Original Research Article

Impact of biofertilizer combinations on quality, yield, and economic returns of strawberry in central region of Punjab

ABSTRACT

Strawberry is a globally cherished fruit, celebrated for their sweet flavor, vibrant color, and rich nutritional profile. The use of biofertilizers in strawberry cultivation is gaining importance in India due to their eco-friendly and sustainable nature. Biofertilizers enhance soil fertility by promoting beneficial microbial activity, which improves nutrient availability and uptake by strawberry plants. This leads to healthier crops with better yields and quality by reduced application of inorganic fertilisers. It ultimately benefits both the environment and farmers' long-term productivity. The experimental results revealed that T_8 (RDF + *Azotobacter* @ 2g/plant + PSB @2g/plant + *Azospirillum* @2g/plant) significantly increased the plant height (16.82 cm), plant spread (32.78 cm), fruit length (45.88 mm), breadth (38.96 mm), weight (12.76 g), TSS (9.42 °Brix), anthocyanin content (26.14 mg/100g) and yield attributes *i.e.*, yield plant^{-1} (238.88 g) and yield hectare^{-1} (13.14 t/ha). It also found that the plants treated with T_8 (RDF + *Azotobacter* @2g/plant + PSB @2g/plant + *Azospirillum* @2g/plant) had maximum leaf nutritional content, namely - nitrogen (3.09%), phosphorus (1.37%), potassium (3.39%), calcium (2.37%) and magnesium (0.39%) and also gave highest net return *i.e.*, Rs 16,61,790 /ha with highest B:C ratio of 3.77. Hence, it can be concluded that the treatment T_8 is most suitable for improving the quality, yield and economic return of strawberry in central region of Punjub.

Keywords: fruit quality, leaf nutrient, microbial activity, net returns, nutrient

INRODUCTION

Strawberry (*Fragaria* × *ananassa*) is a hybrid, octaploid, perennial herb from the Rosaceae family, valued for its rich antioxidant content. In India, four wild species of strawberry are found, thriving in diverse climates, including altitudes up to 12,000 feet (Hossain *et al*., 2019, Jideani *et al*., 2021). In strawberries, indiscriminate and prolonged use of inorganic chemical fertilisers and pesticides raises production costs while contaminating the environment, water, and soil by volatilisation, runoff, leaching, and denitrification. It negatively affects the fertility, vegetation, and fauna of the soil. A beneficial microorganism found in bio-fertilizers includes *Azospirillum, Azotobactor, Pseudomonas, Bacillus, Mycorrhizae fungi, Aspergillus, and Penicillium*. These microorganisms play vital role to boost nutrient availability, absorption, and biological activity in the rhizosphere to affect plant growth and health. According to Reddy et al. (2020), biofertilizers helps in nitrogen fixation from the atmosphere and phosphorus solubilization which aid host plants in tolerating abiotic stress and resisting diseases. Bio-fertilizers are living microorganisms (useful bacteria and fungi) which, by nitrogen-fixing, significantly contribute to enhancing soil fertility, solubilise insoluble soil phosphates, potassium removable and improving plant production (Kumar *et al*., 2019a; Nosheen *et al*., 2021). They contribute significantly to crop productivity and are environmentally beneficial. According to Mishra and Barolia (2020), bio-fertilizers or microbial inoculants, are carrier-based preparations contain advantageous microbes that increase biological activity in the rhizosphere with the goal of enhancing soil

fertility and facilitating plant growth. In other words, biofertilizers depend on renewable energy sources, which are more eco-friendly than inorganic fertilizers (Kaur and Purewal, 2019).

Azotobacter is capable of carrying out a variety of metabolic tasks, including fixing atmospheric nitrogen by converting it to ammonia. The organism with the greatest metabolic rate is *Azotobacter* spp. (Hindersah *et al.*, 2020). Phosphorus-solubilizing bacteria (PSB) are necessary for the transformation of insoluble phosphatic substances such as rock phosphate, bone meal and basic slag into forms that can be utilised (Kumawat *et al.*, 2021). *Azospirillum* is capable of increasing plant growth under abiotic stresses by a variety of mechanisms including antioxidants, osmotic adjustment, phytohormones production, and defence strategies such as pathogen-related gene expression (Jehani *et al.*, 2023).

In the Punjab region, the excessive use of chemicals and inorganic fertilizers in most fruit crops has led to reduced productivity and declining soil health, ultimately affecting overall returns (Gulati *et al*., 2021). To address these concerns, this study was conducted to explore the use of various biofertilizers to improve the health and quality of strawberries.

MATERIALS AND METHODS

The present study was conducted at the Agriculture Research Farm, Department of Agriculture, Mata Gujri College, Sri Fatehgarh Sahib, Punjab. The research farm is situated between 30° 56' 11.90"N latitudes and 76° 18'13.18"E longitudes and at a mean height of 279 meter above sea level. This study examined the influence of several bio-fertilizers treatments as shown in Table 1. The experiment was divided into 24 sub-plots with dimensions of 15 × 1 m. Every plot had three replications and eight treatments under completely Randomized Block Design (CRBD). The significance of variation among the treatments were determined using the ANOVA and critical difference (CD) was tested at 5% ($p<0.05$) level of significance.

The climatic condition of Sri Fatehgarh Sahib was sub-tropical with three distinct seasons *i.e.*, winter, summer and rainy. During the winter months (December-January), temperatures fall 5-9°C or even lower, while in the summer month (May-June) they reach as high as 41-43°C occasional spells of frost and precipitation may occur during winters. Most of rainfall is received in the middle of July to end of September after which the intensity of rainfall decreases. The mean annual rainfall is about 67 cm and soil physicochemical properties shown in Table 2.

The plot was divided into 24 sub plots and the dimension of each plot was 15 m × 1 m. The experiment was laid out in a randomized block design with eight treatments and three replications.

Field preparation

The experimental plot was well prepared by repeated ploughing followed by planking to obtain a fine tilth in last week of September. All the weeds, grass residue were removed from the field followed by planking. Rising of beds, 25 cm in height was prepared for planting the runners.

Planting material

Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter dawn was used for present study. The one-year-old healthy runners of the Winter dawn variety were procured from strawberry grower Virender Verma, Kanog, Sirmour (Himachal Pradesh). Prior to planting roots of runners were treated with Bavistin solution (1 g in liter of water). Roots were dipped in this solution for 1-2 minutes. The strawberry runners having cut the 2/3rd portion of leaves were planted on raised bed of 3 m x 0.80 m size at 40 cm x 30 cm distance with the help of khurpi in the first week of October. The runners were planted taking care that the crown of runners lie just at the surface of the soil, so that the crown remained exposed but all the roots buried thoroughly. The Soil around the plant was packed and patted firm around the base of stem. After planting the plants were watered.

Application methods of fertilizers and bio-fertilizers

Under soil fertilization, a full dose of P_2O_5, K_2O and half dose of nitrogen along with FYM 60 MT/ ha are applied at the time of preparation of beds for planting. These fertilizers are applied in the beds and mixed in the soil. Second half dose of nitrogen was applied in December (before flowering). Water soluble fertilizer like N:P:K (19:19:19), (0:0:50) and Urea are used in experimental field to fulfill the recommended dose of fertilizers in strawberry crop. Bio fertilizers are applied after 45 days of planting according to various treatment combinations. These fertilizers are applied to the plant by mixing it with the soil (2g bio-fertilizer + 2g soil).

VEGETATIVE GROWTH ATTRIBUTES OF PLANT

Plant height: A metre scale was used to measure the plant's elevation from the primary leaf apex to the crown and the findings stated in terms of centimetres (cm). The final number was determined based on the average plant height of five plants.

Plant spread: The maximum spread of plants were recorded east-west and north-south directions separately in centimeter (cm) with the help of a measuring tape and the average of five branches for each directions was calculated to express mean value.

Leaf area: The leaf area of strawberry was measured using the leaf area meter (Systronics Leaf Area Meter 211). To calculate the overall leaf area of a single plant and the outcome should be expressed in cm and calculated by multiplying the average area of each leaf by the number of leaves.

FLOWERING CHARACTERS OF PLANT

Days taken to first flower: The interval between the opening date of first flower and the planting date has been noted in order to calculate the number of days required to generate the first flower.

Number of flowers per plant: The overall quantity of flowers was noted at 10-day intervals, and the average quantity of flowers per plant was calculated to ascertain the quantity of flowers per plant.

FRUIT QUALITY ATTRIBUTES

Fruit length: A digital vernier calliper was used to measure the length of the fruit, and the mean of the observations was computed and expressed in millimetres.

Fruit breadth: The fruit diameter was measured using Digital Vernier Callipers on the same fruits used to measure length, and the mean was given in millimetres.

Fruit weight: After weighing the ten fruits on the above list, the total weight of the fruits was calculated and expressed in grammes.

Total soluble solids: The strained juice of the fruits was analysed for TSS using a 'Erma-hand refractometer' (0 to 32 ºBrix). The refractometer was calibrated with distilled water prior to use and to measure the TSS, a few drops of juice were put on the prism. A temperature correction was performed when it was above or below 20ºC (AOAC, 2002). An average of three readings per treatment was recorded and expressed as ˚Brix.

Titrable acidity **:** The titratable acidity was determined by titrating the juice against standard alkali solution (0.1N NaOH). 10 ml of juice was taken by means of pipette and was transferred into 100 ml volumetric flask and distilled water was added to make the volume 100 ml. 10 ml aliquot of diluted juice was pipetted out and transferred in 250 ml beaker. 1-2 drops of phenolphthalein indicator was added to the solution. The juice of conical flask was titrated against 0.1N NaOH solution. The alkali was added drop by drop to the conical flask with constant stirring until the end point was reached with appearance of pink colour. The percentage of acidity was calculated from the following formula (A.O.A.C. 2002).

$$\text{Acidity (\%)} = \frac{1 \times \text{Eq. Wt of acid} \times \text{Normality of NaOH} \times \text{Titre}}{10 \times \text{Weight of sample}} \times 100$$

Total sugar: Twenty five grams of fruit pulp was taken in a 250 ml volumetric flask and thoroughly homogenized in distilled water. To this 10 ml of 45 per cent saturated lead acetate was added and the contents were shaken and filtered and kept for ten minutes. Thereafter, ten ml of 22 per cent potassium oxalate was added to precipitate the excess of lead and make the final volume 250 ml with distilled water. Then the contents were again filtered and 100 ml of the filtrate was taken in another 250 ml volumetric flask and 5 ml of concentrated hydrochloric acid was added to it. The hydrolysis was carried out by keeping it overnight.

The excess of acid was then neutralized by adding saturated sodium hydroxide and the final volume was made to 250 ml with distilled water. The hydrolyzed aliquot was then taken in a burette and titrated against a boiling mixture of 5 ml solution each of Fehling A and Fehling B using methylene blue as an indicator (A.0.A.C. 1980). The end point was indicated by the appearance of brick red colour. Total sugars were expressed in per cent on fresh fruit weight basis.

$$\text{Total sugar (\%)} = \frac{\text{Fehling factor} \times \text{Dilution} \times \text{Dilution}}{\text{Titre value} \times \text{Volume of aliquate taken for measurement} \times \text{Weight or volume of sample taken (g)}} \times 100$$

Fehling Factor = 0.052

Reducing sugar: The remaining filtered stock solution was used for determination of reducing sugars. Boiling solution mixture containing 5 ml each of Fehling A and Fehling B reagents was titrated against remaining unhydrolyzed, de-leaded and clarified pulp solution obtained from above total sugars solution using methylene blue as an indicator. The end point was indicated by the appearance of brick red colour. The results were expressed as per cent on fresh fruit weight basis as given in (A.O.A.C. 1980).

$$\text{Reducing sugar (\%)} = \frac{\text{Fehling factor} \times \text{Dilution}}{\text{Titre value} \times \text{Weight or volume of sample taken (g)}} \times 100$$

Fehling Factor 0.052

Non-reducing Sugar

$$\text{Non-reducing sugars} = (\text{Total sugars} - \text{reducing sugars}) \times 0.95$$

Anthocyanin content: Anthocyanin pigments of fruit were determined by the method given by Harborne (1973).One gram of berry pulp was taken in a 5ml of methanol containing 1 per cent hydrochloric acid. The contents were allowed to stay overnight Sub-zero temperature in a deep freezer, The absorbance of resultant red coloured solution was recorded at 530 nm on Spectronic-20 colour was read colorimeter. The intensity of colour was read and expressed in absorption units per gram of fresh berry.

Leaf analysis

Collection and preparation of leaf samples

Composite samples for each replication were taken during the month of January from the plant with a total of 20 leaves from each treatment. From the plants that were marked, leaves, including petioles from the mid-terminal shoots of the growth for this season, were gathered. The leaf samples were carried directly to the laboratory and properly cleaned with tap water before being treated with 0.1N HCl and distilled water to eliminate dust particles, as described by Chapman (1964). For surface drying, the washed leaf samples were placed on sheets of filter paper. After that, they were put in paper bags and left for 48 hours at 65 ± 5˚C to dry in a hot air oven. The dehydrated samples were finely pulverized and homogeneous. The ground samples were subsequently stored in butter paper bags and kept in cold and shady place to estimate nutritional components.

Digestion of leaf samples

Leaf samples (1 g) was processed in intense H_2SO_4 with a mixture of K_2SO_4 (400 parts), $CuSO_4$ (20 parts), $HgSO_4$ (3 parts), and Se (1 part) for total nitrogen measurement. The samples were kept boiling until they turned a pale blue tint. Following cooling, the samples were diluted with 100 millilitres of distilled water. The appearance of a slight crimson tint marked the conclusion. To compute P, K, Ca, and Mg, 0.5 g of leaf sample was digested in a di-acid mixture of HNO_3 and $HCLO_4$ in a 4:1 ratio, adopting all appropriate precautions as recommended by Piper (1966).

Nitrogen: The total N was calculated using Micro-Kjeldhal's method (Jackson, 1967), and the outcomes were represented as percent nitrogen on a dry weight basis.

Phosphorus: The Vanado-molybdate Phosphoric Yellow Colour Method (Jackson, 1967) was used to measure total phosphorus. 10 ml of digested aliquot was pipetted into a 25 ml volumetric flask, then 5 ml of vanado molybdate reagent was added in to it. After adding distilled water to dilute the solution to 25 ml, it was left to develop colour for 30 minutes. Following colour development, the concentration of phosphorus in the solution was measured using 470 nm wavelength in Nukes UV-VIS spectrophotometer, with a blank run in parallel to adjust zero absorption. The leaf P was represented in percent on a dry weight basis.

Potassium, Calcium, Magnesium: Total potassium content was assessed utilising the Agilent 5110 ICP-OES as suggested by Jackson (1973) and the results were expressed in per cent (%). Using an Analyst 400 Atomic Absorption Spectrometer, total calcium and magnesium were measured.

Economics (: Cost of cultivation per hectare was calculated on the basis of expenditure on various inputs, cultural and managerial aspects. This expenditure was subtracted from the gross calculated income based on prevailing market selling rate, which gave net profit per hectare. Benefit-cost ratio was calculated by dividing net return to cost of cultivation.

Cost of cultivation: After taking into consideration the variables as well as fixed inputs and corresponding price, the cost of cultivation on each treatment was worked out.

Gross income: Similarly gross income was calculated for each treatment based on market rate of the produce.

Net returns: Net returns were then computed by deducting the total cost of cultivation from the gross income for each treatment.

Net return = Gross income – Total cost of cultivation.

Benefit cost ratio: The cost benefit ratio was calculated by dividing the net returns with total cost of production.

$$\text{Benefit: cost ratio} = \frac{\text{Net return}}{\text{Total cost of production}}$$

RESULTS AND DISCUSSION

Vegetative growth attributes

The data collected for the various growth attributes are displayed in Table.3 which stated that the highest plant height (16.82 cm), plant spread (32.78 cm), number of leaves plant^{-1} (20.00), leaf area (121.53 cm^2) were recorded in T_8 (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant). However, the application of T_1 (control) resulted the minimum plant height (10.66 cm), plant spread (22.90 cm), number of leaves plant^{-1} (11.87), and leaf area (101.02 cm^2). According to Beer *et al.* (2017), the capacity of a biofertilizer to produce antibacterial and antifungal compounds is linked to its growth-promoting properties, in addition to its N-fixing capabilities, growth regulators, and siderophores, resulting in increased vegetative development of strawberries. The use of biofertilizers such as PSB and *Azospirillum* improves biological N_2 fixation and phosphorus availability, both are essential for vigorous vegetative growth (Kumar *et al*., 2019b, Kumar *et al.*, 2015). These findings are consistent with those of Negi *et al.* (2021), Kumar *et al.* (2021) and Kumar *et al*. (2023).

Flowering characteristics

The outcome demonstrated from Table 4. showed the plants need a minimum of 58.99 days to generate their first blooming which were treated with T_8 (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant). However, maximum number of days taken to induce first flowering (70.55days) was noted in T_1 (control). The highest number of flowers plant^{-1} (24.13) was recorded in T_8 (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant) and lowest number of flowers plant^{-1} (14.60) were recorded in T_1 (control). According to Bashandy *et al.* (2019), *Azotobacter* and *Azospirillum* reduced the number of days for the first flower to bloom compared to the control in both years. It's feasible that application of bio-fertilizers makes nitrogen more available to plants, forcing them to transition from the vegetative to reproductive phase earlier. Strawberry plants treated with biofertilizers took the fewest days to produce their first blossom, according to research by Tripathi *et al.* (2016). Similar outcomes have also been documented by Singh *et al.* (2015), Kushwah *et al.* (2018), Kumar *et al.* (2019a) and Jaiswal *et al.* (2023).

Yield characteristics

Table 4. represented the combination of biofertilizers had a notable variance in the quantity of fruits, yield plant^{-1}, and yield hectare^{-1}, where highest number of fruits plant^{-1} (18.73), yield plant^{-1} (238.88 g) and yield hectare^{-1} (13.14 t/ha) was found in the plants that received RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant (T_8). However lowest number of fruits plant^{-1} (10.87), yield plant^{-1} (91.04 g) and yield hectare^{-1} (5.01 t/ha) was noted in control plants. Increased production could also be attributed to improved nutrient absorption and utilisation due to the combined use of inorganic and organic fertilisers, as well as bio-fertilizers (Kumar *et al*., 2024). The biofertilizer's positive effect on harvesting duration and fruit yield could be attributed due to advantageous effects on vegetative growth and flowering, which probably gave the inoculated plants access to more photosynthates for a longer period of time, boosting fruit yield and lengthening the harvesting season (Gupta and Tripathi,2012). Similar outcomes were reported by Jain *et al.* (2017), Singh *et al.* (2015), and Reddy and Goyal (2020).

Physico-chemical attributes of the fruit

A considerable rise in fruit length, width, and weight was observed under this experiment (Table 5). The highest fruit length (45.88 mm), breadth (38.96 mm), weight (12.76 g) along with the quality attributes viz. total soluble solid (9.42 °Brix), total sugar (7.58 %), reducing sugar (4.38 %) and anthocyanin content of the fruit (26.14 mg/100g) were recorded in treatment T_8 (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant). However, minimum fruit length (34.31 mm), breadth (31.43 mm), weight (8.38 g), total soluble solid (6.90 °Brix), total sugar (5.68 %), reducing sugar (3.73 %) and anthocyanin content of the fruit (16.39 mg/100g FW) were estimated in treatment T_1 (control). The appropriate supply of macro and micronutrients may have contributed to the improved fruit physical as well as biochemical quality. Further, hormones that promote growth are also generated by different biofertilizers used in varied combinations with RDF treatments. This may be related to more fruit filling from a more balanced food intake, which may have enhanced the plant's metabolic processes and increased the synthesis of proteins and carbohydrates (Kumar *et al*., 2024; Nazir *et al.*, 2015). The release of growth-promoting compounds, the increased availability of P and the improved ability of microbial inoculants to fix atmospheric N that quicken physiological processes like carbohydrate synthesis could all be responsible for greater ascorbic acid content in the harvested fruits (Beer *et al.*, 2017). Rise in anthocyanin pigment following the administration of nitrogen and *Azotobacter* is consistent with the results of Kumar *et al.* (2019a), who noticed strawberry's increased red pigment following the simultaneous treatment of nitrogen and bio-fertilizers. The given results are consistent comparing said by Kumar *et al.* (2023), Singh *et al.* (2018) and Jain *et al*. (2017).

Leaf nutrient content

The results showed in Table 6. demonstrated that the maximum leaf nutritional content namely, nitrogen (3.09%), phosphorus (1.37%), potassium (3.39%), calcium (2.37%) and magnesium (0.39%) were recorded in T_8 (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant) and minimum nitrogen (2.21%), phosphorus (0.94%), potassium (2.15%), calcium (1.70%) and magnesium (0.11%) were recorded in T_1 (control) (Table 4). The intake of any nutrient from the soil has a significant impact on how much of it

accumulates in the leaves. Weinbaum *et al.* (1978) discovered the presence of leaves was necessary for nitrate uptake in prune trees, and they addressed this phenomenon in terms of the supply of leaf carbohydrates. In a similar vein, adding FYM and vermicompost that had been enhanced with *Pseudomonas* and *Azotobacter* increased the phosphorus levels in strawberry leaves (Negi *et al.,* 2021). Yadav (2010) found that increased nitrogen application led to an increase in nitrogen and phosphorus content in peaches. Furthermore, Azotobacter and PSB boosted leaf phosphorus content, indicating that biofertilizers may have produced a specific microbial community in the roof rhizosphere zone to improve phosphorus absorption. Singh *et al.* (2012) and Verma and Rao (2013) found that organic manures and biofertilizers had a similar favourable effect on the NPK content of strawberry leaves. These findings unequivocally demonstrate that bacterial strains would have facilitated the correct uptake of soil nutrients and that the nutritional condition of leaves was positively correlated with increased availability of soil nutrients.

Soil health attributes

In the current study's, the application of bio-fertilizers in combination with RDF had a substantial effect on soil electrical conductivity, organic carbon, and soil pH (Table 7). Lowest soil pH (7.13) and soil electrical conductivity (0.36 dS/m) were measured after applying T_8 treatment (RDF + Azotobacter @ 2g/plant + PSB @ 2g/plant + Azospirillum @ 2g/plant). However, maximum soil pH (7.70), soil electrical conductivity (0.65 dS/m) was resulted in treatment T_1 (control). On the other side highest organic carbon (0.64%), available nitrogen (349.93 kg/ha), phosphorus (59.17 kg/ha) and potassium content (150.77 kg/ha) was recorded in T_8 (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant) and minimum organic carbon (0.41%), available nitrogen (271.57 kg/ha), phosphorus (36.70 kg/ha) and potassium content (127.97 kg/ha) was observed in T_1 (control) (Table 5). Bio-fertilizers may have boosted biological nitrogen fixation and phosphate solubilisation, resulted in an increase in available N and P content. Singh *et al.* (2012) also indicated that bio-fertilizers improved plant growth and had a direct impact on N_2-fixation and phosphorous mobilisation in strawberry plants. Addition of phosphate-solubilizing microorganisms to inorganic fertilisers also had a considerable impact on the accumulation of accessible phosphorous in the soil. These results align with Sau *et al.* (2017) and Kumar *et al*. (2019a).

ECONOMIC ATTRIBUTES

Economics of strawberry cultivation influenced by different treatments of bio-fertilizers is presented in Table 8. The cost of cultivation of strawberry cv. Winter Dawn computed, in open field circumstances, treatment-wise, for a single season for one hectare area. The result indicated that net return was higher in treatment T_8 (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant). Data pertaining to economics of different treatments showed that maximum gross income (21,02,150 ₹/ha), net return per hectare (16,61,790 ₹/ha) and B:C ratio (3.77) for strawberry production was calculated with the application of RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant. Whereas, the minimum net return per hectare (3,98,969 ₹/ha), gross income (8,01,128 ₹/ha) and B:C ratio (0.99) was estimated with treatment T_1 (control) (Table 8). The increased yield of high-quality fruits may account for the rise in benefit-to-cost ratio (Kumar *et al*. 2018). These results concur with Hazarika *et al.* (2016), Pardeep and Saravanam (2017) and Jaiswal *et al.* (2023).

CONCLUSION

From the entire experiment, it can be concluded that treatment T_8 (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant) is the best treatment for strawberry cultivation with respect to in all the attributes. The treatment significantly increased the vegetative growth (plant height, plant spread, number of leaves, leaf area), flowering attributes (days taken for first flowering and no. of flowers per plant) in strawberry plant. In case of physico-chemical attributes, soil attributes and yield attributes, the maximum result was also obtained with T_8 (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant) as compared to all other treatment combination and also gave us maximum net return (₹ 16,61,790) and highest B:C ratio.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Table 1. Detail of treatments

Treatments	
T_1	Control
T_2	RDF + *Azotobacter*@2g/plant
T_3	RDF + PSB@2g/plant
T_4	RDF + *Azospirillum*@2g/plant
T_5	RDF + *Azotobacter*@2g/plant + PSB@2g/plant
T_6	RDF + *Azotobacter*@2g/plant + *Azospirillum*@2g/plant
T_7	RDF + PSB@2g/plant + *Azospirillum*@2g/plant
T_8	RDF + *Azotobacter*@2g/plant + PSB@2g/plant + *Azospirillum*@2g/plant

RDF (Recommended dose of fertilizer) @ 19:19:19 (N:P:K), PSB (Phosphate solubilizing bacteria)

Table 2. Initial fertility status of soil

Parameters	Value obtained
pH	7.8
EC (dSm^{-1})	0.29
Organic carbon (%)	0.45
Available N (kg ha^{-1})	267.28
Available P (kg ha^{-1})	41.92
Available K (kg ha^{-1})	109.37

Table 3: Effect of biofertiizer on vegetative growth attributes of strawberry cv. Winter Dawn

Treatment	Plant height (cm)	Plant spread (cm)	Number of leaves per plant	Leaf area (cm^2)
T_1	10.66^{e}	22.90^{h}	11.87^{f}	101.02^{h}
T_2	13.59^{c}	27.93^{e}	14.73^{d}	113.45^{d}
T_3	12.22^{d}	27.22^{f}	13.60^{e}	110.37^{f}
T_4	11.69^{d}	26.57^{g}	13.13^{e}	106.76^{g}
T_5	15.01^{b}	31.48^{b}	18.73^{b}	119.10^{b}
T_6	14.89^{b}	29.98^{c}	17.07^{c}	116.53^{c}
T_7	13.9^{c}	29.18^{d}	15.27^{d}	112.02^{e}
T_8	16.82^{a}	32.78^{a}	20.00^{a}	121.53^{a}
$C.D._{(0.05)}$	0.70	0.62	0.65	0.62

SE(m)	0.23	0.20	0.21	0.20
SE(d)	0.32	0.29	0.30	0.28

T_1 : (Control), T_2 : (RDF + *Azotobacter* @ 2g/plant), T_3 : (RDF + PSB @ 2g/plant), T_4 : (RDF + *Azospirillum* @ 2g/plant), T_5 : (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant), T_6 : (RDF + *Azotobacter* @ 2g/plant + *Azospirillum* @ 2g/plant), T_7 : (RDF +PSB @ 2g/plant + *Azospirillum* @ 2g/plant), T_8 : (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant)

Table 4: Effect of biofertiizer on flowering and yield characteristics of strawberry cv. Winter Dawn

Treatment	Days taken to first flowering	Numbers of flower per plant	Number of fruits per plant	Yield per plant (g)	Yield per hectare (t/ha)
T_1	70.55^{a}	14.60^{g}	10.87^{g}	91.04^{g}	5.01^{g}
T_2	63.33^{d}	19.53^{d}	14.87^{e}	165.41^{d}	9.09^{d}
T_3	67.77^{bc}	17.80^{e}	14.40^{e}	153.41^{e}	8.44^{e}
T_4	68.55^{b}	16.73^{f}	13.53^{f}	132.86^{f}	7.31^{f}
T_5	60.77^{e}	23.00^{b}	17.73^{b}	198.57^{b}	10.92^{b}
T_6	62.55^{d}	21.60^{c}	16.80^{c}	187.57^{c}	10.32^{c}
T_7	66.66^{c}	20.73^{c}	15.80^{d}	165.10^{d}	9.08^{d}
T_8	58.99^{e}	24.13^{a}	18.73^{a}	238.88^{a}	13.14^{a}
$C.D._{(0.05)}$	1.75	0.92	0.74	7.76	0.43
SE(m)	0.57	0.30	0.24	2.54	0.14
SE(d)	0.85	0.43	0.34	3.59	0.19

T_1 : (Control), T_2 : (RDF + *Azotobacter* @ 2g/plant), T_3 : (RDF + PSB @ 2g/plant), T_4 : (RDF + *Azospirillum* @ 2g/plant), T_5 : (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant), T_6 : (RDF + *Azotobacter* @ 2g/plant + *Azospirillum* @ 2g/plant), T_7 : (RDF +PSB @ 2g/plant + *Azospirillum* @ 2g/plant), T_8 : (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant)

Table 5: Effect of biofertiizer on physico-chemical attributes of strawberry cv. Winter Dawn

Treatment	Berry length (mm)	Berry breadth (mm)	Berry weight (g)	TSS (°Brix)	Total sugar (%)	Reducing sugar (%)	Anthocyanin content (mg/100g FW)
T_1	34.31^{e}	31.43^{e}	8.38^{e}	6.90^{c}	5.68^{d}	3.73^{d}	16.39^{d}
T_2	40.42^{c}	35.77^{b}	11.13^{b}	8.13^{b}	6.12^{d}	4.04^{b}	20.29^{c}
T_3	39.71^{c}	34.11^{c}	10.65^{c}	8.17^{b}	6.76^{bc}	4.08^{b}	17.65^{d}

T_4	35.18^{e}	33.03^{cd}	9.82^{d}	8.37^{b}	6.63^{c}	3.82^{cd}	17.92^{d}
T_5	42.27^{b}	36.74^{b}	11.20^{b}	8.95^{ab}	7.18^{b}	4.29^{a}	22.57^{b}
T_6	39.11^{cd}	36.08^{b}	11.16^{b}	8.53^{b}	7.01^{bc}	4.05^{b}	23.93^{ab}
T_7	37.52^{d}	32.79^{d}	10.45^{c}	8.15^{b}	6.98^{bc}	3.96^{bc}	18.74^{cd}
T_8	45.88^{a}	38.96^{a}	12.76^{a}	9.42^{a}	7.58^{a}	4.38^{a}	26.14^{a}
C.D.$_{(0.05)}$	1.74	1.21	0.36	0.81	0.40	0.15	2.28
SE(m)	0.57	0.39	0.12	0.26	0.13	0.05	0.74
SE(d)	0.80	0.56	0.16	0.37	0.19	0.07	1.05

T_1 : (Control), T_2 : (RDF + *Azotobacter* @ 2g/plant), T_3 : (RDF + PSB @ 2g/plant), T_4 : (RDF + *Azospirillum* @ 2g/plant), T_5 : (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant), T_6 : (RDF + *Azotobacter* @ 2g/plant + *Azospirillum* @ 2g/plant), T_7 : (RDF +PSB @ 2g/plant + *Azospirillum* @ 2g/plant), T_8 : (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant)

Table 6: Effect of biofertiizer on leaf nutrient content of strawberry cv. Winter Dawn

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Magnesium (%)
T_1	2.21^{h}	0.94^{f}	2.15^{h}	1.70^{g}	0.11^{f}
T_2	2.63^{e}	1.18^{cd}	2.76^{e}	2.02^{d}	0.20^{de}
T_3	2.53^{f}	1.14^{de}	2.54^{f}	1.92^{e}	0.14^{f}
T_4	2.47^{g}	1.09^{e}	2.30^{g}	1.86^{f}	0.17^{ef}
T_5	2.93^{b}	1.28^{b}	3.21^{b}	2.21^{b}	0.31^{b}
T_6	2.82^{c}	1.21^{c}	3.11^{c}	2.13^{c}	0.27^{bc}
T_7	2.71^{d}	1.23^{bc}	2.99^{d}	2.03^{d}	0.24^{cd}
T_8	3.09^{a}	1.37^{a}	3.39^{a}	2.37^{a}	0.39^{a}
C.D.$_{(0.05)}$	0.04	0.04	0.04	0.05	0.02
SE(m)	0.014	0.013	0.015	0.015	0.007
SE(d)	0.02	0.02	0.02	0.02	0.01

T_1 : (Control), T_2 : (RDF + *Azotobacter* @ 2g/plant), T_3 : (RDF + PSB @ 2g/plant), T_4 : (RDF + *Azospirillum* @ 2g/plant), T_5 : (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant), T_6 : (RDF + *Azotobacter* @ 2g/plant + *Azospirillum* @ 2g/plant), T_7 : (RDF +PSB @ 2g/plant + *Azospirillum* @ 2g/plant), T_8 : (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant)

Table 7: Effect of biofertiizer on soil health attributes of strawberry cv. Winter Dawn

Treatment	Soil pH	Soil EC (dS/m)	Organic carbon (%)	Available nitrogen (kg/ha)	Available phosphorus (kg/ha)	Available potassium (kg/ha)

T_1	7.70^{a}	0.65^{a}	0.41^{d}	271.57^{g}	36.70^{g}	127.97^{h}
T_2	7.40^{bc}	0.51^{bc}	0.53^{bc}	333.40^{c}	44.83^{f}	137.80^{d}
T_3	7.43^{b}	0.55^{b}	0.50^{bc}	323.37^{e}	51.07^{d}	133.83^{f}
T_4	7.43^{b}	0.54^{bc}	0.47^{c}	296.83^{f}	46.23^{e}	132.53^{g}
T_5	7.20^{cd}	0.42^{d}	0.56^{b}	344.53^{b}	57.43^{b}	147.10^{b}
T_6	7.30^{bcd}	0.49^{c}	0.54^{b}	342.57^{b}	47.53^{e}	143.50^{c}
T_7	7.47^{b}	0.55^{b}	0.49^{bc}	326.83^{d}	53.50^{c}	135.87^{e}
T_8	7.13^{d}	0.36^{d}	0.64^{a}	349.93^{a}	59.17^{a}	150.77^{a}
$C.D._{(0.05)}$	0.20	0.06	0.02	2.08	1.31	1.29
SE(m)	0.06	0.02	0.01	0.68	0.43	0.42
SE(d)	0.09	0.03	0.01	0.96	0.61	0.59

T_1 : (Control), T_2 : (RDF + *Azotobacter* @ 2g/plant), T_3 : (RDF + PSB @ 2g/plant), T_4 : (RDF + *Azospirillum* @ 2g/plant), T_5 : (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant), T_6 : (RDF + *Azotobacter* @ 2g/plant + *Azospirillum* @ 2g/plant), T_7 : (RDF +PSB @ 2g/plant + *Azospirillum* @ 2g/plant), T_8 : (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant)

Table 8: Effect of biofertiizer on economic attributes of strawberry cv. Winter Dawn

Treatment	Gross income	Net Return	B:C
T_1	8,01,128.5	3,98,969	0.99
T_2	14,55,643	10,18,583	2.33
T_3	13,50,020	9,12,960	2.09
T_4	11,69,127	7,30,967	1.67
T_5	17,47,398	13,09,238	2.99
T_6	16,50,587	12,11,327	2.76
T_7	14,52,886	10,13,626	2.31
T_8	21,02,150	16,61,790	3.77

T_1 : (Control), T_2 : (RDF + *Azotobacter* @ 2g/plant), T_3 : (RDF + PSB @ 2g/plant), T_4 : (RDF + *Azospirillum* @ 2g/plant), T_5 : (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant), T_6 : (RDF + *Azotobacter* @ 2g/plant + *Azospirillum* @ 2g/plant), T_7 : (RDF +PSB @ 2g/plant + *Azospirillum* @ 2g/plant), T_8 : (RDF + *Azotobacter* @ 2g/plant + PSB @ 2g/plant + *Azospirillum* @ 2g/plant)