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RESEARCH ARTICLE

Influence of biofertilizers and bioenhancer on growth and yield of strawberry (*Fragaria × ananassa* Dutch.) cv. Chandler

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Abstract

The present study was conducted in the Department of Horticulture, Chandra Sekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India. The experiment aimed to assess the impact of various biofertilizers (*Azotobacter* and phosphorus solubilizing bacteria (PSB)) and bioenhancers (Panchagavya, Jeevamrit and Amritpani) on the growth and yield parameters of strawberry (*Fragaria × ananassa* Dutch.) cv. Chandler. The experiment was conducted using a randomized block design, featuring ten treatments, each replicated three times. Treatments included combinations of biofertilizers (*Azotobacter*, PSB) and bioenhancers (Panchagavya, Jeevamrit, Amritpani). Among the ten treatments tested, including a control, the treatment T9 (Panchagavya 3 % + PSB 50 g/bed + *Azotobacter* 50 g/bed) showed the best results, significantly enhancing plant height, spread, number of leaves, leaf area, number of crowns and runners per plant. This treatment also shortened the time to first flowering, extended the flowering duration, maximum number of flowers and fruit per plant and minimum days to fruit set. Fruit traits such as length, diameter, weight, volume and specific gravity (g/cc), yield parameters such as yield per plant (g) and yield per plot were also improved under the treatment T9. Thus, the combination of biofertilizers and bioenhancers demonstrated significant potential to increase crop growth and yield in fields. We concluded that the combined use of Panchagavya, PSB and *Azotobacter* should be utilized for improving the vegetative growth, flowering and fruit yield of strawberry cv. Chandler, especially under an organic farming system.

Keywords: *Azotobacter*; chandler; growth; panchagavya; PSB; strawberry

Introduction

Farmers have traditionally used inorganic fertilizers and pesticides to enhance crop yields, but their overuse has led to harmful residues such as nitrates, heavy metals (e.g., cadmium, lead) and persistent pesticides in fruits, vegetables and grains (1-3). These residues pose serious health and environmental risks. As a sustainable alternative, biofertilizers and bioenhancers improve soil health and nutrient uptake without toxic buildup (1). Furthermore, excessive use of synthetic chemicals disturbs the soil's microbial ecosystem, leading to groundwater pollution and environmental degradation (4). The cultivated modern strawberry (*Fragaria × ananassa*) is a hybrid crop developed in 17th century France from *Fragaria chiloensis* and *Fragaria virginiana* (5, 6). Strawberry (*Fragaria × ananassa* Dutch.), a member of the Rosaceae family (2n = 8x = 56), is highly valued not only for its taste and market appeal but also for its rich nutritional profile. It is an excellent source of vitamin C, potassium and dietary fiber, all of which play key roles in supporting immune function, cardiovascular health and digestive wellness (7). Moreover, strawberries are abundant in phenolic compounds including flavonoids, phenolic acids and anthocyanins, known for their strong antioxidant and anti-inflammatory properties. These bioactive constituents contribute to the prevention of chronic diseases such as cancer, diabetes and neurodegenerative disorders, making strawberry an ideal crop for functional food production and human health promotion.

Strawberry cultivation has grown rapidly in India, particularly in regions near urban centers where market demand and profitability are high (8, 9). Significant expansion has been observed in states like Maharashtra (Mahabaleshwar and Pune), Himachal Pradesh, Uttarakhand, Jammu & Kashmir and parts of Uttar Pradesh and Karnataka, driven by favorable agro-climatic conditions and increased consumer awareness. This regional growth reflects the crop's commercial potential and its adaptability under diverse production systems, further justifying research on sustainable practices to enhance yield and quality.

Given the rising demand, it is crucial to address the adverse effects of chemical fertilizers and explore sustainable alternatives to ensure safe and high-quality production. A significant research gap exists in developing eco-friendly approaches to enhance strawberry yield without compromising human and environmental health. Biofertilizers and bioenhancers are promising alternatives to inorganic chemicals (10, 11). Such benefits have also been observed in fruit crops like banana, papaya and pomegranate, as well as in temperate fruits like apple and pear, where organic inputs improved yield, fruit quality and soil health. These findings underscore their relevance in sustainable fruit production systems (12-14).

Bioinoculants such as *Azotobacter* and PSB are beneficial microorganisms that promote nutrient availability and plant growth (5, 15). *Azotobacter* fixes atmospheric nitrogen, while PSB solubilizes soil phosphorus, making it accessible to plants (16). As well, bioenhancers like Panchagavya, Jeevamrit and Amritpani stimulate soil microbial activity and nutrient cycling. Jeevamrit, a fermented blend of beneficial microbes, enhances nutrient availability and decomposes organic matter (17). Amritpani, made from fermented plant materials and Panchagavya, an organic growth promoter, improve soil health and plant growth (14, 18). This study focuses on evaluating the effects of bioinoculants (*Azotobacter* and PSB) and bioenhancers (Panchagavya, Jeevamrit and Amritpani) on the growth and yield of the Chandler variety of strawberry (*Fragaria* × *ananassa).* By investigating these alternatives, the research aims to develop sustainable practices that reduce reliance on synthetic inputs while enhancing strawberry production in an environmentally friendly manner. This is crucial for advancing sustainable agriculture and ensuring safe, high quality food production.

Materials and Methods

Twelve months old Chandler strawberry runners were planted on raised beds measuring 60 cm x 90 cm, elevated by 8-10 cm. The plants were spaced 45 cm apart in rows and 20 cm between each plant, allowing for 6 plants per plot. The research work was conducted at the Department of Horticulture, C S Azad University of Agriculture and Technology, Kanpur 208 002, Uttar Pradesh, India, during the years 2022-23 and 2023-24. The crop was planted in the last week of September each year and harvesting was carried out from the end of December to April. As environmental conditions during this period can significantly influence crop growth and yield parameters, pooled data across both years were analyzed to ensure consistency and reliability. The study included nine treatment combinations, along with one control, all replicated three times in a randomized block design. The ten treatment consisting of T1 control (FYM -5 kg/bed), T2 (Amritpani (20 %) + *Azatobactor* (50 g/bed)), T3 (Panchagavya (3 %) + *Azatobactor* (50 g/bed)), T4 (Jiva amrit (20 %) + *Azatobactor* (50g/bed)), T5 (Amritpani (20 %) + PSB (50 g/bed)), T6 (Panchagavya (3 %) + *PSB* (50 g/bed)), T7 (Jiva amrit (20 %) + PSB (50 g/bed)), T8 (Amritpani (20 %) + PSB (50 g/bed)) + *Azatobactor* (50 g/bed), T9 (Panchagavya (3 %) + PSB (50 g/bed) + *Azatobactor* (50 g/bed) and T10 (Jiva amrit (20 %) + PSB (50 g/bed) + *Azatobactor* (50 g/bed).

The data collected on various parameters during both experimental years were analyzed and presented separately. During the experiment observations were recorded on plant height (cm), plant spread (cm), no. of leaves per plant, leaf area (cm^2), no. of crowns per plant, no. of runners per plant, days taken to produce first flower, no. of flower per plant, duration of flowering, no. of days to fruit set, no. of fruit set/plant, duration of harvesting, fruit length (cm), fruit weight (g), fruit diameter (cm), fruit volume (cc), specific gravity (g/cc), yield per plant (g) and yield par plot (kg). The no. of flowers/plant and fruits per plant was recorded at 5 days intervals throughout the whole growing season. During each harvesting event, data on berry weight and yield per plant were recorded. Besides, the length and width of 10 berries were measured using a vernier calliper.

Statistical analysis

The data recorded for different characteristics during the investigation were analysed using statistical methods (19). The data obtained were statistically analyzed using Randomized Block Design (RBD). The significance of treatment effects was tested through the F-test and critical differences (C D) at 5 % probability levels were calculated for comparison among treatment means. Multivariate relationships among treatments and traits were evaluated using Principal Component Analysis (PCA) performed with SPSS software (version 25.0).

Results and Discussion

Growth characters

The data collected for various growth parameters, proved that the application of bioenhancers and bio-fertilizers had a significant impact on the vegetative growth of the strawberry plant. The vegetative development of strawberry plants was notably enhanced when bioenhancers were used in conjunction with bio-fertilizers, specifically *Azotobacter* and PSB, compared to the application of bioenhancers alone. According to the data presented in Table 1, the plant height and the plant spread (cm) were highest with the use of Panchagavya (3 %) + PSB (50 g/bed) + *Azatobactor* (50 g/bed). In the pooled data, it was observed that the maximum plant height (17.61 cm) and plant spread (22.05 cm) were recorded in plants treated with Panchagavya (3 %) + PSB (50 g/bed) + *Azotobacter* (50 g/bed) per plot (T9). Whereas the minimum plant height (14.06 cm) and plant spread (15.84 cm) were observed in untreated plants (T1). The enhancement in both plant height and plant spread by the application of *Azotobacter* and PSB aligns with findings reported in strawberries (20, 21), as well as in papaya (22, 23). The observed enhancement in vegetative growth parameters may be attributed to the augmented chlorophyll content resulting from the inoculation of nitrogen-fixing microorganisms (20, 23). Besides, the proliferation of plant growth regulators such as indole-3-acetic acid (IAA), gibberellins (GA) and cytokinins synthesized by rhizosphere-associated bacteria like *Azotobacter*, Azospirillum, Bacillus and Pseudomonas could also contribute significantly to enhanced vegetative development. These beneficial microbes colonize the root zone and facilitate nutrient uptake while promoting cell elongation and division, ultimately improving plant growth and vigor.

Accordingly, the observed improvements in vegetative growth can be ascribed to the elevated rates of biological nitrogen fixation (22, 24). Furthermore, enhanced root system development and the potential synthesis of phytohormones such as IAA, GA and cytokinins, along with the direct effects of biofertilizers, may have further facilitated the enhancement of plant growth parameters. Similar findings related to the promotion of vegetative characters were also recorded with the combined application of *Azotobacter* and PSB (each at 6 kg/ha) in strawberry (25). Other growth characters in pooled data, it was observed that the maximum number of leaves per plant (17.09) and leaf area (73.34 cm^2) were recorded in plants treated with Panchagavya (3 %)

Table 1. Effects of bioinoculants (*Azotobacter* and PSB) and bioenhancers (Panchagavya, Jeevamrit and Amritpani) on the different growth and flowering characters of the Chandler variety of strawberry (*Fragaria × ananassa*)

Treatment	Plant height (cm)	Plant spread (cm)	No. of leaves per plant	Leaf area (cm²)	No. of crowns per plant	No. of runners per plant	DTPFF	No. of flower per plant	Duration of flowering	No of days to fruit set
T_1	14.06±0.02c	15.84±0.33g	10.95±0.19f	65.18±1.09c	2.76±0.06g	1.18±0.02g	84.21±0.62a	13.90±0.20g	49.46±0.27f	75.21±1.32a
T_2	15.27±0.03b	17.03±0.02f	11.56±0.27e	65.85±0.24bc	2.79±0.04g	1.22±0.03g	83.39±1.87a	14.00±0.01g	58.71±0.61ab	73.89±0.77a
T_3	17.27±0.41a	17.93±0.03ef	13.38±0.21d	67.50±1.65bc	3.50±0.03e	2.00±0.05f	82.25±1.11a	17.02±0.25e	51.67±0.05e	72.19±0.56ab
T_4	14.80±0.35bc	17.14±0.24f	12.08±0.08e	66.17±0.58bc	3.35±0.03f	1.91±0.04f	82.89±1.51a	15.25±0.26f	55.94±0.41cd	73.12±0.42a
T_5	14.97±0.17bc	18.39±0.47de	14.21±0.07c	67.74±0.25bc	3.82±0.03d	2.46±0.01e	83.14±1.82a	17.43±0.05e	54.63±1.25d	69.82±0.69bc
T_6	15.51±0.37b	19.80±0.44bc	15.33±0.24b	71.25±1.11a	4.29±0.03b	3.03±0.06d	82.07±0.85a	19.94±0.04d	56.92±0.06bc	68.21±1.35c
T_7	14.28±0.33c	19.09±0.06cd	14.24±0.19c	68.13±1.10b	3.99±0.01c	2.51±0.00e	83.14±0.56a	17.63±0.12e	57.40±0.90abc	68.34±1.21c
T_8	17.41±0.39a	20.43±0.22b	15.67±0.10b	71.50±0.63a	4.57±0.04a	3.24±0.01c	76.58±0.32b	20.66±0.30c	57.37±0.84abc	68.05±0.74c
T_9	17.61±0.21a	22.05±0.47a	17.09±0.30a	73.34±0.08a	4.71±0.06a	3.67±0.05a	75.56±1.26b	23.18±0.58a	58.28±0.21ab	66.70±1.14c
T_{10}	17.45±0.18a	20.56±0.27b	15.70±0.07b	72.96±0.49a	4.69±0.07a	3.56±0.06b	75.71±0.35b	21.83±0.40b	59.06±0.65a	68.03±0.57c

+ PSB (50 g/bed) + *Azotobacter* (50 g/bed) per plot (T9) (Table 1). While the minimum number of leaves per plant (10.95) and leaf area (65.18 cm^2) were observed in untreated plants (T1). These findings are in line with previous study suggesting that more vegetative growth by the application of Jeevamrit + Amritpani + *Azotobacter* can be attributed to the synergistic effects of the individual components (20). Similar results were also found in aonla (26). The increment in leaf number and area may be attributed to enhanced nutrient availability and the synthesis of growth regulators by the selected biofertilizer strains within the root zone (27).

The application of various treatments had a significant impact on growth parameters such as the number of crowns and runners, both in combined data. The maximum number of crowns per plant (4.71) and the number of runners per plant (3.67) were recorded in plants treated with Panchagavya (3 %) + PSB (50 g/bed) + *Azotobacter* (50 g/bed) per plot (T9) (Table 1) and the minimum number of crowns per plant (2.76) and the minimum number of runners per plant (1.18) were observed in untreated plants (T1). The observed increase in the number of crowns and runners per plant can be attributed to enhanced vegetative growth, resulting in greater accumulation of photosynthates. This, in turn, facilitates an increase in the production of runners and crowns. These findings corroborate the study conducted, which reported that the highest number of runners per plant in strawberries was achieved through the application of a nutrient regimen comprising 50 % farmyard manure (FYM), 50 % vermicompost, in conjunction with the inoculation of *Azotobacter* and Pseudomonas (28).

Flowering characters

The floral characters exhibited significant variation due to the different treatments (Table 1). The application of Panchagavya (3 %) combined with PSB (50 g/bed) and *Azotobacter* (50 g/bed) resulted in early flowering and an extended flowering duration. In pooled data, early flowering was recorded days from planting to first flower in plants treated with Panchagavya (3 %) + PSB (50 g/bed) + *Azotobacter* (50 g/bed) per plot, with durations of 75.56 days. While the maximum number of days taken to produce the first flower (84.21 days) were recorded in the treatment combination of Amritpani (20 %) + PSB (50 g/bed) and Jiva Amrit (20 %) + PSB (50 g/bed). The minimum duration required for the onset of flowering may be attributed to the judicious application of bioenhancers and biofertilizers. The incorporation of organic manures likely contributed to soil amendment by supplying a balanced amount of nutrients. At the same time, the presence of specific bacterial strains may have facilitated their enhanced bioavailability to the plants, thereby promoting superior floral characteristics. Also, the maximum duration of flowering (59.06 days) was observed in plants treated with Panchagavya (3 %) + PSB (50 g/bed) + *Azotobacter* (50 g/bed) per plot. The minimum duration of flowering (49.46 days) was noted in untreated plants. This indicates that the beneficial effects of the biofertilizers and bio enhancers significantly enhanced both the onset and duration of the flowering period. The findings align with those of early works who observed that the earliest flowering occurred with treatments of NPK combined with PSB, NPK with *Azotobacter and* a combination of Vermicompost, *Azotobacter* and PSB (29). Besides a similar advancement in flowering for tomatoes, calendula and Isabgol, respectively, when using biofertilizers. In the pooled data, the highest number of flowers per plant (23.18) was recorded in plots where plants were fertilized with Panchagavya (3 %)

combined with PSB (50 g/bed) and *Azotobacter* (50 g/bed) (Table 1) (30-32). In contrast, the untreated control plants exhibited the lowest number of flowers per plant (13.90). This effect may be attributed to the application of *Azotobacter* and PSB, which likely promoted inflorescence development and increased leaf production in autumn, both of which are positively correlated with the number of flowers and fruits in the subsequent spring. As well, the increase in the number of flowers may have been due to an elevated number of crowns per plant. Similar findings were reported in strawberries, suggesting that higher doses of *Azotobacter* and PSB (each at 7 kg/ha) led to an increased number of flowers per plant (21). Comparable results were also noted in papaya, Banana and in strawberry (33, 34). The minimum number of days from flowering to fruit set (66.70 days) were recorded in plants fertilized with Panchagavya (3 %) + PSB (50 g/bed) + *Azotobactor* (50 g/bed) per plot, whereas unfertilized plants took maximum days (75.21 days) for fruit set in pooled data. These differences might be due to genetic factors and environmental influences like temperature fluctuations, which can impact the time taken for fruits to set (34, 35).

The maximum number of fruits per plant (15.71) was also observed when the plants were treated with Panchagavya (3 %) + PSB (50 g/bed) + *Azotobactor* (50 g/bed) per plot, followed by Jiva amrit (20 %) + PSB (50 g/bed) + *Azotobactor* (50 g/bed) per plot whereas the least number of fruits per plant (9.27) was recorded from untreated plants (Table 2). This variation can be linked to genetic differences, pollination efficiency and other environmental factors that affect fruit set. The results align with those of earlier researchers (36, 37) in strawberries, who found that the treatment of *Bacillus cereus* KI-2 during the flowering induction phase enhanced overall yield and fruit quantity in *Fragaria vesca* 'Hawaii-4' and garden strawberry 'Hoko-wase'. Nonetheless, they observed that the impact of PGPR (plant growth-promoting rhizobacteria administration on these parameters was dependent upon the variety. *Azotobacter* promotes accelerated plant growth, while PSB enhance root development, both contributing to an increased berry set (16).

The data presented in Table 2 clearly indicate that treatment T9 resulted in the longest harvesting duration. Across both years of experimentation and in the pooled data, the maximum harvesting duration (54.47 days) was observed in plants treated with T9. Conversely, the untreated control plants exhibited the shortest harvesting duration (49.41 days).

By applying *Azotobacter* and PSB, the harvesting period was considerably prolonged during the two years of the current study. The maximum harvesting duration (54.47 days) was recorded in plants treated with T9, while the minimum duration of harvesting (49.41 days) was observed in untreated control plants. These results coincide with the early findings who found that 75 % RDF mixed with Azospirillum at 2 g/plant, PSB at 2 g/plant and a 25 % potassium topdressing resulted in a prolonged harvesting period (38). In a comparable fashion reported an advanced harvesting time of almost one month in strawberries, extending the harvesting period overall (21, 39). Furthermore, previous study discovered that applying vermicompost and *Azotobacter* separately and together considerably extended the harvesting period (29). When plants were treated with *Azotobacter* at (6 kg/ha) and vermicompost (30 t/ha), the longest harvesting period of 70.03 days was recorded.

Table 2. Effects of bioinoculants (*Azotobacter* and PSB) and bioenhancers (Panchagavya, Jeevamrit and Amritpani) on the different fruit physical and yield characters of the Chandler variety of strawberry (*Fragaria × ananassa*)

Treatment	No of fruit set/plant	Duration of Harvesting	Fruit length (cm)	Fruit weight (g)	Fruit diameter (cm)	Fruit volume (cc)	Specific gravity (g/cc)	Yield par plant (g)	yield par plot (kg)
T_1	9.27±0.02f	49.41±0.65d	1.96±0.02h	9.72±0.05f	2.23±0.01g	14.44±0.04f	1.08±0.03b	92.94±2.02i	0.55±0.60i
T_2	9.78±0.12f	50.43±0.00cd	1.99±0.04gh	10.14±0.16ef	2.27±0.05g	14.47±0.14f	1.08±0.02b	111.02±1.91h	0.67±0.90h
T_3	11.90±0.24d	51.54±0.40bcd	2.20±0.04ef	10.38±0.13de	2.82±0.04e	15.05±0.27def	1.10±0.02ab	118.16±0.86g	0.71±0.30gh
T_4	10.93±0.01e	51.43±0.27bcd	2.11±0.04fg	10.24±0.06e	2.48±0.04f	14.71±0.19ef	1.08±0.01b	120.54±2.70g	0.72±0.90g
T_5	12.45±0.27c	52.53±0.66abc	2.29±0.04e	10.81±0.11d	3.00±0.02d	15.37±0.37cde	1.10±0.03ab	137.11±1.64f	0.82±0.60f
T_6	12.86±0.19c	53.13±1.16ab	2.78±0.05c	13.67±0.26b	3.35±0.03c	16.12±0.21bc	1.13±0.02ab	174.16±2.54d	1.04±0.30d
T_7	12.62±0.18c	52.73±0.80ab	2.45±0.01d	11.97±0.09c	3.14±0.07d	15.84±0.23bcd	1.11±0.02ab	159.44±2.16e	0.96±0.70e
T_8	13.90±0.05b	53.22±1.17ab	3.12±0.07b	14.03±0.13b	3.49±0.04bc	16.19±0.00bc	1.13±0.01ab	208.68±2.72c	1.25±0.15c
T_9	15.71±0.15a	54.47±0.59a	3.50±0.07a	14.52±0.34a	3.67±0.06a	17.09±0.38a	1.15±0.01a	225.84±0.82a	1.36±0.27a
T_{10}	15.40±0.23a	53.92±0.00a	3.13±0.02b	14.49±0.20a	3.62±0.08ab	16.58±0.42ab	1.14±0.02a	216.73±0.11b	1.30±0.30b

Fruit characteristics

Significant differences were observed for fruit characteristics among all treatments (Table 2). In the present investigation, the application of Panchagavya, PSB and *Azotobacter* markedly enhanced the fruit size (length and diameter), weight and volume of strawberries. The maximum fruit length (3.50 cm), diameter (3.67 cm), weight (14.52 g) and volume (17.09 cc) were recorded in plants treated with Panchagavya (3 %) + PSB (50 g/bed) + *Azotobacter* (50 g/bed) per plot. In comparison, the control treatment, which did not receive any bio-fertilizer treatment, exhibited the minimum fruit length (1.96 cm), diameter (2.23 cm), weight (9.72 g) and volume (14.44 cc) during the same periods. The control treatment consistently exhibited the lowest values, underscoring the significant role of biofertilizer application in enhancing the fruit characteristics of strawberry. Similar findings were reported by earlier researchers, who observed a marked increase in fruit length and weight under treatments comprising 50 % FYM, 50 % vermicompost, Azotobacter and Pseudomonas (28). In the present study, the improvements in fruit weight, width and length may be attributed to enhanced photosynthetic efficiency and nutrient availability facilitated by bioenhancers, *Azotobacter* and PSB. Although dry matter content was not directly measured, the consistent improvement in fruit size and development across treatments suggests increased assimilate accumulation. Thus, it is reasonable to infer that the above factors likely played a critical role in promoting dry matter accumulation in strawberry fruits. Besides, there is a substantial correlation between dry matter percentage and balanced hormonal levels and fruit size, weight and volume. Nitrogen-fixing bacteria are known to play a part in the accumulation and movement of dry matter as well as the promotion of the synthesis of different growth regulators (40). These findings coincide with those of in ber (*Ziziphus mauritiana*) (41), in strawberry (8, 42), in papaya (22) and in strawberry (12).

Yield enhancement

The data represented in Table 2 shows it is evident that both yields per plant (g) and yield per plot (kg) were highest with treatment T9 comprising Panchagavya (3 %), PSB (50 g/bed) and *Azotobacter* (50 g/bed). The results of the present experiment are similar to those reported previously in strawberry (4, 43). In pooled data, the maximum yield per plant (225.84 g) and yield per plot (1.36 kg) were recorded in plants treated with T9. However, the minimum yield per plant (92.94 g) and yield per plot (0.55 kg) were observed in untreated plants (T1). The cumulative effects of Azotobacter and PSB are supported by the findings of previous studies, which reported that the combination of biofertilizers and organic manures resulted in the highest fruit yield per plant (44). Similar trends were also observed for various yield-attributing traits in other studies (13, 29, 36), further reinforcing the positive impact of integrated nutrient management on crop performance.

A higher number of leaves may have contributed to the observed increases in fruit yield and related characteristics because they served as effective photosynthetic systems, increasing the plant's ability to produce carbohydrates. Furthermore, a greater number of flowers probably helped to improve fruit yield and its qualities. Using 50 % FYM, 50 % vermicompost and *Pseudomonas*, (28) observed similar results, with a maximum yield per plant of 185.08 g and a total yield per plot of 4.63 kg. Similar findings for fruit physical characteristics in strawberry have reported earlier many researchers (45-47).

Principal component analysis

Traits such as fruit weight (g), plant height (cm), fruit length (cm), leaf area (cm^2), yield per plant (g), yield per plot (kg), no. of flower per fruit, plant spread (cm), specific gravity (g/cc), came under cluster I (Fig. 1). However, number of runners per plant, fruit weight (g), fruit volume (cc), fruit diameter (cm), no. of leaves per plant, duration of harvesting, duration of flowering and no. of crowns per plant were categorized under cluster II. Days taken to produce first flower, were categorized under cluster III (Fig. 1) and no. of days to fruit set, categorized under group IV. The PCA biplot indicated that Clusters I and II significantly contributed to PC1, which was strongly associated with treatment T9.

Length and intensity of colour of a vector in biplot expressed how well the qualities are represented and how much they share to the principal components. Traits with longer arrows have a greater contribution to the variability explained by PC1 or PC2. Traits pointing more towards PC1 (x-axis) primarily contribute to PC1 and those pointing towards PC2 (y-axis) contribute to PC2. Most of the parameters in the biplot are in proximity, it indicates strong positive correlations among traits, reflecting shared variability and common underlying factors such as environmental conditions or treatments

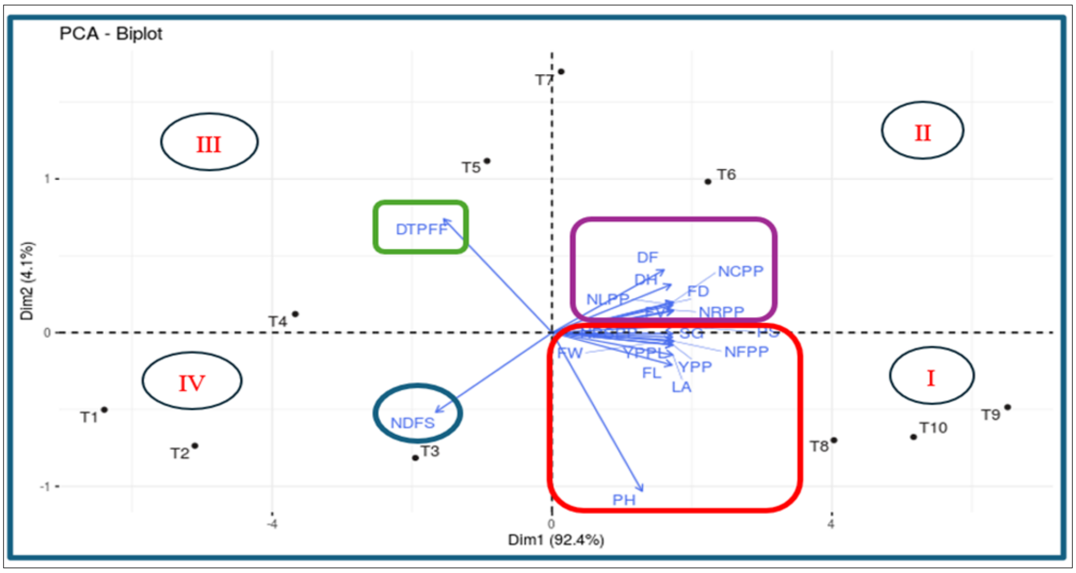

Fig. 1. PCA showing correlation between different treatments and variables.

influencing plant performance collectively. This clustering suggests that these traits contribute similarly to the principal components (PC1 and PC2), with overlapping effects that can make it challenging to isolate the impact of individual parameters. For example, traits like plant height (PH) and leaf area (LA) may respond similarly to water and nutrient availability, while number of fruits per plant (NFPP) and number of crowns per plant (NCPP) might increase under optimal fertility. However, this proximity also highlights potential redundancy in measurements, where some traits provide overlapping information and multicollinearity issues in statistical models, requiring dimensionality reduction techniques like PCA.

Character association for different growth and yield related characters of strawberry

Pearson correlation coefficient analysis was performed to evaluate the effects of bioinoculants (*Azotobacter* and PSB) and bioenhancers (Panchagavya, Jeevamrit and Amritpani) on the growth and yield of the Chandler variety of strawberry (*Fragaria* × *ananassa*) (Fig. 2). The study revealed that trait, plant height (cm) had a positive and significant relationship with leaf area (cm^2), no. of flower per fruit, number of fruit set/plant, fruit length (cm), specific gravity (g/cc), plant spread (cm^2), yield per plot (kg), yield per plant (g), no. of leaves per plant, fruit diameter (cm), no. of runners per plant, fruit weight (g), no. of crowns per plant, fruit volume (cc) and duration of harvesting. The present investigation revealed that the number of crowns per plant showed a positive and significant association with no. of runners per plant, fruit diameter (cm), no. of leaves per plant, no. of flower per fruit, duration of harvesting, no. of fruit set/plant, fruit volume (cc), plant spread (cm^2), yield per plant (kg), yield per plot, specific gravity (g/cc), leaf area (cm2), fruit weight (g), duration of flowering and fruit length (cm), in contrast same trait exhibit significant and negative correlation with no. of days to fruit set and days taken to produce first flower. Yield is an important characteristics for any crop hence its correlation with other traits is essential, traits such as yield per plot (kg), fruit length (cm), fruit weight (g), leaf area (cm^2), plant spread (cm^2), fruit volume (cc), no. of flower per fruit, no. of runners per plant, no. of crowns per plant, specific gravity (g/cc), no. of fruit set/plant, fruit diameter (cm), no. of leaves per plant, duration of harvesting and duration of flowering showed a positive and significant association with yield per plant (kg), this indicates that

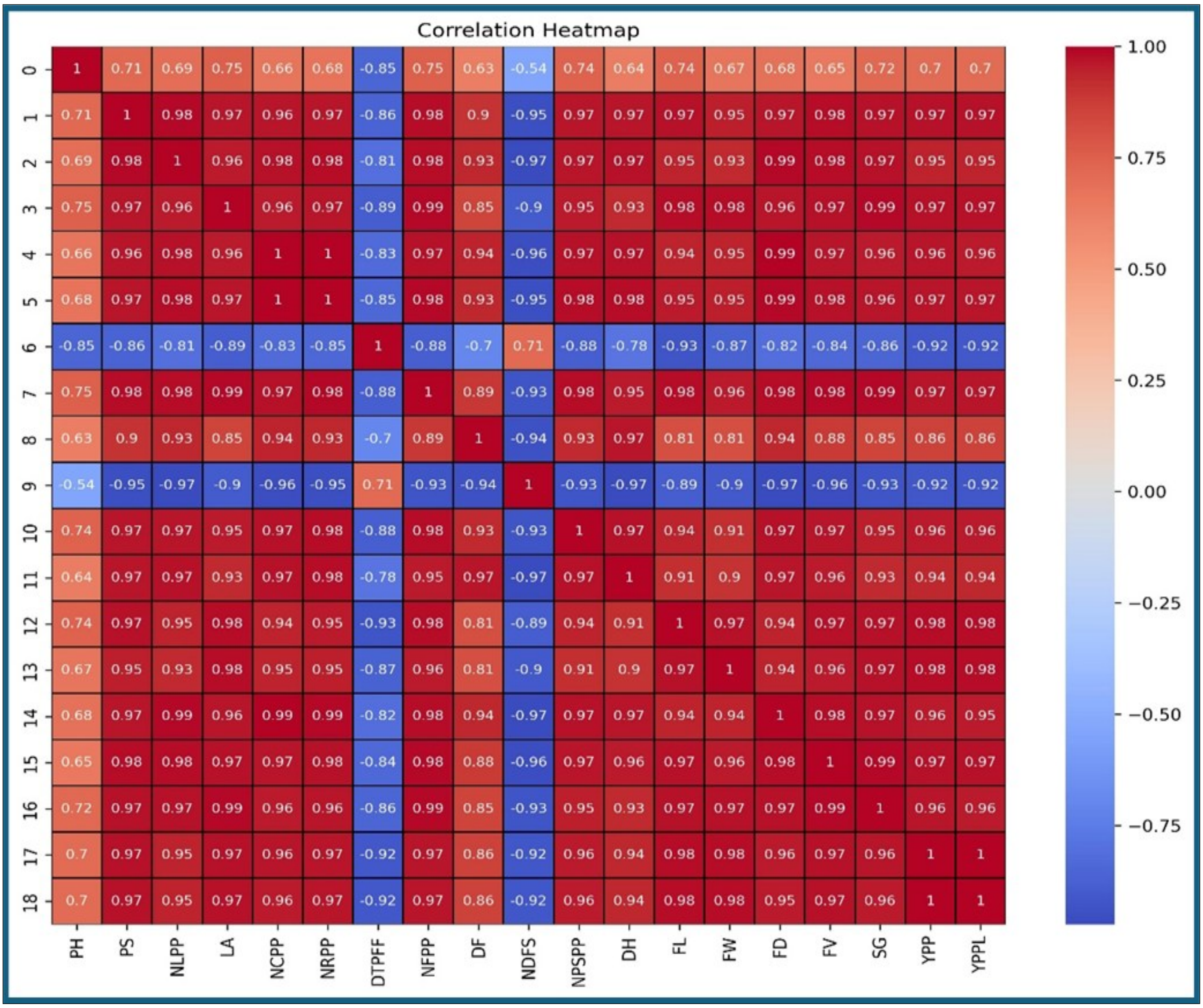

Fig. 2. Correlation analysis of bio-fertilizers and bio - enhancer on growth, yield of strawberry.

PH = plant height (cm), PS = plant spread (cm), NLPP = number of leaves per plant, LA = leaf area (cm^2), NCPP = number of crowns per plant, NRPP = number of runners per plant, DTPFF = days taken to produce the first flower, NFFF = number of flowers per fruit, DF = duration of flowering, NDFS = number of days to fruit set, NFSPP = number of fruit set per plant, DG = duration of harvesting, FL = fruit length (cm), FW = fruit weight (g), FD = fruit diameter (cm), FV = fruit volume (cc), SG = specific gravity (g/cc), YPP = yield per plant (g) and YPPL = yield per plot (kg).

these traits collectively contribute to yield per plant (kg), signifying their importance in yield improvement strategies. However, the same trait showed a significant negative correlation with the no. of days to fruit set and the days required for first flowering.

Conclusion

The findings show that application of biofertilizers and bioenhancers simultaneously improves the host plant's utilization of soil nutrients, leading to higher strawberry yields and better quality. As a result, it can be said that combining biofertilizers with bioenhancers is a good way to produce cost-effective, high-quality strawberries in a sustainable manner. This approach is particularly advantageous for smallholder farmers who operate with limited resources and low input capacity.

Further research on scaling and optimizing these bioinputs across diverse agro-climatic conditions is recommended.

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Authors' contributions

SS conducted the experiment and wrote the main manuscript text. VKT provided substantial guidance and facilitated the research by offering necessary laboratory facilities. SS assisted with data analysis. VKT provided experimental guidance and contributed to the manuscript draft preparation. All authors reviewed and approved the manuscript.

Compliance with ethical standards

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