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Enhancing Quality and Yield of Strawberry Through Chemical and Mechanical Interventions

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ABSTRACT

Fruits are integral to human nutrition, offering essential nutrients that contribute to health and well-being. Strawberries (Fragaria × ananassa), a prominent member of the Rosaceae family, represent a significant agricultural commodity, particularly in temperate climates such as Himachal Pradesh, India. Despite their broad adaptability and considerable health benefits including high levels of vitamin C, fiber, and potassium, and antioxidants, Strawberry cultivation is beset by challenges such as climate variability, water scarcity, and postharvest losses attributable to their perishable nature. This paper examines effective chemical growth regulators and mechanical techniques that can enhance the quality and yield of strawberry production. The findings and discussions presented in this paper underscore the necessity of employing integrated strategies that encompass both chemical and mechanical interventions to enhance strawberry quality and production. Through the adoption of growth regulators and improved pollination methods, coupled with sustainable agricultural practices, the challenges facing strawberry cultivation can be mitigated, ultimately leading to a more robust and health promoting fruit supply.

Keywords: Mulching, Aggregate fruit, Induced pollination, Randomised Block Design, Critical Difference

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INTRODUCTION

Fruits serve as a vital component of the human diet, offering essential nutrients that promote health and well-being. Humans consume fruits not only for their flavor and visual appeal but also to satisfy their nutritional needs. Fruits exhibit a variety of organoleptic and chemical properties that are crucial for supplying the necessary nutrients and growth factors essential for maintaining optimal health. The strawberry (Fragaria × ananassa) is a widely cultivated hybrid species within the Rosaceae family, comprising 20 naturally occurring hybrid varieties (Hummer et al., 2011). The etymology of the term "strawberry" is believed to stem from the practice of growers covering their plants with straw, as the berries began to form. This delectable red fruit is characterized by its unique flavor, which is influenced by three principal components: sugars (approximately 0.5%), acids (0.90-1.85%), and aromatic compounds (Sahana et al., 2020).

The modern cultivated strawberry originate from the hybridization of two North American species: Fragaria chiloensis and Fragaria virginiana. Fresh strawberries are distinguished by their alluring aroma, vibrant light red color, juicy texture, and delightful sweetness, all of which contribute to their exceptional sensory appeal (Sharma and Godara, 2020).

Strawberries are not only enjoyable and flavorful but also nutrient-rich, containing high levels of vitamin C, fiber, potassium, and antioxidants, which are linked to numerous health benefits (Paikra et al., 2020). Originally limited to temperate climates, strawberries have demonstrated remarkable adaptability, thriving in diverse climatic conditions due to their genetic diversity, high heterozygosity, and broad climatic tolerance. In India, strawberry cultivation has gained significant traction, particularly in the temperate regions of Himachal Pradesh, which account for over 90% of the country's total strawberry production.

Despite their global popularity, strawberry cultivation faces several challenges, including climate change, water scarcity, and the need for sustainable farming practices. Due to their perishable nature and susceptibility to mishandling, substantial quantities of fruit are often lost throughout the supply chain, resulting in significant waste of their health-promoting compounds. Additionally, maintaining fruit quality and size presents ongoing challenges for strawberry producers. However, various growth regulators have been found effective in enhancing different aspects of strawberry plant and fruit development. For instance, gibberellic acid has been shown to stimulate growth characteristics including

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plant height, canopy spread, leaf area, petiole length, and stem elongation, while also promoting higher fruit quality, earlier flowering, and premature berry harvesting. Similarly, the growth inhibitor chlormequat chloride has been reported to manage excessive vegetative growth, enhance root development, and improve yield and fruit quality (Roussos et al., 2009). Natural growth stimulant triacontanol has also demonstrated efficacy in enhancing root mass and length, facilitating early maturity, and reducing fruit drop in strawberry crops, while acting as a promoter of photosynthesis and an enzyme activator to improve fruit sugar content (Klatt et al., 2013).

Strawberry flowers possess both male and female reproductive organs, making pollination crucial for fruit formation, despite the edible portion not arising from the ovary. Strawberry fruits are classified as aggregate fruits, and their flowers have a poly-carpellary, apocarpous structure. Each individual pistil must undergo pollination, as any un-pollinated pistil will compromise fruit development. Adequate pollination is imperative for producing strawberries of optimal size, shape, and quality; moreover, insect pollination can enhance fruit quality and prolong shelf life (Klatt et al., 2013). Insufficient pollination can lead to smaller or misshapen berries, thereby reducing the yield of marketable

MATERIALS AND METHODS

Location of Experiment and Cultural Operations

The experiment was conducted at the agricultural fields of the Department of Agriculture, Sant Baba Bhag Singh University, during the 2023–2024 growing season. This site is situated in the Bist Doab region of northeastern Punjab and falls under the jurisdiction of the Jalandhar revenue division. Prior to planting strawberries, the experimental plot underwent thorough preparation, including initial ploughing followed by leveling with a plank to create an optimal seedbed. All weeds, residual plant material, and debris were meticulously removed to ensure a clean environment for planting. To maintain uniform water distribution throughout the plot, proper leveling techniques were employed. A recommended dose of nitrogen fertilizer, in the form of urea, was applied in two installments: 50% before transplantation and 50% afterward. Manual weeding was conducted periodically to manage competing flora, and irrigation was provided based on the specific water requirements of the crop.

Planting Material

Strawberry saplings of Chandler cultivar, recognized for its elevated yield and superior fruit quality, were procured from a certified nursery in Jammu to serve as the planting material. The particular cultivar is well-established in the Jalandhar climatic zone, which justifies its selection for this study.

Treatments

A. Chemical Strategies

This study evaluated several chemical strategies utilizing four growth regulators: Gibberellic Acid (GA3), Naphthalene Acetic Acid (NAA), Triacontanol (TRIA), and Chlormequat Chloride (CCC), each applied at a concentration of 75 ppm. The application occurred through foliar spray, conducted on two occasions: once during the early growth stage and again just prior to flower initiation.

Gibberellic Acid (GA3) is a di-terpenoid plant growth regulator known for its role in facilitating various developmental processes in plants, including enhancement of fruit set, increase in plant height, improved fruit retention, and promotion of fruit enlargement.

Naphthalene Acetic Acid (NAA) acts as an auxin-like growth regulator and positively influences fruit set and retention, both of which are vital for maximizing yield.

Triacontanol (TRIA), a long-chain aliphatic alcohol, is recognized for its ability to enhance overall plant growth and photosynthetic efficiency.

Chlormequat Chloride (CCC) is categorized as a plant growth regulator with growth-retarding properties, effectively limiting excessive elongation in plants; while it is primarily used to regulate vegetative growth, it also contributes to the enhancement of flowering processes.

B. Mechanical Strategies

The mechanical strategies employed in this study included mulching and various modes of pollination.

Mulching serves a range of agronomic functions, including soil moisture conservation, weed suppression, and temperature regulation. Several pollination techniques, such as self-pollination, wind pollination, natural pollination, and manual pollination, were evaluated to determine their effects on yield and fruit quality in strawberry plants.

Self-pollination was facilitated by covering flower buds with butter paper bags (Fig.1A).

Wind pollination, flower buds were enclosed in cloth bags to prevent insect intrusion while allowing airflow (Fig.1B).

Natural pollination leverages the ecosystem services provided by pollinator fauna (e.g., bees and other insects) to enhance fruit set and quality (Fig.1C).

Manual (induced) pollination involved using fine brushes during peak flowering periods to ensure thorough pollination of all pistils. Pollen grains from mature anthers were collected on watch glasses and subsequently applied to the stigmas of selected flowers using the brush technique. This treatment involved manual pollination in addition to natural pollination (Fig.1A).Additionally, the study examined the synergistic effects of combining GA3, natural pollination, mulching, and induced pollination techniques.

Experimental Design

A randomized block design (RBD) was employed, with the treatments given in Table 1. Each treatment was replicated three times, resulting in a total of 33 experimental units.

Statistical Analysis

The data were subjected to analysis of variance (ANOVA) using statistical software [OPSTAT, HAU] to determine the significance of treatment effects, with means compared using Tukey's HSD test ($p<0.05$).

This detailed methodology focuses on enhancing strawberry quality and yield through the strategic application of chemical growth regulators, effective pollination techniques, and sustainable practices using mulching. The combination of these methods aims to provide a comprehensive approach to address the challenges faced in strawberry cultivation.

Table 1: Summary of Treatments

Sr. No.	Treatment Code	Treatment Detail
1	T1	GA3 spray 75 ppm
2	T2	NAA spray 75 ppm.
3	T3	TRIA spray 75 ppm
4	T4	CCC spray 75 ppm.
5	T5	Mulching with black polythene Mulch.
6	T6	Self-pollination.
7	T7	Wind pollination.
8	T8	Natural Pollination
9	T9	Mechanical (Induced) pollination
10	T10	GA3, Mulching, Natural and Induced pollination

Fig. 1A: Flowers covered with Butter paper bag (self-pollination)

Fig. 1B: Flowers covered with net cloth bag (Wind pollination)

Fig. 1C : Insect pollination

Fig. 1D: Induced pollination

RESULTS AND DISCUSSION

Observation Recording and Measurement Methodology

Flowering and Fruit Development Evaluation

Number of Flowers per Plant: A total of ten distinct plants were assessed to quantify the floral production during each flowering flush throughout the cropping season. The average number of flowers per plant was subsequently calculated.

Number of Fruits per Plant: Post-flowering, a systematic evaluation of ten selected plants was conducted to determine the total number of developing fruits at 15-day intervals. The cumulative counts were utilized to calculate the overall yield per plant after all harvesting activities.

Pollination Success: Flower-to-fruit set ratio was calculated to gauge pollination efficiency. The data relating to the role of Flowering and Fruit Development Evaluation are presented in Table 2.

Table 2: Effect of treatments on pollination success rate

Sr. No.	Treatment	No. of Flowers per plant	No. of Fruits per plant	Pollination Success rate (%)
1	T1 (GA_3)	22.00 ±0.57	18.66 ±0.33	84.96 ±2.76
2	T2 (NAA)	19.00 ±0.58	14.67 ±0.34	77.30 ±1.10
3	T3 (TRIA)	17.00 ±0.57	13.33 ±0.33	78.49 ±1.40
4	T4 (CCC)	16.00 ±0.57	12.67 ±0.33	79.24 ±1.43
5	T5 (Mulching)	20.33 ±0.33	16.33 ±0.67	80.31 ±2.90
6	T6 (Self Pollination)	14.33 ±0.66	11.66 ±0.33	81.55 ±1.55
7	T7 (Wind Pollination)	14.66 ±0.67	11.67 ±0.67	79.46 ±0.89
8	T8 (Natural Pollination)	16.00 ±0.57	12.67 ±0.33	79.24 ±1.43
9	T9 (Induced Pollination)	17.66 ±0.33	15.66 ±0.34	88.77 ±3.11
10	T10 (T1+T5+T8+T9)	25.33 ±0.66	23.67 ±0.33	93.58 ±3.39
	C.D. (P<0.05)	**1.16**	**0.97**	**6.80**

The highest number of flowers per plant (25.33) was counted in treatment T10 followed by T1, T5. Similar trend was found in case of number of fruits. Pollination success rate was highest in treatment T10 (93.58), followed by T9 and T1. The results depicted that more flowers got converted into fruits where artificial pollination was involved. GA3 treatment also significantly increased high pollination success rate. Saima et al. (2014) recorded that application of GA3 75 ppm resulted in higher yield, flower per plant and number of berries. Lata et al. (2018) studied different modes of pollination on fruit set and found that among the different modes of pollination studied, maximum fruit set was seen in cross-pollination, followed by hand and open pollination, whereas least fruit set was registered in self-pollination.

Yield and Yield-Attributing Characteristics

Fruit Length (cm): Fruit lengths were measured using vernier calipers on a sample of ten randomly selected plants from each plot.

Fruit Width (cm): The breadth of ten fruits from each treatment replication was recorded using vernier calipers, with data expressed in centimeters.

Fruit Weight (g): Fruits from ten individual plants were selected from each replication and weighed individually using an electronic balance. The average fruit weight was calculated and expressed in grams.

Yield per Plant (kg): At each harvest, the total yield of each plant was quantified by weighing and counting the harvested fruits, with results documented in grams.

Yield (q/ha): The cumulative fruit yield from each plant was assessed and converted to a quintal per hectare basis. This assessment was performed for each plot individually, followed by an average yield calculation.

Table 3: Effect of treatments on fruit characteristics

Sr. No.	Treatment	Fruit Length (cm)	Fruit Breadth (cm)	Fruit Weight (g)
1	T1(GA_3)	3.70 ±0.05	2.63 ±0.08	12.93 ±0.03
2	T2 (NAA)	3.16 ±0.03	2.33 ±0.08	8.50 ±0.15
3	T3 (TRIA)	3.33 ±0.03	2.30 ±0.05	9.93 ±0.12
4	T4 (CCC)	3.13 ±0.08	2.50 ±0.05	8.73 ±0.08
5	T5 (Mulching)	3.90 ±0.05	2.80 ±0.11	11.56 ±0.12
6	T6 (Self Pollination)	2.63 ±0.08	2.06 ±0.08	5.23 ±0.12
7	T7 (Wind Pollination)	2.86 ±0.06	2.10 ±0.05	5.66 ±0.08

8	T8 (Natural Pollination)	3.20 ±0.05	2.73 ±0.03	12.46 ±0.03
9	T9 (Induced Pollination)	4.20 ±0.05	3.26 ±0.08	4.96 ±0.08
10	T10 (T1+T5+T8+T9)	4.83 ±0.06	3.53 ±0.03	16.50±0.03
	C.D. (P<0.05)	**0.186**	**0.24**	**0.29**

The data outlined in the table 3 show that fruit length and fruit width are linked with fruit weight. It is clearly seen that fruit length and breadth are highest in treatment T10 and correspondingly fruit weight is highest with this treatment. The second best treatment is T9 in terms of fruit size and weight. In this treatment pollination rate was enhanced through induced pollination. Negi et al. (2018) also found that Cross pollination had profound role in increasing fruit quality in terms of fruit length and breadth indicating necessity of compatible pollinizers and pollinators to ensure adequate quality and yield in strawberry field. In our study we found that self-pollination decreased fruit size and weight. Similarly Klatt et al. (2013) concluded that self-pollination decreased the commercial value per fruit by 54.3% as compared with bee pollination (Klatt et al., 2013).

Table 4: Effect of treatments on pollination success rate

Sr. No.	Treatment	Yield /Plant (g)	Yield/Plot (kg.)	Yield/Hectare (t)
1	T1 (GA3)	241.40 ±3.70	6.99 ±0.11	11.65
2	T2 (NAA)	124.76 ±5.00	3.61 ±0.14	6.01
3	T3 (TRIA)	132.36 ±1.75	3.83 ±0.05	6.38
4	T4 (CCC)	110.66 ±3.80	3.20 ±0.11	5.33
5	T5 (Mulching)	188.76 ±5.90	5.66 ±0.17	9.43
6	T6 (Self Pollination)	61.13 ±3.08	1.83 ±0.09	3.05
7	T7 (Wind Pollination)	64.30 ±5.51	1.93 ±0.16	3.21
8	T8 (Natural Pollination)	157.90 ±3.96	4.68 ±0.16	7.80
9	T9 (Induced Pollination)	234.43 ±4.07	15.66 ±0.34	11.71
10	T10 (T1+T5+T8+T9)	390.53 ±6.70	23.67 ±0.33	17.25
	C.D. (P<0.05)	**11.14**	**1.15**	**1.92**

Quality Attributing Parameters

Total Soluble Solids (%): A sample of fruits from ten different plants in each replication was weighed using an electronic balance. The average fruit weight was recorded prior to determining the percentage of total soluble solids with the help of Brix refractometer.

pH of Juice: The pH of extracted fruit juice was measured using a calibrated digital pH meter. Calibration was conducted using standard pH buffer solutions to ensure measurement accuracy before initiating the pH.

Titrable Acidity of juice: It was measured from the juice extracted from selected fruits.

Table 5: Effect of treatments on fruit Quality characters

Sr. No.	Treatment	pH	TSS	Titrable Acidity
1.	T1 (GA3)	3.80 ±0.05	8.76 ±0.12	0.87 ±.006
2	T2 (NAA)	3.43 ±0.08	7.96 ± 0.08	0.75 ±.006
3	T3 (TRIA)	3.03 ±0.12	7.50 ±0.05	0.64 ±.009
4	T4 (CCC)	3.00 ±0.05	7.30 ±0.17	0.69 ±.006
5	T5 (Mulching)	4.00 ±0.06	9.00 ±0.11	0.89 ±.009
6	T6 (Self Pollination)	2.70 ±0.10	6.20 ±0.05	0.57 ±.009
7	T7 (Wind Pollination)	3.03 ±0.12	6.33 ±0.03	0.58 ±.012
8	T8 (Natural Pollination)	3.90 ±0.05	7.16 ±0.12	0.89 ±.009
9	T9 (Induced Pollination)	4.13 ±0.03	8.90 ±0.05	0.94 ±.012
10	T10 (T1+T5+T8+T9)	4.26 ±0.12	9.50 ±0.25	0.98 ±.012
	C.D. (P<0.05)	**0.27**	**0.39**	**0.027**

The data presented in all Tables including Table 4 and 5 indicate that treatment T10, which comprises a combination of GA3 application, mulching, natural pollination, and induced pollination, exhibited superior outcomes across all evaluated parameters, including flower and fruit count per plant, pollination success rate, fruit dimensions (length and breadth), and fruit weight. Treatments T1 (GA3 application), T5 (mulching), and T8 (natural pollination) also yielded favorable results. Conversely, self-pollination and wind pollination demonstrated significantly inferior performance. Prasad et al. (2012) conducted experiments across various strawberry cultivars and reported favorable results associated with GA3 treatment and black mulch in relation to plant height, flower count, fruit yield, and overall productivity. Tables 4 and 5 illustrate the effects of varied treatments on quality and yield parameters. Once again, treatment T10, characterized by a synergistic interaction of GA3, mulching, natural pollination, and induced pollination, achieved the highest performance metrics.

The results further indicate that treatments employing GA3, mulching, natural pollination, and induced pollination, when applied individually, closely approached the efficacy of treatment T10, significantly enhancing both the quality and yield of strawberries. Quality parameters such as Total Soluble Solids (TSS) and titratable acidity were comparable across the treatments involving GA3, mulching, natural pollination, and induced pollination. Treatment T10 (a composite of treatments T1, T5, T8, and T9) markedly increased yield relative to other treatments, followed by T9, T1, and T5. In contrast, treatments T6 (self-pollination) and T7 (wind pollination) yielded markedly poor results.

Among the chemical treatments, GA3 application at 75 ppm, administered twice, was the most effective. While treatments employing other plant growth regulators (PGRs) such as NAA, TRIA, and CCC resulted in some improvements across various parameters, these improvements did not reach the magnitude of those observed with GA3. From the perspective of mechanical treatments, induced pollination and mulching were identified as particularly effective, whereas self-pollination and wind pollination were shown to be least effective.

Previous studies have corroborated similar findings. Rajbhar et al. (2015) reported that a combination of GA3 at 100 ppm and vermicompost at 100 q/ha resulted in enhanced TSS (10.68 ºBrix) in the strawberry variety Douglas. Kumar et al. (2012) noted optimal fruit length-diameter ratios (1.28 cm), juice content (87.35%), and TSS (9.07%) associated with GA treatment. Kumar et al. (2022) investigated the effects of mulching and GA3 application on strawberry and reported optimal outcomes for flower count, fruit count, and fruit weight attributable to these treatments. Furthermore, Gudowska (2024) established that pollinators significantly enhance the production of superior strawberries, while Menzel (2023) highlighted that fruit set in strawberries is moderately reliant on insect pollinators and is constrained by the availability of pollen under natural open conditions.

CONCLUSION

The floral architecture of Fragaria spp. (strawberries) encompasses several critical components integral to reproductive success and fruit maturation. The flower is polycarpellary and apocarpous: each flower bears many free carpels (ovaries) surrounded by multiple stamens. Strawberries are aggregate accessory fruits—the fleshy receptacle enlarges around numerous achenes, which are the true fruits enclosing the seeds. A strong correlation exists between fruit weight and the production of achenes; specifically, an increase in the number of achenes correlates with increased fruit weight Therefore, it is evident that every individual pistil must undergo pollination for optimal seed/berry development. Research reveals that self-pollination and anemophily often fail to adequately pollinate all pistils, resulting in the development of smaller, lighter, and malformed fruits with reduced commercial viability. On the other hand plants subjected to natural pollination methods supplemented by artificial pollination techniques markedly improves fruit size, weight, and overall quality. Gibberellic acid (GA3) is a potent growth regulator that can increase growth, photosynthesis, and fruit quality; mulching helps to optimize soil moisture and temperature. In trials, GA3 at 75 ppm with black mulch produced superior growth, higher fruit weight, and better quality. Treatment T10—GA3 (75 ppm) plus black mulch, natural pollination, and manual pollination—performed best for size, yield, and quality. Thus, integrating natural and supplemental pollination with GA3 application (75 ppm) and mulching is recommended to maximize strawberry fruit quality and economic returns.

CONFLICT OF INTEREST

All the author, both individually and collectively, affirms that they do not possess any conflicts of interest either directly or indirectly related to the research being reported in the publication.

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