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Effect of exogenous application of gibberellic acid and 1-naphthaleneacetic acid on the growth, yield, quality and storage behaviour of Strawberry cv. Chandler under the Northeast region of India

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Abstract

Strawberry (*Fragaria annanasa* Dutch.) is a prominent fruit with a distinct fragrance, colour, and texture, as well as a high nutritional values and economical importance. It has gained prominence as a fruit of global importance. The effect of gibberellic acid and 1-naphthaleneacetic acid help to regulate growth and enhance the berries quality and extend the shelf life. The field experiment was carried out with nine treatments and three replications of GA_3 and NAA, *viz.*, 0, 25, 50, 75, and 100 ppm with control in a randomized block design (RBD). Vegetative growth attributes (plant height, number of leaves per plant, leaf area, runners per plant), flowering attributes (first flower, flowers per plant), yield and physical parameters (fruit set, fruits per plant, fruit weight, and yield) and bio-chemical attributes (total soluble solids, titratable acidity, total soluble solid/titratable acidity ratio, ascorbic acid, total sugar and anthocyanin content) were evaluated. Sensory quality, physiological loss in weight and decay loss were also analysed for determination of storage quality during 0, 1, 2, 3 and 4 days after harvesting at 25 ± 2°C and 85 ± 5% relative humidity. GA_3 significantly improved growth, yield, and quality while also extending shelf life; 1-Naphthaleneacetic acid lowered titratable acidity, and higher-dose GA_3 raised runner per plant and anthocyanin content. The results revealed that among various treatments, GA_3 at the rate of 75 ppm significantly improved the qualitative as well as quantitative traits along with storage qualities.

Introduction

Strawberry (*Fragaria × ananassa* Duch.) is an herbaceous perennial fruit crop that belongs to the Rosaceae family. It is one of the most delicious, nutritious, perishable, luscious, soft, and attractive berries among fruit crops (Chakraborty et al. 2023). It is a monoecious octaploid hybrid (2n = 8x = 56) between, *Fragaria chiloensis* Duch. and *Fragaria virginiana* Duch. (Liu et al. 2020). This fruit crop can be cultivated under protected condition (Sharma and Sharma, 2004), open fields (Chakraborty et al. 2024) and also in soilless growing substrates (Rathod et al. 2021a). Strawberry is a non-climacteric fruit, known for its rapid softening, short shelf life after harvest and quick deterioration. Strawberries are an excellent source of vitamins, containing a good amount of vitamin A (60 IU) and vitamin C (30–120 mg/100g) (Parmar et al. 2021). They are also high in minerals such as manganese, magnesium, potassium, phosphorus, calcium, and iron, as well as ellagic acid, which has anti-inflammatory, antioxidant, anti-neurodegenerative, and anti-cancer properties (Patel et al. 2022). It is propagated through runners and is red in colour due to the presence of anthocyanin, pelarogonidin, 3-monoglucoside, and traces of cyanide (Srivastav et al. 2018). The use of plant growth regulators modifies both the physical and biochemical properties of the fruits. Growth regulators such as auxin and gibberellin are used in strawberry in order to increase fruit size, improve fruit set, promote growth, and yields (Rathod et al. 2021b). Among them, auxins are applied to promote receptacle enlargement, enhance fruit size growth, and delay fruit ripening, while gibberellins inhibit the ripening process (Bisht et al. 2018).

Gibberellin treatment accelerates vegetative development and flower development, elongates the main stem internode, increases runner formation, promotes stolon formation, increases leaf area, and

increases petiole length. It also reduces the rosette habit and delays blossom initiation in strawberry (Fagherazzi et al. 2016). Gibberellic acid (GA_3) significantly enhances plant height, the number of flowers, fruit set percentage, fruit count, as well as fruit size, weight, overall quality also extends the shelf life by minimum cumulative physiological loss in weight and higher vitamin C retention (Rathod et al. 2021a; Trejo et al.2023). Naphthaleneacetic acid (NAA), a synthetic auxin, facilitates cell elongation and division, vascular tissue differentiation, root initiation, and apical dominance. Additionally, it plays a role in leaf senescence, leaf and fruit abscission, enhances fruit set, prevents fruit drop, and promotes the flower sex ratio and improving the total sugar content, ascorbic acid levels, and titratable acidity percentage (Rathod et al. 2021a). The North eastern states of India have the potential to cultivate strawberries this region offers numerous opportunities for successful strawberry farming due to its mild and favourable climate. However, no research has been conducted to determine the effect of these plant growth regulators on physical, physiological, bio-chemical as well as storage attributes of strawberry cultivar Chandler under the Northeast region of India. Therefore, this study aims to explore the application of plant growth regulators, specifically NAA and GA_3, to enhance sustainable yields and extend the storage period of the strawberry.

Materials and Methods

Experimental site and Treatment Details

The present experiment was conducted at the Experimental Field (24°48'52.4"N and 93°53'23.1"E), College of Agriculture, Central Agricultural University, Imphal, Manipur. The field was properly prepared by repeated ploughing with the help of a power tiller, and a well-rotted farm was integrated into the soil and applied recommended doses of fertilizers and during the third week of September, disease-free, healthy runners of strawberry cv. Chandler were procured from Central Farm, Lamphelpat, Central Agriculture University, Imphal, Manipur and were dipped in carbendazim (2.0 g l^{-1} water) for 10.0 min. to prevent fungal diseases before planting. The treated runners were planted at 180 cm length and 90 cm wide raised beds at 30 cm × 30 cm spacing. There were eighteen (18) plants per bed. Each bed was considered as a unit of one replication. Black polythene mulch was used as a bedding material in the raised beds of strawberries. Foliar plant growth regulator treatments consisted of 25 ppm GA_3, 50 ppm GA_3, 75 ppm GA_3, 100 ppm GA_3, 25 ppm NAA, 50 ppm NAA, 75 ppm NAA, 100 ppm NAA and only water (control) were sprayed to the strawberry plants at 30, 60 and 90 days after planting. Other cultural practices like irrigation, weeding and management of pest and diseases were carried out as and when required.

Plant Growth, Flowering, Fruiting and Quality Attributes

Five plants in each bed were randomly selected and tagged for recording the plant growth, flowering and fruiting parameters. The plant growth parameters were noted 120 days after planting. The leaf area was measured using a leaf area meter (Leaf Area Metre 211, Systronics). The TSS of strawberries was

measured using a digital refractometer (ATAGO Co., PAL-1, Tokyo, Japan). The biochemical properties of fruits were determined according to the method described by AOAC (2006). Anthocyanin pigmentation was measured in (spectrophotometer 166, Systronics) absorbance units/g of fresh fruit at 530 nm and expressed in mg per 100g as per the method described by Ranganna (2007).

Storage Attributes

Post-harvest storage studies were carried out up to 4 days after harvestings of fruits to assess the effect of preharvest treatment on shelf life and quality of strawberries. Sixty (60) fruits with similar maturity, size, shape, and no damage were chosen for the experiment and separated into three groups as replicates. They were packaged in transparent plastic boxes and stored at ambient conditions (26 ± 2°C and 80 ± 5% RH). The TSS and TA were analysed day to day during the storage period. The physiological loss in weight (PLW) in percentage was determined as the variation between the initial weight and the weight at the moment of measurement. Fruit decay percentage was calculated by counting the number of fruits with visible mould lesions on the surface (Gonçalves et al. 2010).

Statistical Analysis

The statistical data obtained from the field experiments were analyzed in randomised block design (RBD) with nine treatments and each treatment was replicated thrice. The storage studies of strawberries were designed in factorial completely randomised design (CRD) with three replication and analysed with the help of analysis of variance to test the significance at 5.0% level of significance with the help of R studio.

Results and Discussion

Plant Growth and Flowering Attributes

The exogenous application of gibberellic acid and 1-naphthaleneacetic acid significantly affected the growth and flowering of strawberries (Table 1). The maximum plant height (35.63 cm), plant spread (32.23 cm) number of leaves (39.80), and leaf area (23.27 cm^2) were recorded from plants treated with 75 ppm GA_3. All these parameters were noted minimum in control plants. Gibberellins known to stimulate the cell division and cell elongation processes. Exogenous application of gibberellins also reported to be increased the endogenous auxin synthesis in the plant system (Liu et al.2022; Gulzar et al. 2025). Gibberellic acid promotes shoot development by down regulating the growth suppressor DELLA proteins (Davière and Achard, 2016). The increase in leaf number and leaf area with the application of gibberellic acid might be linked to the increased cell division and cell elongation of the epidermal and parenchyma cells that present in sub-apical meristems. Further, gibberellic acid is reported to be helped in the expansion of leaf area (Ritonga et al.2023). Similar type of findings was also reported in strawberry (Rathod et al.2021a). The maximum number of runners (12.40) were produced by the plants

treated with 100 ppm GA_3. More number of leaves and larger leaf area in GA_3 treated plants were responsible for synthesis of more photosynthates and that promoted the production of more runners (Rathod et al.2021a). Further, differentiation of axillary buds following gibberellic acid treatment might also be responsible for production of more runners per plant (Black, 2004). The plants received foliar application of 100 ppm GA_3 resulted earliest flowering within 109 days after planting. Application of gibberellic acid reported to be reduced the required for flower emergence in strawberry (Paroussi et al. 2002). The number of flowers per plant found maximum (29.87) in the plants treated with 75 ppm GA_3. The increase in the number of flowers with the application of gibberellin might be related to the rapid growth of inflorescence that increased the number of blooms per plant (Paroussi et al. 2002). Similar findings were also reported earlier in strawberry (Rathod et al.2021a).

Table 1
Effect of plant growth regulators on plant growth and flowering of strawberry cv. Chandler

Treatments	**Plant height (cm)**	**Plant Spread (cm)**	**Leaves per plant**	**Leaf area (cm^2)**	**Runners per plant**	**Flowers per plant**	**Days taken to first flowering (Days)**
25 ppm GA_3	30.17^{b}	28.97^{a}	36.60^{bc}	20.76^{b}	9.47^{c}	28.60^{c}	111.27^{e}
50 ppm GA_3	32.47^{ab}	30.82^{a}	36.80^{bc}	20.88^{b}	11.20^{b}	28.93^{bc}	111.53^{e}
75 ppm GA_3	35.63^{a}	32.23^{a}	39.80^{a}	23.27^{a}	12.17^{a}	29.87^{a}	112.00^{de}
100 ppm GA_3	34.73^{ab}	32.21^{a}	38.80^{ab}	21.15^{b}	12.40^{a}	29.47^{ab}	109.00^{e}
25 ppm NAA	20.43^{c}	24.30^{b}	38.40^{ab}	21.48^{b}	7.60^{d}	28.40^{c}	114.80^{cd}
50 ppm NAA	21.77^{c}	23.83^{b}	38.20^{ab}	19.13^{c}	6.87^{de}	27.47^{d}	116.67^{c}
75 ppm NAA	20.23^{c}	22.33^{b}	35.47^{cd}	19.31^{c}	6.50^{e}	27.27^{d}	117.53^{c}
100 ppm NAA	19.74^{c}	21.93^{b}	34.00^{d}	19.25^{c}	6.40^{e}	26.93^{d}	122.13^{b}
Control (Water Spray)	14.80d	21.18^{b}	30.40^{e}	13.62^{d}	7.67^{d}	22.27^{e}	127.33^{a}
S. Ed (±)	2.15	1.92	0.97	0.60	0.44	0.27	1.35
$CD_{0.05}$	4.55	4.07	2.07	1.26	0.94	0.57	2.87

Mean with the same letter within column are not significant by DMRT test at $p < 0.05$, S. Ed (±), Standard Error of Difference

Fruiting Attributes

The maximum fruit set percentage (84.38%), number of fruits per plant (25.31) per plant, fruit weight (12.61 g), yield per plant (312.17g) and yield per hectare (34.72 tons) were found in the plants treated with 75 ppm GA_3 (Table 2). The increase fruit set owing to the gibberellin's treatment might be related to the rapid growth of inflorescence, which might also increase the fruit set (Paroussi et al.2002). Inflorescence development might had led to enhance flower production and thereby increased the number of flowers that were acquired with the spray of gibberellic acid (Rathod et al.2021a). Application of GA_3 increased the number of fruits per plant, weight, and yield by accelerating the translocation and mobilization of stored photosynthates or their metabolites from source to sink (Sekhar et al.2016). Therefore, photosynthate partitioning across competing sink fruits on the same inflorescence may be determined by the sink strength and sink dominance of each fruit (Hidaka et al.2019). Increase in number of fruits, fruit weight and yield of strawberry with the application of gibberellic acid were also reported earlier in the cultivar Winter Dawn (Rathod et al.2021a).

Table 2
Effect of plant growth regulators on fruiting of strawberry cv. Chandler

Treatments	Fruit set (%)	Fruits per plant	Fruit weight (g)	Fruit yield	
				Per plant (g)	Per ha (ton)
25 ppm GA_3	82.99^{ab}	23.84^{bc}	12.19^{ab}	284.03^{b}	31.59^{b}
50 ppm GA_3	83.19^{ab}	24.17^{b}	12.13^{ab}	286.67^{ab}	31.88^{b}
75 ppm GA_3	84.38^{a}	25.31^{a}	12.61^{a}	312.17^{a}	34.72^{a}
100 ppm GA_3	83.26^{ab}	24.64^{ab}	12.24^{ab}	295.01^{ab}	32.81^{ab}
25 ppm NAA	80.98^{bc}	23.11^{c}	12.51^{a}	283.02^{b}	31.48^{b}
50 ppm NAA	80.58^{bc}	22.24^{d}	12.39^{ab}	269.44^{bc}	29.97^{bc}
75 ppm NAA	79.73^{c}	21.84^{d}	11.72^{ab}	250.76^{cd}	27.89^{cd}
100 ppm NAA	79.21^{c}	21.44^{d}	11.29^{b}	236.26^{d}	26.28^{d}
Control (Water Spray)	73.96^{d}	16.57^{e}	8.59^{c}	137.71^{e}	15.33^{e}
S. Ed (±)	1.17	0.36	0.49	11.91	1.32
$CD_{0.05}$	2.48	0.77	1.03	25.26	2.81

Mean with the same letter within column are not significant by DMRT test at $p < 0.05$, S. Ed (±), Standard Error of Difference

Fruit Quality Attributes

The exogenous application of plant growth regulators had a significant effect on fruit quality of strawberry (Table 3). The findings reflected that foliar application of 75 ppm GA_3 resulted maximum TSS (14.15 ° B) in strawberry fruits. Total soluble solids levels might be raised due to increase in volatile compounds and hydrolysis of starch (Basak et al.2022). The lowest titratable acidity (1.01%) was noted in the fruits from the plants treated with 75 ppm NAA. The reduction in titratable acidity could be related to the conversion of larger quantities of organic acids and photosynthates into sugars during the fruit ripening stage in GA_3 treated plants (Mastuane et al.2016). The fruits with the highest ascorbic acid content (64.37 mg/100 g) were harvested from the plants treated with 75 ppm GA_3. The improvement in the ascorbic acid content of strawberry in GA_3 treated plants might be due to increase the activities of enzymes responsible for ascorbic acid biosynthesis or by downregulating the activity of the ascorbate oxidase (Netam and Sharma, 2014). Higher ascorbic acid with the application of gibberellic acid has also been reported in cape gooseberry (Kumar et al.2017). The maximum reducing sugar (5.08%) and total sugar (7.69%) were recorded in the fruits from the plants treated with 75 ppm GA_3. Gibberellins application is known to enhance the activities of αamylase and invertage (Pérez and Gomez, 2000). Higher activity of these enzymes converted the starchy polysaccharides of strawberry fruits into simple sugars and resulting in higher total sugar content in GA_3 treated plants (Tripathi and Shukla 2007). However, the non-reducing sugar (2.96%) was found maximum in the fruits from the 100 ppm GA_3 treated plants. Higher metabolic changes in the fruits might responsible for enhanced non-reducing sugar content in 100 ppm GA_3 treated plants (Paikra et al.2018). The highest anthocyanin content (35.41 mg/100g) of fruits was recorded in the plants treated with 100 ppm GA_3. Increased anthocyanin content with the application of gibberellic acid was also reported in grape fruit (Zhou et al.2024).

Table 3
Effect of plant growth regulators on fruit quality of strawberry cv. Chandler

Treatments	TSS (°B)	Titratable acidity (%)	Ascorbic acid (mg 100 g^{-1})	Reducing sugar (%)	Non-reducing sugar (%)	Total sugar (%)	Anthocyanin (mg 100 g^{-1})
25 ppm GA_3	12.98c	1.35a	61.03c	4.78b	2.45c	7.37c	28.80bcd
50 ppm GA_3	13.70b	1.28b	62.77b	4.64bc	2.74abc	7.52bc	30.44b
75 ppm GA_3	14.15a	1.26b	64.37a	5.08a	2.81ab	8.04a	31.60b
100 ppm GA_3	13.00c	1.36a	61.15c	4.57bc	2.96a	7.69b	35.41a
25 ppm NAA	12.60d	1.05de	60.42c	4.44cd	2.80ab	7.38c	26.26cd
50 ppm NAA	12.10e	1.07cd	59.78c	4.41cd	2.64bc	7.19d	28.10bcd
75 ppm NAA	11.70g	1.01e	59.81c	4.30d	2.44c	6.89e	29.32bc
100 ppm NAA	11.82f	1.11c	59.75c	4.43cd	2.42c	7.02e	28.77bcd
Control (Water Spray)	8.85h	1.38a	51.88d	3.98e	2.03d	6.12f	25.33d
S. Ed (±)	0.06	0.02	0.63	0.11	0.14	0.08	1.56
$CD_{0.05}$	0.12	0.05	1.33	0.24	0.29	0.17	3.30

Mean with the same letter within column are not significant by DMRT test at $p < 0.05$, S. Ed (±), Standard Error of Difference

Storage Attributes

It is evident from the Fig. 1 that physiological loss in weight (A) and fruit decay (B) were increased steadily upto second day of storage, then a rapid increase of these parameters was noted in ambient storage. Fruits harvested from the plants treated with 75 ppm GA_3 resulted least changes in both physiological loss in weight and decay upto end of storage period. The most rapid loss of physiological weight and decay of fruits were recorded in fruits from the control plants. The reduction in physiological weight loss and decay with the pre-harvest application of GA_3 could be attributed to its capacity to retain more water, countering the effects of evaporation. Gibberellic acid is known to act as an anti-aging and anti-respiration agent and supress the catabolic processes of ripening related changes and resulting in

minimum loss in physiological weight (Zhang et al.2018). Strawberry is a highly perishable fruit. Under ambient condition, decay rate of strawberry is reported to be 15.20 per cent on just one day after harvest and the rate might went up to 99.40 per cent within storage period of four days (Rahman et al.2016). Fruit decay of strawberry sis primarily caused due to pathogens like *Botrytis*, *Mucor*, *Colletotrichum*, *Penicillium* and many others (Feliziani and Romanazzi, 2016). Gibberellic acid might have a substantial impact on the structural integrity of the fruit's cuticular layer and pores present in the fruit skin that prevented the entry of such decay causing pathogens in strawberry (Aghdam et al.2018).

The results demonstrated in Fig. 1indicated a progressive increase in total soluble solid (C) during the storage period, while acidity content (D) of the fruits decreased steadily. Maximum TSS was recorded in the fruits that were harvested from the plants received foliar application of 75 ppm GA_3 during storage. The increase in TSS might be due to activation of enzymes such as α-amylase and β-amylase that hydrolyzed the starch and raised the TSS level. The least changes in acidity content in 75 ppm GA_3 treated strawberries indicating slower rate of ripening related changes such as respiration (Rahman et al.2016).

Conclusion

This study revealed that foliar application of 75 ppm GA_3 was beneficial for improvement of growth, maximizing the yield and enhancement of fruit quality. Additionally, this foliar treatment is also helpful during ambient storage of strawberries.

Declarations

Author Contribution

Alok Singh: Conceptualization, Methodology, Experimentation, Formal Analysis, Writing Original Draft; Ngangbam Piloo: Mentoring, Validation, Supervision; Ajay Kumar: Review and editing, Validation; Alok Kumar Gupta: Formal Analysis, Writing; Sanasam Angousana: Review and editing, Software, Validation; Alok Kumar: Data collection,

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Figures

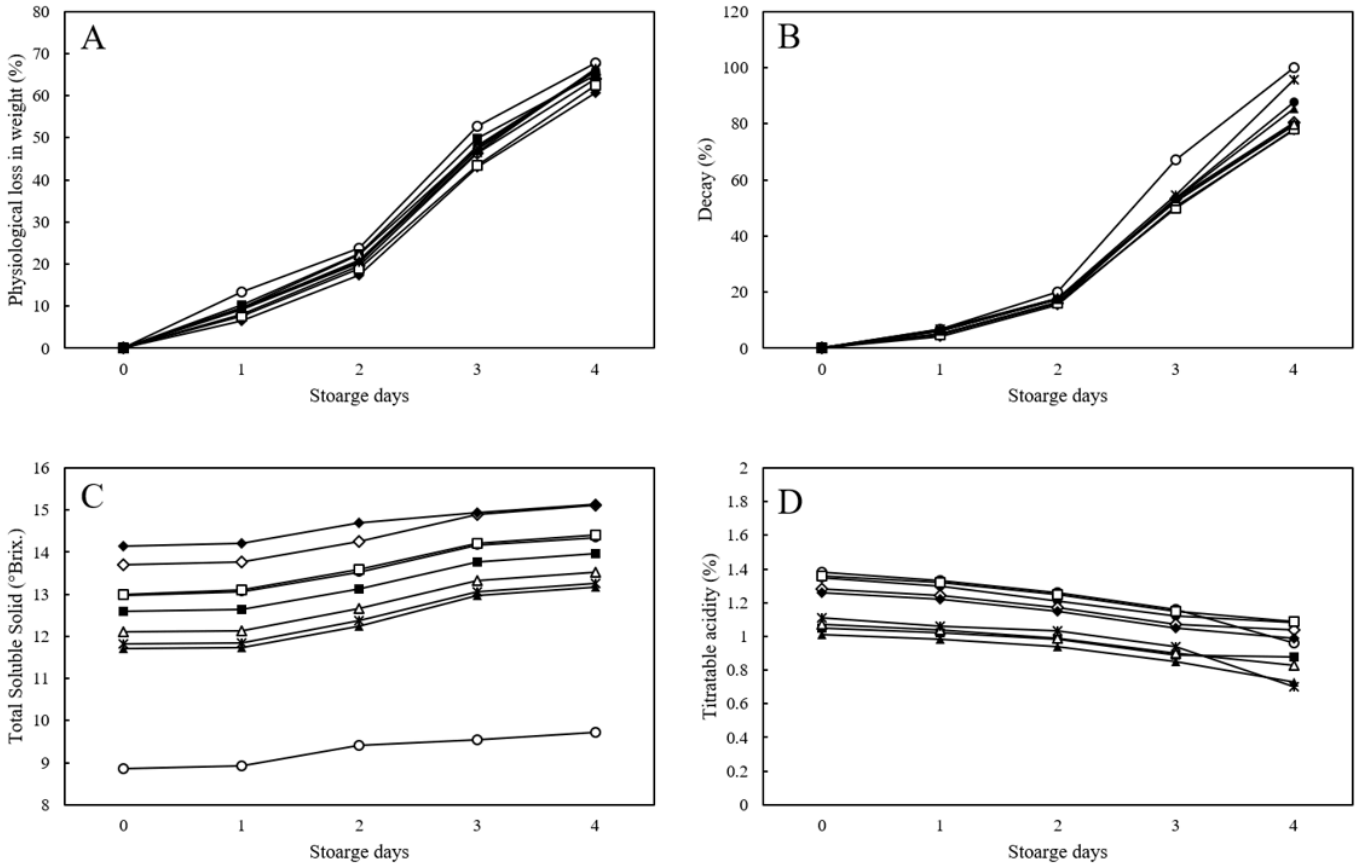


Figure 1

Storage behaviour of strawberry cv. Chandler upto fourth day of ambient storage. A: Changes in physiological loss in weight, B: Decay, C: Total Soluble Solid, D: Titratable acidity.