RESEARCH ARTICLE

Optimizing Strawberry Quality: Comparative Analysis of Chemical Fertilizers, Biofertilizers, and Their Combination

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Abstract

The experiment conducted at Farm Unit - 02, Department of Agriculture, Integral Institute of Agricultural Science and Technology (IIAST), Integral University, spanned two consecutive years, 2022-23 and 2023-24, to investigate the Economizing chemical fertilizer Through biofertilizers on Strawberry Production (Fragaria × ananassa Duch) cv. Winter Down. The study comprised 10 treatments, each replicated thrice in a randomized block design, with treatments consisting of various combinations of mineral and bio-fertilizers at different levels. All doses of mineral and bio-fertilizers were administered at the time of planting. The data collected over both years of the experiment were pooled and subjected to comprehensive analysis. Notably, Treatment 8 (T8) emerged as the most promising, exhibiting superior performance across multiple parameters. In terms of nutritional content, T8 demonstrated the highest levels of total sugars (8.25%), total soluble solids (14.45°Brix), reducing sugars (5.25%), and non-reducing sugars (2.87%). Additionally, it displayed elevated levels of ascorbic acid (55.56 mg), indicating enhanced vitamin C content, a crucial nutritional aspect in strawberries. Furthermore, T8 exhibited an extended shelf life (4.58 Days), which is desirable for marketability and consumer satisfaction. T8 demonstrated favorable attributes in terms of acidity, with lower titratable acidity (0.54%) and a higher TSS: acid ratio (26.67%). These parameters contribute to the overall sensory appeal and palatability of strawberries. In contrast, the control group yielded minimal results across all the aforementioned parameters, underscoring the significance of biofertilizers in optimizing strawberry production while reducing reliance on chemical fertilizers

Keywords: Strawberry, Mineral, Bio-fertilizers, Chemical, Phosphate Solubilizing Bacteria (PSB), Potassium Solubilizing Bacteria Azotobacter.

Highlights

- Enhanced strawberry quality with chemical and biofertilizer synergy.
- Improved color, taste, and texture in strawberries through fertilization.
- Biofertilizer supplementation for heightened nutrient absorption in strawberries.
- Biofertilizers reducing chemical dependency for Sustainable farming.
- Enhanced shelf life and post-harvest quality with fertilizer synergy.

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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. (Singh *et al.,* 2015). In terms of nutrition, strawberries are low in calories and high in fiber, vitamin A (60 IU/100 g of edible portion), vitamin C (30–120 mg/100 g of edible portion), and pectin (0.55%), which is found as calcium pectate. Most of the strawberry fruit (90%) is made of water. The most significant element influencing the growth, yield, and quality of strawberries is nutrition, which also directly affects bearing and production. Because strawberries are very productive and cost-effective, their cultivation has expanded significantly over the past 20 years worldwide, with an annual production of over 7.7 million tons. (FAO 2022). The widespread use of chemical fertilizers has been shown to have a negative impact on soil health, which lowers agricultural yield and quality. (Umar *et al.,* 2009). Therefore, to maintain improved soil health, be environmentally friendly, and support the economy, plant nutrients must be used efficiently by combining chemical fertilizer with biofertilizer (Singh *et al.,*2006).

The fundamental idea behind this idea is to provide biofertilizers in the most effective way possible, along with chemical fertilizers and organic manures, for sustainable crop development. It is well known that using chemical fertilizers in addition to biofertilizers, such as PSB, KSB, Azotobacter, and many more, has positive impacts (Patil *et al.,* 2004). For the majority of horticultural crops, a balanced application of biofertilizers combined with inorganic and organic fertilizers seems to be the best way to satisfy nutritional requirements. Using mineral fertilizer is especially crucial for strawberries if you

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want to get better returns, quality, and yield. To create nutrient management for the strawberry cultivar Sabrina, research was conducted using different combinations of organic, inorganic, and biofertilizer treatments. (Tripathi *et al.,* 2008).

Strawberries have so many nutrients that chemical fertilizers have been employed extensively in strawberry farming. Chemical residues in soil and water can cause contamination of the water, deterioration of the soil, and damage to animals. Furthermore, over time, the constant use of chemical fertilizers may cause the fertility of the soil to decline, which would hinder plant growth and yield reduction. (Kaur, R., and Kapoor, K. 2017).

Organic and environmentally friendly substitutes for chemical fertilizers are biofertilizers. They are made from organic resources, including plant matter, compost, and animal dung. Beneficial microorganisms, including fungi, bacteria, and algae, are abundant in biofertilizers, enhancing soil fertility and plant health. (Yadav *et al.,*2009). It has been demonstrated that using biofertilizers improves strawberry productivity, quality, and flavor. Furthermore, biofertilizers don't leave chemical residue in the soil or water, making them eco-friendly. Additionally, by using fewer synthetic fertilizers, which may be expensive and detrimental to the environment, they support sustainable agriculture. (Singh, R., and Pandey, P. 2019). Both chemical and biofertilizers offer benefits and drawbacks when it comes to strawberry production, according to a comparison study. Chemical fertilizers boost output and offer a high nutritional content, but over time, they degrade soil fertility and have an adverse effect on the ecosystem. However, biofertilizers have a lower environmental effect, increase plant health and soil fertility, and are sustainable (Yusuf *et al.,* 2003).

As demonstrated by lower rates of disease, higher fruit marketability, and a higher cost-benefit ratio, the use of biofertilizers in addition to inorganic fertilizers is essential for sustaining strawberry output and enhancing produce quality (Reddy *et al.,* 2020).

Materials And Methods

The location, sample and research unit: For the next two years, or 2022–2023 and 2023–2024, fieldwork was conducted in the agronomic region of the central humid subtropical zone of India at the Department of Agriculture, IIAST, Integral University, U.P. Situated 49 meters above sea level, the experiment location is located at latitude 26.950 N and longitude 80.990 E. The experiment was conducted in three repetitions using a simple RBD design in a clay soil that was well-drained (58.07% sand, 32.75% silt, and 9.18% clay), hyperthermal, and had an electrical conductivity of 0.25 dS/m, organic carbon of 0.54%, available nitrogen of 254.0 kg/ha, available phosphorus of 23 kg/ha, and available potash of 342.0 kg/ha (Table 2). These parameters were typical recommendations with a pH range of 6-7 soil to solution ratio (1.0M KCl) of 1:15. The mean lowest temperature was 5–10°C throughout the growth season, while the mean highest temperature was 38 to 40°C. About 670 mm of precipitation falls on the study area per year. From the Dr. Y. S. Parmar University of Horticulture and Forestry in Himachal Pradesh, India, strawberry runners were brought for the current study, Winter Down. The runners were placed in the field in plots after being left for one to three days to harden. That was dispersed at random inside the plant layout. Standard cultural norms were followed during the trial period to preserve quality and performance.

Treatment and Experimental Details

The experiment was set up with three replicates and, an individual plot size of 2.0 m (width) and a net plot size of 1.0 m (length). For all treatments, plant spacing was kept at 45 x 45 cm. The total number of treatments is nine with absolute control. The nine treatments were the following (Table 1).

RDF- 120:80:100 N:P:K Kg/ha^{-1}

Using urea (46%), SSP (16% phosphorus), and murate of potassium (containing 60% potash), nitrogen, phosphorus, and potash were applied. Throughout the investigation, all planting materials were maintained according to a standard procedure. Throughout the growing season, the leaf characteristics of strawberry plants were noted. Fruits were harvested, biochemical analysis was done, and physiochemical parameters were once again noted as the fruits were being harvested. Before relocating runners to the main experimental plots for various physicochemical analyses, the soil was sampled. Before moving the runner, a sample of soil from the researched field that was between 0 and 15 and between 15 and 30 cm deep was taken for soil nutrient analysis to assess the baseline of the soil's attributes. Prior to chemical analysis, the obtained soil sample was dried in the open air, crushed using a hardwood roller, and then run through a 2 mm sieve. Cation exchange capacity was estimated by using sodium acetate ($C_2H_3NaO_2$) (buffered to pH 8.2) and ammonium acetate (CH_3COONH_4) (buffered to pH 7.0). Soil organic carbon estimated through. Ammonium acetate (CH_3COONH_4) buffered at pH 7 Thomas was used to determine exchangeable cations. To estimate available nitrogen by the Kjeldahl method. The use of a spectrophotometer estimated plant-available phosphorus. Soil micronutrients were determined by diethylenetriaminepentaacetic acid ($C_{14}H_{23}N_3O_{10}$) (DTPA) extraction method. pH of the soil was estimated in 1:2 method. Extracts and calcium carbonate ($CaCO_3$) concentrations. The biofertilizer was purchased online from Indian Farmers Fertilizer Cooperative Limited (IFFCO).

Preparation of working solution of biofertilizers

Azoto, PSB and KSB were used as the source of Azotobacter, PSB and KSB strains, respectively. On the day of planting, working

Table 1: Treatment and experimental details

Treatment No.	*Treatment*
T_0	100% RDF (Control)
T_1	100 % RDF + 3g Azoto
T_2	100% RDF + 3g PSB
T_3	100 % RDF + 3g KSB
T_4	100 % PK + 25% N + Azoto @ 3 g/plant
T_5	100 % NK + 25% P + PSB @ 3 g/Plant
T_6	100% NP + 25% K + KSB @ 3 g/Plant
T_7	100 % PK +50% N + Azoto @ 3 g/ Plant
T_8	100 % NK + 50% P+PSB @ 3 g/Plant
T_9	100% NP + 50% K + KSB @ 3 g/Plant

Table 2: The site of experimental conditions and mean of weather performance at Department of Agriculture, IIAST, Integral University, Lucknow, India

Parameters	*Units*	*Cropping season*	*Maximum temp. (^0C)*	*Minimum temp. (^0C)*	*Humidity (%)*	*Sunshine (in hours)*
Altitude	49 m above sea level	Agro-climatic parameters during October 2020 to April 2021 (First year)				
Longitudes	80.99^0 E	October	30.8	22.4	52	7.85
Latitudes	26.95^0 N	November	25.28	12.68	51.76	6.87
Climate	Humid subtropical	December	17.55	8.85	59.82	4.8
Average annual rainfall	670 mm	January	16.60	8.75	63.28	3.8
Soil	Loamy soil	February	23.15	11.87	52	7.42
Sand	58.07%	March	31.25	18.75	43.63	7.48
Silt	32.75%	April	34.75	21.37	45.83	8.48
Clay	9.18%	Agro climatic parameters during October 2021 to April 2022 (Second year)				
Ph	6.5 to 7.5	October	32.8	21.7	55.25	8.52
Soils to solution ratio	1.15	November	22.18	12.55	50.78	6.85
EC	0.25 ds/m	December	18.78	8.75	60.25	4.65
Organic carbon	0.54%	January	18.69	9.40	61.96	4.45
Available Nitrogen	254 kg/ha	February	26.34	12.89	59.47	7.70
Available Phosphorus	23 kg/ha	March	32.17	14.77	40.78	7.85
Exchangeable K	342 kg/ha	April	38.52	21.35	44.78	8.70

Table 3: Soil properties of the experimental site

Soil Properties	*Value*
Texture	Loamy
pH	6.8
Saltiness (%)	0.05
Lime (%)	37.13
Organic Matter (%)	0.51
P2O5 (kg/da)	2.97
K2O (kg/da)	37.77
Ca (%)	0.7033
Mg (%)	0.0358
Na (%)	0.0056
Fe (mg kg^{-1})	1.99
Cu (mg kg^{-1})	1.16
Mn (mg kg^{-1})	0.94
Zn (mg kg^{-1})	0.28

solutions of Azotobacter, PSB and KSB were prepared in the morning by dissolving 3 g of each biofertilizer liquid in separate buckets containing 1 L of water.

Preparation method of experimental field

The experimental plot was well prepared by repeated plowing followed by planking to obtain a fine tilth. All the weeds, grasses/plant residues and other materials were removed from the field, followed by planking. Raised beds of 15 cm in height were prepared for planting of cv. Winter Down runners at a row to row 45 cm and plant to plant 30 cm. Weeding and hoeing were done manually with the help of a trowel. It is done after light irrigation to loosen the soil, which facilitates weeding and hoeing. Weeding was done to keep the plots clean, pulverized and adequately aerated. First weeding was done after 30 days after transplanting, second weeding after 50 days of transplanting and later on as when required.

Soil Sampling, Treatment, and Analyses

Following the instructions, the experimental area's soil properties were examined before the experiment. The pH of the loamy soil structure in the treatment region was 6.8 (Table 3). In the experiment, fresh seedlings were used. The RBD technique was used to sow the seedlings in October 2022–2023 and October 2023–2024. Following planting, KSB, PSB, and Azoto were produced and administered to the plant roots at a rate of 3 g/plant for 15 days at intervals (in accordance with treatments). From March until the conclusion of the trial, fertilizer treatments were administered every month as the weather warmed up and fruit development and plant growth quickened. Both chemical and biological fertilizers were administered a total of five times during the experiment. The treatments' abbreviations are specified below.

Parameters Studied

During the study, many vegetative, reproductive, and quality criteria of the chosen and tagged plants were evaluated.

Data Collection and Traits

The 21 most profitable traits of the experiment: Leaf length (cm), leaf width (cm), leaf area (cm^2), fresh weight of leaves (g), dry weight of leaves (g), chlorophyll –a (mg g^{-1}), Chlorophyll-b (mg g^{-1}), total Chlorophyll content (mg g^{-1}), days to first flower, number of flower/ plant, duration of harvesting in days, reducing (%) and non-reducing sugar (%), ascorbic acid (mg/100g), specific gravity, Total Sugar, TSS: Acid Ration (%), Titratable Acidity (%), Post-harvest life of fruits (Days), TSS ^{0}Brix and Benefit cost ratio.

Leaf and Flower Characters Analysis

The dimensions of the leaf were measured using the measurement scale's width and length. The youngest completely grown mature leaf was measured with a leaf area meter. Leaves' dry weight: Ten leaves were weighed, and after a few days in a hot air oven at their typical fresh weight, the weight of the dried leaf was computed and given in grams. Fresh weight of leaf: After weighing ten leaves, the average weight of the leaves was determined and reported in grams. The quantity of chlorophyll was measured using a spectrophotometer. The time difference between the planting date and the first flower opening date was observed in order to calculate the number of days till the first flower. The amount of blossoms on each plant indicated when it will fruit. The time interval from the planting date to the first flower opening (anthesis) was recorded in order to calculate the number of days till the first flowering. The first and last dates of picking were recorded, and the amount of time that elapsed between them was computed and given in days. To ascertain the fruit's post-harvest life at a typical ambient temperature of 8–10°C, the number of days it took for the fruit to rot in the tagged plants after harvesting was noted.

Quality Analysis

TSS (^{0}Brix)

Total soluble solids present in the fruit pulp were recorded at room temperature using a hand refractometer and expressed as ^{0}Brix. The values were corrected at 20°C with the help of a temperature correction chart.

Titratable Acidity %

Titratable acidity was determined using the titration method for this 2 g of fruit sample was weighed and added to 50 mL water. It was thoroughly mixed and then filtered. The filtered sample was titrated against 0.1 N NaOH using a few drops of 1% phenolphthalein solution as an indicator. The observed titre value was used for calculating acidity and the results were expressed as a percentage of citric acid. The formula used for its calculation was expressed as grams of anhydrous citric acid per 100 g of pulp.

$$\text{Titratable acidity (\%)} = \frac{\text{Volume of 0.1 N NaOH consumed}}{\text{Volume of juice taken}} \times \frac{64}{1000} \times 100$$

Total sugars (%)

Total sugar was also used in the copper titration method. In this method, 50 ml of juice was taken in a flask, 5 mL concentrated HCl was added to it and kept for 24 hours. It was neutralized with 40% sodium hydroxide solution. For testing, complete neutralization of blue and red litmus paper was used. This solution was then titrated against Fehling's solution A and B as in the case of reducing sugar and the amount of total sugar in juice was worked out considering 10ml of Fehling's solution A and B equal to 0.05 g of glucose.

Reducing sugar (%) and non-reducing sugar (%)

For the titration, an aliquot of 5 mL of diluted fruit juice was taken from 100 mL and combined with 10 mL of Fehling 'A' and 'B'. Using ethylene blue as an indicator, this was titrated against 1.0% glucose in a boiling solution. Additionally, a blank using 10 mL of Fehling 'A' and 'B' was run. The outcome was given as a percentage of reducing sugar.

$$\text{Reducing sugar (\%)} = \frac{(\text{blank titratable value} - \text{sample titrable value}) \times \text{volume made up}}{\text{Aliquot taken} \times \text{weight of sample}} \times 100$$

The proportion of non-reducing sugar was determined by subtracting the amount of reducing sugar from the total amount of inverted sugars then multiplying the result by 0.95.

Ascorbic acid (mg /100 g of pulp)

Using metaphosphoric acid as a stabilizing agent, samples were titrated with 2,6-dichlorophenol indophenol dye to assess the ascorbic acid content.

$$\text{Ascorbic acid (mg/100 g)} = \frac{\text{Titre x Dye factor x Volume made up}}{\text{Aliquot of extract taken for estimation x Wt. of sample taken x 100}}$$

Specific gravity

The specific gravity of fruits was calculated by dividing the selected average fruit weight to the average volume of water displaced by fruit (mL).

$$\text{Specific gravity} = \frac{\text{Fruit weight (g)}}{\text{Volume of water displaced by fruit (ml)}}$$

Post-harvest life of fruit (Self Life)

Post-harvest life of fruit was assessed in normal ambient temperature (8–10°C) by fruit was harvested through tagged plants and data was recorded from the harvesting stage to the rotting stage.

Benefit Cost Ratio

The benefit to cost ratio was estimated by the of given formula:

Benefit cost ratio = Net Return (Rs. /ha)/Cost of cultivation (Rs. ha^{-1})

Result And Discussion

Vegetative characters

Table 4 makes it evident that using chemical fertilizer with biofertilizers at various treatment combinations led to a considerable increase in the following leaf metrics: fresh weight of leaves (g), dry weight of leaves (g), leaf length (cm), leaf Width (cm), and leaf area (cm^2). The extreme leaf length (8.55 cm) was recorded in $T_{8,}$ which was statistically similar to all other treatments except control. Maximum leaf width (9.01 cm) was observed in $T_{8,}$ which was found statistically at par to all other treatments (Fig. 1) and (Fig. 2). Maximum leaf area (94.54 cm^2) was found in T_8 however, minimum result was recorded in T_0 control (Fig. 3), maximum fresh weight of leaves and dry weight of leaves was recorded (9.99 g) and (1.95 g) respectively in T_8 which was treated with 100% NK + 50% P+PSB @ 3 g/Plant while minimum result was recorded untreated plant that is 100% RDF (Control). The highest chlorophyll 'a' and 'b' was found in the plants grown

Table 4: Impact of Chemical Fertilizer with Biofertilizer on Leaf Parameter on Strawberry

Treatments	*Leaf Parameter*							
	Leaf Length (cm)	*Leaf Width zz(cm)*	*Leaf Area (cm^2)*	*Fresh Weight of Leaf (g)*	*Dry Weight of Leaf (g)*	*Chlorophyll a mg g[1])*	*Chlorophyll b mg g[1])*	*Total Chlorophyll mg g[1]) fresh weight*
T_0	4.85	7.43	84.54	4.58	1.18	1.26	0.44	1.67
T_1	4.99	7.78	87.82	5.71	1.41	1.42	0.53	1.86
T_2	5.56	7.74	91.92	6.38	1.42	1.45	0.55	1.95
T_3	6.01	8.13	91.97	7.89	1.59	1.48	0.57	1.97
T_4	6.78	8.61	92.77	8.52	1.68	1.52	0.67	2.09
T_5	7.02	8.97	93.45	8.95	1.82	1.54	0.57	2.18
T_6	7.58	8.37	93.85	9.24	1.92	1.61	0.68	2.27
T_7	8.04	8.03	93.90	9.52	1.93	1.72	0.70	2.48
T_8	8.55	9.01	94.54	9.99	1.95	1.82	0.73	2.58
T_9	8.05	8.94	93.97	9.67	1.94	1.73	0.71	2.51
S.E. ±	0.87	1.39	11.12	1.47	0.41	0.08	0.03	0.07
C.D. (P=0.05)	2.61	4.28	30.74	4.54	1.29	0.27	0.06	0.21

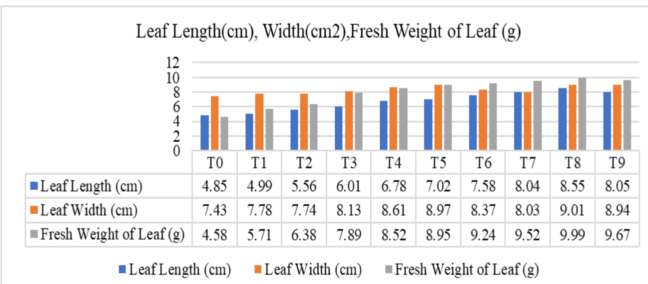

Fig. 1: Effect of inorganic and bio-fertilizers on leaf parameter

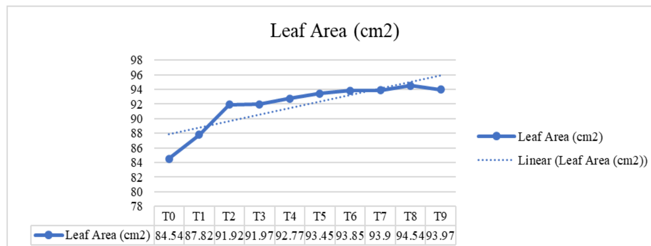

Fig. 3: Effect of inorganic and bio-fertilizers on leaf area (cm^2)

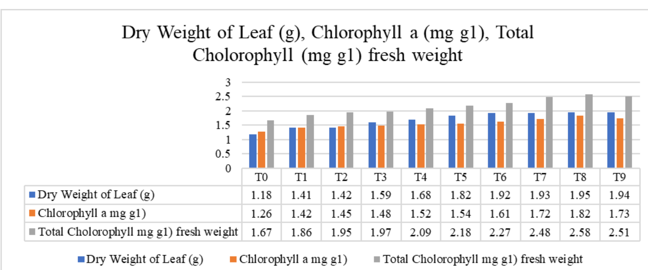

Fig. 2: Effect of inorganic and bio-fertilizers on leaf chlorophyll and weight

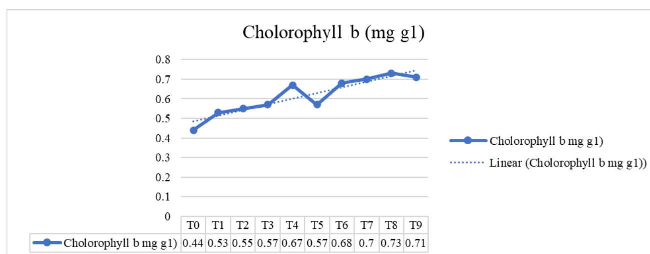

Fig. 4: Effect of inorganic and bio-fertilizers on chlorophyll b (mg g1)

on the soil treated with 100 % NK + 50% P+PSB @ 3g/Plant chlorophyll-a (1.82 mg g[1]) (Fig. 2), which was found statistically at par with T_9, T_7 and T_6 and maximum chlorophyll-b (0.73 mg g[1]) was found in T_8 (Fig. 4), which was found statistically at par with T_9 and T_7 treatments another hand total maximum chlorophyll (2.58 mg g[1]) were recorded under the T_8 which was found statistically at par with T_9 and T_7 while lowest total chlorophyll (1.67 mg g[1]) was recorded in control at time of investigation (Table 4). The inoculation of nitrogen fixers may have increased the amount of chlorophyll content, which could account for the increase in other metrics and vegetative development. Another explanation for the rise in vegetative growth could be the rhizosphere's microorganisms producing plant growth regulators, which the roots then ingest. Thus, more biological nitrogen fixation may be responsible for enhanced vegetative growth. Improved root system development, potential manufacture of plant growth hormones such as indole acitic acid, gibberellic acid, cytokinins, and the direct impact of biofertilizers (Gajbhiye *et al.,* 2003) and (Similar as Pandey *et al.,* 2018). The utilization of biofertilizers such PSB, which solubilizes fixed soil phosphorus, and *Azotobacter*, which fixes nitrogen and modifies microbial balance to solubilize fixed soil phosphorus, may be the primary contributors contributing to the higher chlorophyll content in this study. This might be because the rhizosphere has the highest concentration of nutrients, which could aid in the synthesis of photosynthates. (Kamatyanatti *et al.,* 2019) and (Similarly Chtouki *et al.,* 2022). The greater percentage of nitrogen from the nitrogen-fixing culture and the growth regulators produced by

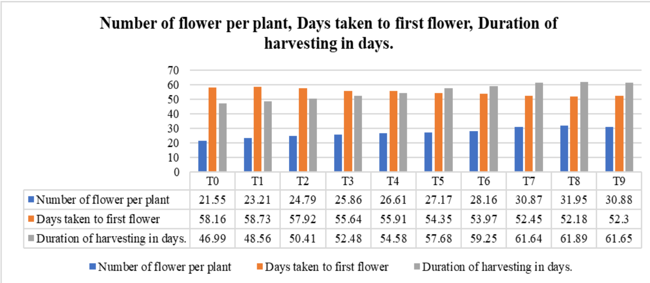

Fig. 5: Impact of chemical fertilizer with biofertilizer on reproductive parameter

Table 5: Impact of chemical fertilizer with biofertilizer on reproductive parameter on strawberry (Floral characters)

Treatments	*Floral characters*			
	Number of flowers per plant	*Days taken to first flower*	*Duration of harvesting in days*	*Specific gravity*
T_0	21.55	58.16	46.99	1.22
T_1	23.21	58.73	48.56	1.31
T_2	24.79	57.92	50.41	1.50
T_3	25.86	55.64	52.48	1.60
T_4	26.61	55.91	54.58	1.65
T_5	27.17	54.35	57.68	1.78
T_6	28.16	53.97	59.25	1.78
T_7	30.87	52.45	61.64	1.92
T_8	31.95	52.18	61.89	1.95
T_9	30.88	52.30	61.65	1.93
S.E. ±	3.07	3.94	7.04	0.06
C.D. (p = 0.05)	9.66	12.21	22.06	0.15

the potassium solubilizing bacteria (PSB) in the root zone may have contributed to the rise in leaf area. (Rana and Chandel *et al.*, 2003) similar result was obtained by (Sahana *et al.*, 2020)

Floral characters

In the current study, during transplanting, the inoculation of chemical fertilizers and biofertilizer on the strawberry cultivar 'Winter Down' root zone produced a maximum number of flowers and first flowering as compared to the T_0. It is clearly shown from Table 5 and (Fig. 5) that during flowering maximum number of flowers per plant was counted (31.95) in $T_{8,}$ which was found statistically similar to all other treatments except the control, while the least number of flower (21.55)/ plant were recorded in control. Minimum days taken to first flower in T_8 (52.18) which found statistically similar to rest of treatments however maximum days taken (58.16) in untreated plots.

The reason for this could be that the application of NK (50% Dose), P and PSB hastened the growth of inflorescence and leaf number in the fall, which is positively connected with the quantity of flowers and fruits. Similar explanations were also stated by (Mishra *et al.*, 2012) in strawberry and these findings get support from (Tripathi *et al.*, 2014) and comparable results also stated by (Pandey *et al.*, 2017).

Duration of Harvesting

In Table 5 and Fig. 5, it is clearly showed that the maximum duration of fruit harvesting in days was recorded in T_8 (61.89), which was found statistically similar to all other treatments; however, least duration of days (46.99) of fruit harvesting was recorded in T_0 control plots. Comparable results also stated by (Tripathi *et al.*, 2017) and (Singh and Singh 2009) in strawberries, who received an advance harvesting period (earliness) of around one month, so extending the harvesting time.

Quality characters

The analysis of quality metrics revealed significant disparities among the different treatments, with the notable exception

Table 6: Effect of inorganic and bio-fertilizers on quality characters of strawberry

Treatments	*Yield attributes*							
	TSS ^{0}Brix	*Titratable acidity (%)*	*Ascorbic acid*	*Reducing sugar*	*Non-reducing sugar*	*Total sugar*	*Self-life*	*TSS: Acid ration (%)*
T_0	8.25	0.79	45.35	4.08	2.11	6.25	2.13	10.40
T_1	8.33	0.75	46.33	4.18	2.18	6.44	2.30	11.05
T_2	9.46	0.69	48.76	4.33	2.26	6.58	2.40	13.64
T_3	9.75	0.64	50.48	4.51	2.35	7.01	2.56	15.14
T_4	10.43	0.63	51.20	4.60	2.47	7.24	2.69	16.58
T_5	10.65	0.61	52.93	4.58	2.53	7.26	2.79	17.25
T_6	11.36	0.60	53.65	4.81	2.59	7.56	2.90	18.81
T_7	13.56	0.59	54.51	5.00	2.66	7.68	3.52	22.90
T_8	14.45	0.54	55.56	5.25	2.87	8.25	4.58	26.67
T_9	12.41	0.61	54.15	4.55	2.42	7.17	3.25	20.17
S.E. ±	0.332	0.010	0.091	0.063	0.049	0.998	0.041	0.332
C.D. (p = 0.05)	1.076	0.034	0.294	0.204	0.159	0.308	0.134	1.076

Table 7: Impact of different treatments under chemical fertilizer with biofertilizer on gross return, net return, and benefit cost ratio of strawberry (2022–23 and 2023–24)

Treatments	*Cast benefit ratio (B:C Ratio)*					
	Cost of cultivation (Rs. ha)	*Yield (q ha^{-1})*	*Sale rate (Rs./q)*	*Gross Return (Rs./ha) Yield (q ha^{-1})x Sale rate (Rs./q)*	*Net Return (Rs./ha) Cost of cultivation (Rs. ha)- Gross Return (Rs./ha*	*Benefit : Cost ratio Net Return (Rs./ha)/ Cost of cultivation(Rs. ha)*
T_0	289,518	97.3	20,000	1946000	1656482	5.7/1
T_1	291118	102.8	20,000	2056000	1764882	6.06/1
T_2	291118	130.6	20,000	2612000	2320882	7.9/1
T_3	291814	146.94	20,000	2939200	2647386	9.06/1
T_4	287500	169.70	20,000	3394000	3106500	10.8/1
T_5	278461	169.15	20,000	3383000	3104539	11.1/1
T_6	271667	214.16	20,000	4283200	4255533	15.6/1
T_7	288706	258.74	20,000	5174800	4886094	16.9/1
T_8	282680	308.33	20,000	6166600	5883920	20.8/1
T_9	271667	224.59	20,000	4491800	4220133	15.5/1

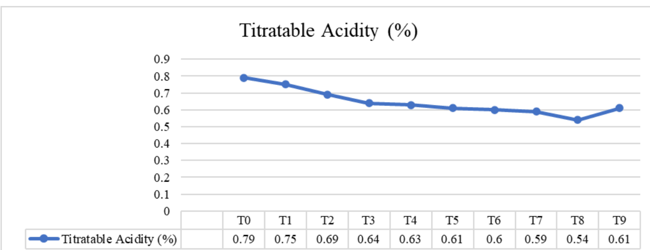

Fig. 6: Effect of inorganic and bio-fertilizers on titratable acidity (%)

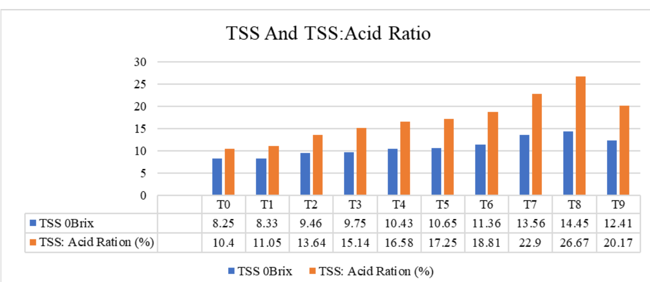

Fig. 7: Effect of inorganic and bio-fertilizers on TSS And TSS: Acid ratio

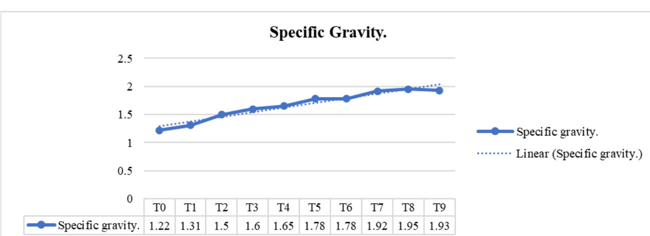

Fig. 8: Impact of chemical fertilizer with biofertilizer on specific gravity

of non-reducing sugars. It is clearly presented in (Table 6). Notably, the plants treated with 100% NK + 50% P+PSB @ 3 g/plant (T8) treatment exhibited remarkable levels across various parameters. Specifically, they recorded the highest concentrations of titratable acidity of (0.54), and a TSS:acid ratio of (26.67) (Figs 6 and 7). These findings underscore the efficacy of the T_8 which was found statistically at par with T_9 and T_7 however, a minimum was recorded in T_0 treatment regimen in enhancing multiple quality attributes in the plants under study. (Ahmad and Mohammad 2012), (Mohamed *et al.*, 2011), (Shehata *et al.*, 2011), (Pesakovic *et al.*, 2013) and (Rayees *et al.*, 2015). The synergistic impact of applying the optimal nitrogen treatment alongside the biofertilizer appears to have contributed to the observed elevation in total soluble solids (TSS) within the plants. The maximum TSS was recorded in T_8 (14.45) which was found statistically at par with T_9 and T_7 however minimum was recorded in T_0 (8.25) (Fig. 7). In case highest value of specific gravity was recorded in T_8 (1.95) which was found statistically at par with T_9 and T_7 while value of specific gravity was recorded in $T_{0,}$ (Table 5) and (Fig. 8). On the other hand it should be noted that maximum total sugar (%), reducing sugar (%) and non-reducing sugar (%) was found in T_8 (8.25), (5.25) and (2.87) which was found statistically at par with T_9 and T_7 however minimum Total Sugar (%), reducing sugar (%) and non-reducing sugar (%) was recorded in T_0 (Fig. 9), and extreme ascorbic acid (mg/100g) was noted under T_8 (55.56 mg/100g) T_0 and T_1 treatments was found statistically dissimilar and other was found statistically similar regarding this parameter (Fig. 10), In case of post-harvest life in days of fruit maximum post-harvest life of fruits were recorded in T_8 (4.58) while T_9 and T_7 treatment was found statistically at per with T_6 while minimum post-harvest life in days of fruits was observed (2.13) in T_0 control (Table 5) and (Fig. 11). Many researchers regarding specific gravity parameter similar result and conclusions were found by (Singh and Singh, 2006; and Nazir *et al.*, 2006) in strawberry and comparable finding was stated that (Singh *et al.*, 2010). The increase in total sugar, reducing and non-reducing sugars may be linked to the absorption of nitrogen, which plays a regulatory role as a significant component of endogenous factors affecting fruit quality. Fruits heavily draw on the carbohydrate reserves of the stem and root during fruit ripening, which may have led to higher fruit sugar content. The current findings are in line

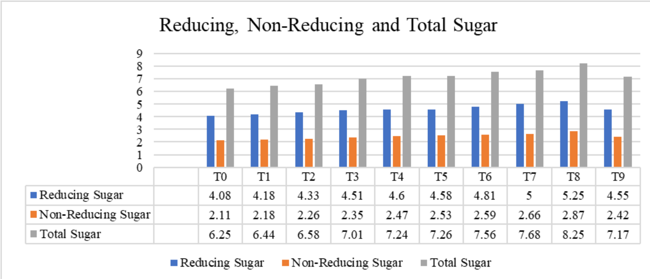

Fig 9: Effect of inorganic and bio-fertilizers on reducing, non-reducing, and total sugar

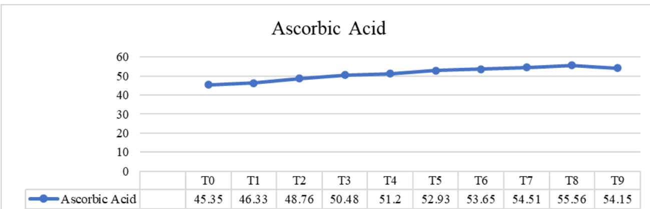

Fig. 10: Effect of inorganic and bio-fertilizers on ascorbic acid

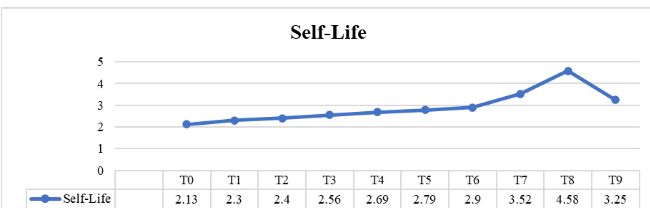

Fig. 11: Effect of inorganic and bio-fertilizers on self-life

with the findings of (Ahmad D. *et al.,* 2012; Umar, I., *et al.,* 2009; and Rayees, A., *et al.,* 2015). The microbial inoculants' enhanced ability to fix the nitrogen from the atmosphere, the augmented availability of phosphorous, and the secretion of growth-promoting substances that speed up physiological processes like the synthesis of carbohydrates could all be contributing factors to the corresponding increase in ascorbic acid content. These findings were also supported by the findings of (Singh *et al.,* 2009) in the ber fruit crop, (Yadav *et al.,* 2009) in strawberry crop. Better fruit fillings can result in more balanced nutrient absorption, which in turn promotes better metabolic activities and higher levels of protein and carbohydrate synthesis. This can explain why fruits have a larger volume (Ahmad, D. *et al.,* 2012) and similar findings were obtained by (Subraya *et al.,* 2017).

Benefit cost ratio

Net revenue and benefit: A crop's cost ratio is evident in (Table 7), and farmers use it as a determining factor when selecting how to modify it for commercial production. For this reason, it's critical to determine the financial gain associated with using each treatment combination to boost strawberry yield. Net revenue and benefit: A crop's cost ratio determines whether or not farmers would adapt it for commercial production. For this reason, it's critical to determine the financial gain associated with using each treatment combination to boost strawberry yield. In both years, the highest (20.8:1) benefit: cost ratio was discerned in T_8, which was followed by T_7 (16.9:1). Net income was calculated as (Rs**.** 58,83,920) in T_8 treatment, while Minimum (5.7:1) benefit: cost ratio was found from T_0 while minimum net income was estimated under control (Rs. 16,56,482). Numerous studies have also documented increased net return and cost-benefit ratios associated with the use of biofertilizers and organic fertilizers. viz. (Varma *et al.,* 2020) and (Yadav *et al.,* 2010) in strawberries, (Javaria and Khan 2010) in tomatoes.

Conclusion

The treatment T8 -100% NK + 50% P+PSB @ 3g/Plant has demonstrated outstanding efficacy in enhancing strawberry cultivation, especially for the cv. Winter Down. This innovative approach not only promotes vigorous growth and development of plants but also significantly elevates the quality of strawberries produced. Furthermore, it exhibits the highest cost-benefit ratio among tested treatments and contributes positively to soil fertility. These compelling results underscore T8 as a sustainable alternative to conventional chemical fertilizers, perfectly aligned with the growing preference for environmentally friendly farming practices. Emphasizing improved fruit quality, increased marketable yield, and optimized cost-effectiveness, the T8 treatment emerges as the forefront method for advancing subtropical strawberry cultivation into a prosperous and sustainable future.

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Authors Contribution

AKS Planning of study, review and editing of MS. MAN Conceptualization of idea and Head of Department and supervision of the study. MHS Review and editing of MS and correction as per suggestion from reviewer and editor. AS and DS correction as per suggestion from reviewer and editor. SD and SS conceptualization of idea and writing the original draft of Manuscript and collection of review literature and compilation.

Conflict of interest

None

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