table 3). Result on different PGR (NNA, GA3, BA) combination indicated that T9 {BA(6-benzyladenine) 75ppm} recorded maximum Number of fruits per plant 16.66 whereas minimum number of fruits per plant 8.66 recorded in T0 (control), and recorded maximum TSS (Total Solid Soluble) of 10.17% whereas minimum TSS (Total Solid Soluble) of 5.33% was recorded in T0 (Control), and recorded maximum acidity of 1.33% whereas minimum 0.60% was recorded in T0 (Control), and recorded maximum ascorbic acid % (mg/100g) 58.66% whereas minimum ascorbic acid % (mg/100g) 51.30% recorded in T0 (control), When minimum

result show in control T0. BA (6-benzyledenin) was applied to fruits, which massively improved total soluble solids and decreased titratable acidity. With foliar treatment of 75 ppm BA, the highest total soluble solid was recorded. However, in the current investigation, the control group had the lowest levels of total soluble solids. These results support those of Prasad et al. (2013), who demonstrated that BA concentrations responded favourably to a strawberry quality measure.

4. CONCLUSION

From the results obtained during the present investigation with different treatment of NAA, GA3 and {BA6-benzyladenine) 75ppm} on vegetative growth, flowering, yield and quality of strawberry (fragaria x ananassa duch) cv. (winter down), it is concluded that plants treated with Treatment T9 {BA6-benzyladenine) 75ppm} significantly increased the height of plant days to first flower, Days to first fruiting, fruit set, number of fruits per plant and fruit yield per plant. So far as the yield, the response of strawberry plants treated with T9 {BA6-benzyladenine) 75ppm} plants produced higher yield. TSS of T9 {BA6-benzyladenine) 75ppm} was higher as compared to other treatments. Total Acidity treated with {BA6-benzyladenine) 75ppm} were higher than the other treatments. Ascorbic acid titratable was recorded in plants treated with T9 {BA6-benzyladenine) 75ppm}. Treatment T9 recorded as the best treatment of yield and quality of strawberry. The B: C ratio was highest in the treatment T9 {BA6-benzyladenine) 75ppm} with (4.45).

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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