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Effect of Micronutrients and Biofertilizers on the Growth and Yield of Strawberry (*Fragaria × ananassa* Duch.) cv. Winter Dawn

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ABSTRACT: Micronutrients are essentially as important as macronutrients to have better growth, yield and quality in plants. As a component of proteins, zinc acts as a functional, structural, or regulatory cofactor of a large number of enzymes. The main functions of boron relate to cell wall strength and development, cell division, fruit and seed development, sugar transport and hormone development. Biofertilizers play a very significant role in improving soil fertility by fixing atmospheric nitrogen, both, in association with plant roots and without it, solubilise insoluble soil phosphates and produces plant growth substances in the soil. Keeping all these points in mind the present study was planned at Khalsa college, Amritsar in year 2023-2024. Strawberry cultivation trials integrating micronutrients and biofertilizers faced challenges such as inconsistent nutrient uptake, variability in soil microbial activity, difficulty in optimizing dosage combinations, environmental stress effects on plant response, and limited standardization of application methods under field conditions. The study was laid out in randomized block design with fifteen treatments and replicated thrice. The results were statistically analyzed at $p \leq 0.05$ level of significance. The results revealed that foliar application of micronutrients and biofertilizers significantly effect the growth and yield of strawberry. The treatment Azotobacter (6 kg/ha) + $ZnSO_4$ (0.4%) (T_8) produced the best overall results.

Keywords: Strawberry, micronutrients, biofertilizers, growth and yield attributes.

INTRODUCTION

Strawberry (*Fragaria × ananassa* Duch.) is a major temperate fruit crop that can also be cultivated in tropical and subtropical regions with proper management. It is highly appreciated for its appealing shape, pleasant aroma, and refreshing taste (Ali and Gaur 2007). Considered one of the world's most flavourful fruits, strawberry holds a significant position in both processing industries and global fresh markets (Sharma and Sharma 2004). The cultivated strawberry originated from the hybridization of two dioecious octaploid species, *Fragaria chiloensis* Duch. and *Fragaria virginiana* Duch. It is a small herbaceous plant grown either annually or perennially, with all leaves, roots, flowers, and runners emerging from its crowns (Bowling, 2000). Although primarily a short-day crop suited to temperate climates, it can also be successfully grown in tropical and subtropical regions (Bakshi *et al*., 2014). Mulching plays an important role in improving yield, fruit quality, and harvest duration by enhancing nutrient availability, reducing weed growth, protecting plants from frost, and minimizing the occurrence of dirty or diseased berries (Sharma, 2002).

Micronutrients are crucial for the overall growth and development of plants, including strawberries. While macronutrients such as nitrogen, phosphorus, and potassium are required in large amounts, micronutrients are needed in smaller quantities to support essential physiological functions. Zinc, for instance, is vital for plant development but remains poorly mobile in soils, often leading to deficiencies in crops like mango, banana, guava, litchi, apple, grape, and pomegranate (Ganeshamurthy *et al.*, 2018). Zinc-dependent enzymes are involved in carbohydrate metabolism, membrane stability, protein synthesis, auxin regulation, and pollen formation (Hafeez *et al.*, 2013). Boron is another key micronutrient affecting plant growth, productivity, and quality (Pereira *et al.*, 2021). Present in soils mainly as tetrahydroxy borate and boric acid (Hrmova *et al.*, 2020), boron is required for hormone production, fruit and seed development, sugar transport, cell wall strengthening, and cell division (Rasheed, 2009).

Biofertilizers are organic products containing living cells of different type of microorganisms, which have the capability to convert nutritionally important elements from unavailable to available form through biological processes. Biofertilizers or microbial inoculants, contain living or dormant cells of beneficial microorganisms. They provide a cost-effective and sustainable alternative to chemical fertilizers by enhancing soil fertility, improving flower quality, and increasing yields (Kumari *et al.*, 2016). Azotobacter is one of the free living N_2 fixing, non-symbiotic and heterotrophic bacteria ascribed to fix nitrogen from the atmosphere. It is also associated with the production of growth promoting substances, phytohormones and antifungal substances (Singh and Varu 2013). Vesicular arbuscular mycorrhizal (VAM) fungi further benefit plants by improving nutrient uptake—especially phosphorus—through their extensive hyphal networks. They enhance soil structure, moisture retention, and disease resistance, leading to improved plant vigor (Pradeep & Saravanam 2018). VAM fungi also aid in the absorption of additional nutrients such as calcium, copper, manganese, sulphur, and zinc (Abbasi *et al.*, 2015).

MATERIALS AND METHODS

Runners of the cultivar 'Winter Dawn' were transplanted in the first week of November at a spacing of 45 × 30 cm using the double-row planting system in the Nursery of the Department of Agriculture, Khalsa College, Amritsar, during 2023-2024. The experiment consisted of fifteen treatments; each replicated three times. Strawberry plants were treated with either individual applications or various combinations of micronutrients and biofertilizers. Treatment details are as follows:

Treatments	Details
T_1	Control
T_2	$ZnSo_4$ (0.2%)
T_3	$ZnSo_4$ (0.4%)
T_4	Borax (0.2%)
T_5	Borax (0.4%)
T_6	Azotobacter (6 kg/ha)
T_7	Azotobacter (6 kg/ha) + $ZnSo_4$ (0.2%)
T_8	Azotobacter (6 kg/ha) + $ZnSo_4$ (0.4%)
T_9	Azotobacter (6 kg/ha) + Borax (0.2%)
T_{10}	Azotobacter (6 kg/ha) + Borax (0.4%)
T_{11}	VAM (6 kg/ha)
T_{12}	VAM (6 kg/ha) + $ZnSo_4$ (0.2%)
T_{13}	VAM (6 kg/ha) + $ZnSo_4$ (0.4%)
T_{14}	VAM (6 kg/ha) + Borax (0.2%)
T_{15}	VAM (6 kg/ha) + Borax (0.4%)

To prepare the solution of $ZnSO_4$ (0.2% and 0.4%) and Borax (0.2% and 0.4%) concentration, 2g and 4g were dissolved in 1 litre of distilled water, respectively. Biofertilizers (Azotobacter and VAM) were applied @6 kg/ha under the soil near roots before transplanting.

A. Observations noted

Observations on various growth and yield parameters were collected from each replication of every treatment throughout the study period. The recorded data included plant height, number of leaves per plant, leaf area (cm²), days to flowering, number of flowers per plant, fruit length (cm), fruit breadth (cm), fruit weight (g), palatability score, number of fruits per plant, and yield per plant (g). Plant height was recorded with centimeter scale. Number of leaves (per plant) was counted manually from tagged plants at end of trail. Leaf area was recorded by using graph paper method. Days to first flowering were noted from days to transplanting. Number of flowers and fruits were noted in each flush and added at end of trail to receive an average number of flowers and fruits per plant. Fruit length and breadth were measured with the help of Digital Vernier Caliper's. Fruit weight and yield per plant was recorded by using digital weighing balance.

B. Statistical analysis

The experiment's data were analyzed using a Randomized Block Design (RBD), with results expressed as Mean ± Standard Error (S.E.). Analysis of Variance (ANOVA) and Tukey's post hoc test were used to compare different treatments for each parameter, with differences indicated by different letters. Statistical analysis was performed at a 5% significance level using SPSS software (version 30).

RESULTS AND DISCUSSION

A. Growth Attributes

The results presented in Table 1 indicate that the application of various micronutrients and biofertilizers significantly improved all growth parameters at each stage of development compared with the control during the study. The treatment consisting of Azotobacter (6 kg/ha) + $ZnSO_4$ (0.4%) (T_8) recorded the highest values for plant height (18.90 cm), number of leaves per plant (21.13), leaf area (24.88 cm²) and number of flowers per plant (25.30). In contrast, the control treatment (T_1) showed the lowest plant height (15.74 cm), leaf number (15.06), leaf area (22.28 cm²) and number of flowers (13.28). Plants receiving the T_8 treatment also flowered earliest (47.66 days), while the control plants required the most time to flower (59.41 days).

The positive effects of $ZnSO_4$ on growth are attributed to its role in activating enzymes, promoting auxin synthesis, enhancing root development, and increasing chlorophyll content. Azotobacter contributes to improved growth through its production of growth-promoting substances that stimulate cell elongation and division in meristematic tissues. When applied together, Azotobacter and $ZnSO_4$ enhance nitrogen availability, support enzymatic activity, promote hormone synthesis, and improve overall plant vigor, leading to superior growth performance in strawberries. These results align with the findings of Bahadur *et al.* (2022); Chandramohan and Goyal (2020); Saha *et al*. (2019) in strawberry.

Table 1: Effect of foliar application of micronutrients and biofertilizers on growth attributes of strawberry cv. Winter Dawn.

Treatments	Plant height	Number of leaves per plant	Leaf area (cm^2)	Days taken for flowering	Number of flowers per plant
T_1	15.74 ± 0.07^{h}	15.06 ± 0.61^{i}	22.28 ± 0.02^{m}	59.41 ± 1.28^{a}	13.28 ± 0.90^{h}
T_2	16.82 ± 0.06^{f}	16.40 ± 0.34^{hi}	22.95 ± 0.02^{k}	55.25 ± 0.66^{bcd}	17.58 ± 0.33^{fg}
T_3	17.05 ± 0.09^{ef}	16.80 ± 0.60^{gh}	23.21 ± 0.03^{j}	49.66 ± 0.62^{hi}	22.15 ± 0.80^{bc}
T_4	16.13 ± 0.23^{gh}	16.20 ± 0.60^{hi}	22.75 ± 0.03^{l}	56.66 ± 0.87^{b}	15.66 ± 0.78^{gh}
T_5	16.62 ± 0.10^{fg}	16.40 ± 0.34^{hi}	22.88 ± 0.03^{k}	54.00 ± 1.39^{bcde}	17.55 ± 1.19^{fg}
T_6	17.98 ± 0.08^{bcd}	19.60 ± 0.34^{bcd}	23.96 ± 0.02^{f}	48.83 ± 0.62^{hi}	23.38 ± 0.74^{ab}
T_7	18.59 ± 0.30^{ab}	20.20 ± 0.34^{abc}	24.72 ± 0.03^{b}	52.66 ± 1.66^{def}	23.61 ± 1.18^{ab}
T_8	18.90 ± 0.09^{a}	21.13 ± 0.64^{a}	24.88 ± 0.04^{a}	47.66 ± 0.94^{i}	25.30 ± 0.85^{a}
T_9	18.14 ± 0.15^{bcd}	20.06 ± 0.30^{abcd}	24.07 ± 0.03^{e}	53.08 ± 0.52^{cdef}	20.06 ± 0.61^{de}
T_{10}	18.28 ± 0.45^{bc}	20.93 ± 0.61^{ab}	24.48 ± 0.03^{c}	52.25 ± 1.50^{efg}	23.03 ± 0.56^{b}
T_{11}	16.51 ± 0.20^{fg}	17.60 ± 0.34^{fgh}	23.45 ± 0.03^{i}	52.25 ± 0.43^{efg}	18.78 ± 0.40^{ef}
T_{12}	17.57 ± 0.20^{de}	18.03 ± 0.60^{efg}	23.59 ± 0.03^{h}	53.16 ± 1.18^{cdef}	21.95 ± 1.95^{bcd}
T_{13}	16.69 ± 0.20^{fg}	18.60 ± 0.60^{def}	24.37 ± 0.03^{d}	50.66 ± 1.04^{fgh}	23.85 ± 0.97^{ab}
T_{14}	17.76 ± 0.15^{cd}	19.06 ± 0.41^{cdef}	23.78 ± 0.04^{g}	55.58 ± 1.80^{bc}	19.93 ± 0.64^{de}
T_{15}	17.86 ± 0.24^{cd}	19.20 ± 0.60^{cde}	23.87 ± 0.02^{fg}	53.25 ± 0.66^{cdef}	20.33 ± 0.64^{cde}

B. Physical Parameters

It is also evident from the data given in Table 2 that the increased fruit length (3.96 cm), fruit breadth (2.96 cm), fruit weight (13.39 g), palatability rating (8.86), number of fruits per plant (14.83) and yield per plant (198.71 g/plant) were obtained when plants were treated with treatment (T_8) azotobacter (6 kg/ha) + $ZnSO_4$ (0.4%), while minimum fruit length (2.56 cm), fruit breadth (2.09 cm), fruit weight (9.98 g), palatability rating (5.80), number of fruits per plant (11.61) and yield per plant (115.93 g/plant) were recorded under treatment (T_1) control. The possible reason for increment in yield might be associated to the involvement of zinc in many physiological and metabolic activities e.g., enzymatic activities, photosynthates production, fruit production maturation, plant hormones stimulation and starch formation. The biofertilizer's positive effect on 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 (Gupta and Tripathi 2012). When both azotobacter and zinc are used together they enhances plant growth and nutrient availability, leading to healthier, better- development strawberries. These results are in line with the findings of Kumar and Tripathi (2020); Sabahat *et al* (2021); Rahman *et al* (2016) in strawberry.

Table 2: Effect of foliar application of micronutrients and biofertilizers on physical parameters of strawberry cv. Winter Dawn.

Treatments	Fruit length (cm)	Fruit breadth (cm)	Fruit weight (g)	Number of fruits per plant	Palatability rating	Yield (g/plant)
T_1	2.56 ± 0.04^{l}	2.09 ± 0.03^{k}	9.98 ± 0.05^{n}	11.61 ± 0.04^{m}	5.80 ± 0.30^{i}	115.93 ± 1.03^{l}
T_2	2.82 ± 0.03^{j}	2.27 ± 0.02^{ij}	10.15 ± 0.06^{m}	12.34 ± 0.04^{k}	6.36 ± 0.37^{ghi}	125.56 ± 1.32^{j}
T_3	2.93 ± 0.02^{i}	2.31 ± 0.01^{hi}	10.95 ± 0.056^{k}	12.57 ± 0.05^{j}	6.50 ± 0.30^{ghi}	136.29 ± 2.13^{i}
T_4	2.64 ± 0.04^{k}	2.14 ± 0.02^{k}	10.08 ± 0.03^{m}	11.99 ± 0.04^{l}	6.23 ± 0.25^{hi}	120.46 ± 1.47^{k}
T_5	2.75 ± 0.05^{j}	2.22 ± 0.01^{j}	10.41 ± 0.06^{l}	12.09 ± 0.04^{l}	6.56 ± 0.40^{fghi}	125.89 ± 1.34^{j}
T_6	3.56 ± 0.02^{e}	2.58 ± 0.01^{e}	11.48 ± 0.04^{h}	13.32 ± 0.05^{h}	6.86 ± 0.30^{defgh}	152.99 ± 1.46^{g}
T_7	3.91 ± 0.02^{ab}	2.87 ± 0.01^{b}	13.19 ± 0.04^{b}	14.53 ± 0.04^{b}	8.40 ± 0.17^{ab}	191.74 ± 1.48^{b}
T_8	3.96 ± 0.01^{a}	2.96 ± 0.01^{a}	13.39 ± 0.05^{a}	14.83 ± 0.05^{a}	8.86 ± 0.30^{a}	198.71 ± 1.49^{a}
T_9	3.62 ± 0.02^{de}	2.64 ± 0.01^{d}	11.73 ± 0.02^{g}	14.04 ± 0.02^{d}	7.50 ± 0.30^{bcde}	164.83 ± 1.64^{f}
T_{10}	3.85 ± 0.03^{bc}	2.82 ± 0.02^{b}	13.03 ± 0.04^{c}	14.31 ± 0.04^{c}	8.16 ± 0.35^{abc}	186.32 ± 1.74^{c}
T_{11}	3.07 ± 0.02^{h}	2.35 ± 0.02^{h}	11.09 ± 0.04^{j}	12.85 ± 0.03^{i}	6.63 ± 0.15^{efghi}	142.54 ± 0.84^{h}
T_{12}	3.67 ± 0.02^{d}	2.69 ± 0.02^{d}	12.48 ± 0.03^{e}	13.77 ± 0.02^{f}	7.20 ± 0.40^{defg}	172.02 ± 1.69^{e}
T_{13}	3.77 ± 0.02^{c}	2.76 ± 0.01^{c}	12.89 ± 0.04^{d}	13.89 ± 0.05^{e}	7.63 ± 0.15^{bcd}	179.17 ± 1.33^{d}
T_{14}	3.25 ± 0.02^{g}	2.41 ± 0.01^{g}	11.33 ± 0.04^{i}	13.36 ± 0.03^{h}	7.16 ± 0.35^{defg}	151.55 ± 1.83^{g}
T_{15}	3.47 ± 0.01^{f}	2.51 ± 0.02^{f}	12.15 ± 0.04^{f}	13.52 ± 0.04^{g}	7.46 ± 0.30^{cdef}	164.31 ± 1.10^{f}

CONCLUSION

Foliar application of various micronutrients and biofertilizers was successful in improving growth and yield of strawberry as compared to control. But from all treatments, Azotobacter (6 kg/ha) + $ZnSO_4$ (0.4%) (T_8) was most successful in enhancing the growth and yield of strawberry. Plants treated with Azotobacter (6 kg/ha) + $ZnSO_4$ (0.4%) (T_8) treatment flowered earliest (47.66 days), recorded the highest values for plant height, number of leaves per plant, leaf area, number of flowers per plant, fruit length, fruit breadth, fruit weight, palatability rating, number of fruits per plant and yield per plant.

FUTURE SCOPE

Strawberries command a high market price, thereby enhancing farmer's income and profitability. Strawberry cultivation using Azotobacter and zinc is very promising, especially under sustainable and organic farming systems. With rising demand for high-quality fruits and reduced chemical inputs, this combination offers strong research and commercial potential.

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