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Effect of foliar application of zinc, boron, copper and iron on flowering, fruiting and yield of strawberry (*Fragaria* × *ananassa* Duch.) cv. Chandler under semi-arid conditions

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ABSTRACT

Micronutrient nutrition plays an important role in flowering, fruit set, fruit development and yield of strawberry, particularly under intensive production systems. The present investigation was conducted during 2025 at Nathwana, Sangaria, Hanumangarh, Rajasthan, India, to evaluate the effects of selected micronutrients on flowering, fruiting and yield of strawberry (*Fragaria* × *ananassa* Duch.) cv. Chandler. The experiment was laid out in a randomized block design with ten treatments and three replications. The treatments comprised individual applications of zinc sulphate, copper sulphate, ferrous sulphate and boric acid, a combination of zinc sulphate and boric acid, and a combined application of zinc sulphate (0.1%) + boric acid (0.1%) + copper sulphate (0.1%) + ferrous sulphate (0.1%). Among the treatments, the combined micronutrient application (T_{10}) recorded the earliest flowering (41.42 days), maximum number of flowers plant⁻¹ (24.30), highest fruit set (83.98%), minimum days to fruit maturity (19.05 days), maximum number of fruits plant⁻¹ (20.40), highest individual fruit weight (16.52 g), and maximum fruit yield plant⁻¹ (434.40 g). The highest fruit yield was recorded under T_{10} (10.26 t ha⁻¹). Overall, the combined application of Zn, B, Cu and Fe resulted in greater improvement in flowering, fruiting and yield attributes than the individual micronutrient treatments. The findings suggest that foliar application of Zn, B, Cu and Fe may enhance the reproductive performance and yield of strawberry cv. Chandler under the semi-arid conditions of north-western Rajasthan. Further evaluation across seasons and locations is required to validate the consistency and practical applicability of the treatment.

Keywords: Strawberry, *Fragaria* × *ananassa*, Cv. Chandler, Zinc, Boron, Copper, Iron, Foliar application, Fruit set, Fruit yield

1. Introduction

Strawberry (*Fragaria* × *ananassa* Duch.) is an economically important small fruit crop valued for its attractive appearance, pleasant flavour, and nutritional and functional-food properties. The crop has gained considerable importance in commercial horticulture because of its high consumer demand and economic value. Successful strawberry production requires adequate vegetative growth followed by efficient flowering, fruit set, fruit development, and yield formation. As strawberry has a relatively shallow root system and is commonly cultivated under intensive production systems, adequate and balanced mineral nutrition is essential for maintaining healthy plant growth and achieving optimum fruit yield.

Micronutrients, although required in relatively small quantities, play essential roles in various physiological and biochemical processes associated with plant growth and reproduction. Zinc is involved in enzyme activation, membrane function, and several metabolic processes, whereas boron plays an important role in cell-wall development, reproductive growth, pollen germination, and pollen-tube development. Iron is essential for chlorophyll formation and electron-transfer processes, while copper participates in redox reactions and various enzyme systems. An adequate supply of these micronutrients is therefore important for maintaining normal physiological activity and reproductive development. Deficiency or imbalance of micronutrients may adversely affect flowering, fruit set, fruit development, and ultimately crop productivity.

Foliar application is an effective approach for supplying nutrients directly to the aerial parts of plants and may provide rapid nutrient availability during critical stages of crop development. It can be particularly useful when nutrient availability in the soil or nutrient uptake through the root system is limited. Previous studies have reported beneficial effects of foliar application of micronutrients, particularly zinc, boron, and iron, on growth, flowering, fruiting, yield, and quality attributes of strawberry. Combined application of micronutrients has also been reported to improve fruit yield and quality in strawberry, including cv. Chandler.

However, the response of strawberry to micronutrient application can vary depending on cultivar, agro-climatic conditions, nutrient concentration, method and timing of application, and overall production system. Therefore, location-specific evaluation of suitable micronutrient combinations is important for developing efficient nutrient management practices. Under the semi-arid conditions of north-western Rajasthan, information on the response of strawberry cv. Chandler to foliar application of selected micronutrients and their combinations remains limited.

Therefore, the present investigation was undertaken to evaluate the effects of selected micronutrients and their combinations on flowering, fruiting, and yield of strawberry (*Fragaria* × *ananassa* Duch.) cv. Chandler under the agro-climatic conditions of Hanumangarh district, Rajasthan.

2. Materials and methods

2.1 Experimental site

The experiment was conducted during 2025 at Nathwana, Sangaria, Hanumangarh, Rajasthan, India, under field conditions using strawberry (*Fragaria* × *ananassa* Duch.) cv. Chandler. The experimental site represents the semi-arid agro-climatic conditions of north-western Rajasthan.

2.2 Experimental design and layout

The experiment was laid out in a Randomized Block Design (RBD) comprising ten treatments and three replications, resulting in a total of 30 experimental plots. Each experimental plot measured 2.0×2.0 m. Strawberry plants were established at a spacing of 30×30 cm, accommodating 36 plants per plot. Three representative plants were randomly selected and tagged in each plot for recording observations throughout the experimental period.

2.3 Planting and crop management

Uniform runners of strawberry cv. Chandler were transplanted on 15 November 2025. The plants were established on raised beds covered with black polyethylene mulch. Drip irrigation was used for irrigation and water management. All other recommended cultural and crop-management practices were maintained uniformly across the treatments in accordance with the experimental protocol to minimize variation other than that arising from the treatments.

2.4 Treatments and their application

Ten treatments were evaluated in the experiment as follows:

The micronutrient treatments were applied as foliar sprays according to the experimental schedule. Repeated foliar applications were made at approximately 15–20-day intervals. The treatments were applied uniformly according to the prescribed concentrations and experimental protocol.

2.5 Observations recorded

Observations were recorded on the following flowering, fruiting and yield attributes:

1. Days to first flowering
2. Number of flowers plant⁻¹
3. Fruit set (%)
4. Days to fruit maturity
5. Number of fruits plant⁻¹
6. Individual fruit weight (g)
7. Fruit yield plant⁻¹ (g)
8. Fruit yield (t ha⁻¹)

The observations were recorded from the tagged representative plants of each experimental plot, and treatment-wise values were used for statistical analysis.

2.6 Statistical analysis

The experimental data were statistically analyzed using the analysis of variance (ANOVA) appropriate for a Randomized Block Design. The significance of treatment effects was tested using the *F*-test. Treatment means were compared using the Critical Difference (CD) at the 5% level of significance. The statistical analysis was carried out separately for each growth, flowering, fruiting and yield parameter.

3. Results

3.1 Effect on flowering and fruiting characteristics

Micronutrient treatments significantly influenced the reproductive behaviour of strawberry cv. Chandler. Micronutrient application significantly affected the flowering and fruiting characteristics of strawberry cv. Chandler (Table 1). The days required for first flowering varied markedly among the treatments. The earliest flowering was recorded under T_{10} (41.42 days), followed by T_7 (49.25 days) and T_5 (50.65 days), whereas the control (T_1) recorded the longest period to first flowering (87.26 days). Based on the reported treatment means, T_{10} advanced the onset of flowering by 45.84 days compared with the control.

Treatment	Treatment details
T_1	Control – RDF 100:60:60 kg N:P ha ⁻¹
T_2	Azotobacter @ 5 kg ha ⁻¹
T_3	PSB @ 5 kg ha ⁻¹
T_4	<i>Azospirillum</i> @ 5 kg ha ⁻¹
T_5	Zinc sulphate @ 0.4%
T_6	Copper sulphate @ 0.4%
T_7	Ferrous sulphate @ 0.4%
T_8	Boric acid @ 0.4%
T_9	Zinc sulphate @ 0.2% + boric acid @ 0.2%
T_{10}	Zinc sulphate @ 0.1% + boric acid @ 0.1% + copper sulphate @ 0.1% + ferrous sulphate @ 0.1%

The number of flowers plant⁻¹ was also highest under T_{10} (24.30), followed by T_9 (18.66) and T_7 (18.29), while the lowest value was recorded under T_1 (13.78). Thus, T_{10} produced 76.34% more flowers plant⁻¹ than the control. The treatment differences exceeded the corresponding critical difference at the 5% level for several treatment comparisons, indicating a significant treatment effect.

Fruit set was highest under T_{10} (83.98%), followed by T_9 (77.38%) and T_5 (76.82%), whereas the minimum fruit set was recorded in T_1 (68.07%). Compared with the control, T_{10} increased fruit set by 15.89 percentage points, corresponding to an increase of approximately 23.35% over T_1 .

A similar treatment response was observed for days to fruit maturity. T_{10} recorded the minimum duration to fruit maturity (19.05 days), followed by T_2 (21.22 days) and T_7 (24.23 days), whereas the maximum duration was recorded under T_1 (27.12 days). The reduction in the duration to fruit maturity under T_{10} relative to the control was 8.07 days.

Overall, among the evaluated treatments, T_{10} recorded the highest values for flowers plant⁻¹ and fruit set, together with the earliest flowering and minimum duration to fruit maturity. These results indicate a pronounced response of reproductive development to the combined application of Zn, B, Cu and Fe under the conditions of the present experiment.

Table 1. Effect of treatments on flowering and fruiting characteristics of strawberry cv. Chandler

Treatment	Days to first flowering	Flowers plant ⁻¹	Fruit set (%)	Days to fruit maturity
T ₁	87.26	13.78	68.07	27.12
T ₂	58.21	14.10	71.10	21.22
T ₃	84.44	14.52	70.71	27.01
T ₄	82.40	14.27	70.92	23.59
T ₅	50.65	17.27	76.82	24.72
T ₆	57.30	14.62	72.60	27.01
T ₇	49.25	18.29	76.27	24.23
T ₈	55.41	16.30	74.74	25.26
T ₉	52.48	18.66	77.38	25.00
T₁₀	41.42	24.30	83.98	19.05
CD (5%)	2.657	0.848	2.891	1.001
SEm±	0.894	0.285	0.973	0.337

3.2 Effect on number of fruits and fruit weight

Table 2. Effect of micronutrient treatments on fruit number, fruit weight and yield

Treatment	Fruits plant ⁻¹	Fruit weight (g)	Yield plant ⁻¹ (g)	Yield (t ha ⁻¹)
T ₁	10.22	10.10	152.43	3.89
T ₂	13.34	11.71	203.96	5.73
T ₃	13.02	11.25	192.79	5.37
T ₄	11.12	10.69	181.47	4.86
T ₅	13.35	13.53	269.40	8.39
T ₆	10.92	12.53	211.97	6.90
T ₇	13.98	13.90	305.33	8.81
T ₈	12.33	13.02	242.53	7.76
T ₉	14.41	13.96	357.27	9.47
T₁₀	20.40	16.52	434.40	10.26
CD (5%)	0.829	0.802	13.43	1.018
SEm±	0.279	0.270	4.52	0.342

Micronutrient treatments markedly affected fruit number, individual fruit weight and fruit yield of strawberry cv. Chandler (Table 2). The number of fruits plant⁻¹ ranged from 10.22 in the control (T₁) to 20.40 under the combined micronutrient treatment (T₁₀). Among the micronutrient treatments, T₁₀ recorded the highest number of fruits plant⁻¹ (20.40), followed by T₉ (14.41) and T₇ (13.98), whereas the minimum value was recorded under T₁ (10.22). The number of fruits plant⁻¹ under T₁₀ was approximately 99.6% higher than that recorded under the control.

Individual fruit weight showed a similar treatment response. The maximum fruit weight was recorded under T₁₀ (16.52 g), followed by T₉ (13.96 g), T₇ (13.90 g) and T₅ (13.53 g), while the minimum value was observed under T₁ (10.10 g). Thus, fruit weight under T₁₀ was approximately 63.6% higher than that under the control. The observed treatment differences were greater than the reported CD (5%) in several comparisons, indicating substantial treatment effects on individual fruit weight.

Fruit yield plant⁻¹ varied considerably among treatments. T₁₀ recorded the highest yield (434.40 g plant⁻¹), followed by T₉ (357.27 g plant⁻¹), T₇ (305.33 g plant⁻¹) and T₅ (269.40 g plant⁻¹), whereas T₁ recorded the lowest yield (152.43 g plant⁻¹). On comparison with the control, T₁₀ increased fruit yield plant⁻¹ by approximately 185.1%. The difference between T₁₀ and T₁ (281.97 g plant⁻¹) was considerably greater than the reported CD (5%) of 13.43 g plant⁻¹.

The estimated fruit yield on a hectare basis followed the same general trend. The highest yield was recorded under T₁₀ (10.26 t ha⁻¹), followed by T₉ (9.47 t ha⁻¹), T₇ (8.81 t ha⁻¹) and T₅ (8.39 t ha⁻¹), whereas the lowest yield was recorded under T₁ (3.89 t ha⁻¹). Relative to the

control, T₁₀ represented an increase of approximately 163.8% in estimated fruit yield.

Taken together, the combined application of Zn, B, Cu and Fe under T₁₀ was associated with higher fruit number, greater individual fruit weight and consequently higher fruit yield than the control and the other treatments evaluated in the experiment. The consistency of the response across these yield-related attributes suggests that the treatment effect was expressed through both fruit number and fruit size, which contributed to the higher fruit yield recorded under T₁₀.

4. Discussion

The present study revealed substantial variation in the reproductive and yield performance of strawberry cv. Chandler in response to foliar micronutrient treatments. The combined treatment T₁₀, comprising ZnSO₄ 0.1% + boric acid 0.1% + CuSO₄ 0.1% + FeSO₄ 0.1%, was associated with earlier flowering, greater flower production, higher fruit set and earlier fruit maturity. The response may be attributed to the complementary physiological functions of Zn, B, Fe and Cu in enzyme activation, reproductive development, pollen-related processes and overall plant metabolism.

The greater fruit number and individual fruit weight recorded under T₁₀ translated into higher fruit yield. Improved fruit set provides a direct basis for increased fruit number, while adequate micronutrient availability during fruit development may have supported assimilate accumulation and fruit growth. Previous studies on strawberry have also reported beneficial effects of foliar micronutrient application, particularly treatments involving Zn and B, on reproductive and yield-related traits. Differences in the magnitude of response among

studies may reflect variation in cultivar, environmental conditions, nutrient concentration and application timing.

The comparatively favourable performance of the combined treatment indicates that supplying multiple micronutrients can influence several components of strawberry productivity simultaneously. However, since the present experiment was not factorial in design, the observed response should not be interpreted as statistical synergism among Zn, B, Cu and Fe. Rather, T_{10} performed favourably among the treatments evaluated under the specific experimental conditions of the study. Further investigations involving factorial combinations, different nutrient concentrations and application schedules would help to clarify individual nutrient contributions and nutrient interactions.

5. Practical implications

The findings indicate that foliar micronutrient management can be considered as a potential component of nutrient management for strawberry cv. Chandler under semi-arid conditions. The treatment combination evaluated as T_{10} showed favourable reproductive and yield responses in the present experiment. However, its broader commercial recommendation requires validation across seasons, locations and contrasting soil and production conditions. Optimization of spray concentration and application frequency is also necessary to ensure adequate nutrient supply without causing foliar or fruit injury.

6. Conclusion

The present study demonstrated that foliar micronutrient application influenced flowering, fruit set, fruit development and yield of strawberry cv. Chandler under the agro-climatic conditions of Hanumangarh, Rajasthan. Among the treatments evaluated, T_{10} comprising ZnSO_4 0.1% + boric acid 0.1% + CuSO_4 0.1% + FeSO_4 0.1% recorded the most favourable overall response, with earlier flowering and fruit maturity, greater flower and fruit production, higher fruit set and individual fruit weight, and consequently higher fruit yield. The improved performance may be attributed to the complementary physiological roles of Zn, B, Fe and Cu in reproductive development, pollen-related processes, enzyme activity and fruit development, although the present experimental design does not permit their individual or interactive effects to be separated. Therefore, the tested mi-

cronutrient combination showed potential for improving strawberry productivity under the conditions of the present study. Further multi-season and multi-location studies are required to validate the consistency of the response and to establish an agronomically and economically appropriate foliar spray schedule

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