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Research Article

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Performance of NanoZinc Oxide and Iron Oxide on Growth, Flowering and Yield of Strawberry (*Fragaria × ananassa* Duch) cv. Winter Dawn

Lakhwinder Singh*, **Ramesh Kumar Sadawarti, Shailesh Kumar Singh and Anis Ahmad Mirza**

Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

***Correspondence to:**
Lakhwinder Singh
Department of Horticulture,
School of Agriculture,
Lovely Professional University,
Phagwara, Punjab, India.
E-mail: lakhwindersingh60478@gmail.com

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Abstract

Research was carried out at Lovely Professional University, Horticulture farm, Punjab (India), throughout 2022-23 to ascertain the impact of nanofertilizers (zinc oxide (ZnO) and iron oxide (FeO)) at different concentrations on various parameters of strawberry. The trial was conducted in a randomized block design and replicated thrice with 16 treatments. Findings of the research depicted that among all the different treatments, combined applications of ZnO and FeO nanoparticles (NPs) @150 ppm, that is, T_{15} Z_3F_3 (150 ppm ZnO + 150 ppm FeO) followed by $T_{11}Z_2F_2$ (100 ppm ZnO + 100 ppm FeO) demonstrated significant effectiveness across various parameters of crop's growth, flowering, and yield. During plants' initial growth stage, measurements were maximum in T_{15} (150 ppm ZnO + 150 ppm FeO) compared to other treatments. T_{11} (100 ppm ZnO + 100 ppm FeO) followed closely behind T_{15} in terms of crop growth, e.g., plant height (7.3 cm) at 90 days after transplanting (DAT), number of leaves (15.00) at 110 DAT, leaf length (5.7 cm), chlorophyll content (55.47 μmol/m^2), stem girth (7.67 mm), and petiole length (22.99 cm) parameters. Besides this, the flowering, e.g., the number of flowers per plant (11.00), duration of flowering (55.00), and yield, e.g., the number of fruits per plant (9.67), yield per plant (299 gm), number of harvesting (6.00) parameters were also observed higher in T_{15} (150 ppm ZnO + 150 ppm FeO). The impact of varying concentrations of ZnO and FeO NPs on the growth, flowering, and yield of strawberry (*Fragaria×ananassa* Duch) cv. Winter Dawn is investigated in this study. The dose concluded combined application (foliar) of ZnO and FeO NPs at the concentration of 150 ppm depicts significant results under the Punjab region of India concerning strawberry crop cv. Winter Dawn.

Keywords

Strawberry, Winter Dawn, Nano-fertilizers, Zinc oxide, Iron oxide, Growth yield

Introduction

Strawberries (*Fragaria*) are a popular and nutritious fruit from the Rosaceae family. Strawberries belong to the genus *Fragaria*, which includes several species and numerous cultivars. The most common species is *Fragaria × ananassa*, a hybrid species resulting from crossbreeding two wild strawberries: *Fragaria chiloensis* and *Fragaria virginiana* [1]. Strawberries are rich in essential nutrients and bioactive compounds, containing vitamins 'C', folate, potassium, and manganese. They also contain dietary fiber and are low in calories. Additionally, strawberries are known for their high antioxidant content, including flavonoids, anthocyanin, and ellagic acid [2]. The nutrient requirements of strawberry plants must be carefully managed to ensure optimal growth and productivity. Strawberry plants require a well-balanced supply of nutrients for healthy growth and fruit production.

Imbalances in nutrient levels can lead to reduced yields, poor fruit quality, and increased susceptibility to diseases and pests. Therefore, it is essential to maintain proper nutrient balance by providing the required nutrients in the right proportions to the crop [3].

Fertilizers supply essential nutrients that may be deficient or insufficient in the soil, ensuring that the strawberry plants have an adequate nutrient supply [4]. The primary macronutrients required by strawberries include Nitrogen (N), Phosphorus (P), Potassium (K), and Magnesium (Mg), while micronutrients like Zinc (Zn), Iron (Fe), Molybdenum (Mo), Copper (Cu), and Boron (B) are necessary for optimal growth and development of the plants. Adequate fertilization can significantly impact strawberry yield and fruit quality. Balanced nutrient availability ensures optimal plant growth, productivity, and maximum flowering, leading to larger fruit size, increased yield per plant, and enhanced overall quality of fruits in terms of taste, color, texture, and nutritional value. Proper fertilization practices are essential during fruit set, enlargement, and ripening [5].

Alternate fertilizers, including organic and inorganic fertilizers, can be used for strawberry crops. On the other hand, nanofertilizers, a relatively new technology in agriculture, have gained attention for their potential benefits in enhancing nutrient uptake and improving crop productivity in berry fruit crops [6]. Nanofertilizers' controlled-release and targeted delivery features can minimize nutrient losses to the environment. Reducing leaching and runoff helps prevent water contamination and nutrient pollution in nearby ecosystems [7]. It is crucial to conduct comprehensive research and risk assessments to ensure the safety and sustainability of nanofertilizers applications. It's worth noting that the field of nanofertilizers is still evolving, and their commercial availability and specific formulations may vary. Further research and development are necessary to optimize nanofertilizers formulations for different fruit plant species and growing conditions, considering their specific nutrient requirements and physiological responses [8].

Zn is a requisite micronutrient for plant growth, and its deficiency can negatively impact the plant's mechanism. Zn is crucial in activating and stabilizing various enzymes involved in plant metabolism. It is essential for auxin synthesis, which plays a crucial role in plant growth and is mandatory for chlorophyll production and the pigment responsible for photosynthesis [9]. Sufficient Zn availability promotes optimal photosynthetic activity, improving plant growth and vigor. Zn implicates protein synthesis and is necessary to form certain enzymes and proteins required for plant development. Zn has been associated with optimum plant growth, improved flowering, and fruit-setting percentage in strawberry plants. Adequate Zn levels can enhance flower production and pollination, increasing fruit yield [10].

Iron is another primary micronutrient required for the healthy growth of plants. Iron is a crucial component of the photosynthetic process. It performs a prominent role in chlorophyll synthesis and the transfer of electrons during photosynthesis. Iron is an ingredient of numerous intricate enzymes in the electron transport chain, which is essential for plant energy production [11]. Iron is necessary for the activity of nitrogenase, an enzyme responsible for nitrogen fixation in plants. Nitrogen fixation enables plants to convert atmospheric nitrogen into a usable form, contributing to their nitrogen nutrition. Iron plays a role in cellular respiration, facilitating the breakdown of sugars and the release of energy for plant growth and development. Iron in strawberry plants prevents chlorosis and ensures healthy leaf coloration [12]. Zn and iron can be applied as foliar sprays or incorporated into the plants as fertilizers to address strawberry deficiencies [13]. Standardizing proper dosages and application methods is critical, considering the specific nutrient requirements of the strawberry plants with appropriate soil conditions [14].

Materials and Methods

The research trail started in November and was conducted at Lovely Professional University, School of Agriculture, Horticulture Research Farm (Punjab, India). A summary of materials and methodology are mentioned below:

The plants of strawberry cv. Winter Dawn were transplanted by the 7th and 8th of November 2022 under protected and open field conditions. Before transplanting of plants, the field was prepared well. The vermicompost was properly mixed into the soil before making beds under protected and open fields. Total nitrogen was determined through the Microkjheldahl method (Jackson; 1973), while total phosphorus was estimated by the Vandomolybdophospheric yellow color method (Jackson; 1973), and total potash was estimated on Flame photometer (Jackson; 1973). Plant height and leaf length were measured using a measuring scale (cm), leaf area by leaf area meter, stem girth by vernier caliper, and chlorophyll content by digital spadmeter; other parameters like number of leaves, number of flowers were measured by the naked eye. The results of all the micro-nutrients will be computed on a dry weight basis and expressed the removal as kg hac^{-1}.

The experiment consisted of various treatments such as T_0 (Control 100% RDF), T_1Z_1(50 ppm ZnO NPs), T_2Z_2(100 ppm ZnO NPs), T_3Z_3(150 ppm ZnO NPs), T_4F_1(50 ppm FeO NPs), T_5F_2(100 ppm FeO NPs), T_6F_3(150 ppm FeO NPs), $T_7Z_1F_1$(50 ppm ZnO NPs + 50ppm FeO NPs), $T_8Z_1F_2$(50 pm ZnO NPs + 100 ppm FeO NPs), $T_9Z_1F_3$(50 ppm ZnO NPs + 150 ppm FeO NPs), $T_{10}Z_2F_1$(100 ppm ZnO NPs + 50 ppm FeO NPs), $T_{11}Z_2F_2$(100 ppm ZnO NPs + 100 ppm FeO NPs), $T_{12}Z_2F_3$(100 ppm ZnO NPs + 150 ppm FeO NPs), $T_{13}Z_3F_1$(150 ppm ZnO NPs + 50 ppm FeO NPs), $T_{14}Z_3F_2$(150 ppm ZnO NPs + 100 ppm FeO NPs), $T_{15}Z_3F_3$ (150 ppm ZnO NPs + 150 ppm FeO NPs).

The present research study named "Performance of ZnO and FeO NPs on Growth, Flowering, and Yield of Strawberry (*Fragaria* × *ananassa* Duchesne) cv. Winter Dawn" was performed on the experimental site of Horticulture Department. The Lovely Professional University (Phagwara) experimental site is nearly 237 m (768 ft.) above mean sea level and is in the Punjab state at 31.2232°N latitude and 75.7670°E longitudes, with an average annual rainfall of 816 mm. Ploughing and harrowing were used to fine-tilt the experimental field properly. The testing area was separated into tiny portions. Preliminarily transplanting the runners of strawberry var. Winter Dawn was done, and after that, the suggested amount of manure, i.e., farmyard manure and vermicompost, was added accordingly. Weeding at regular intervals kept the plots clear during the growth season. Weeding started after 30 days of planting and continued as needed. Mild irrigation (drip irrigation) was done immediately after planting, and later irrigation was done depending on the wetness of the soil.

Results and Discussion

Effect on vegetative growth of the plants

Vegetative growth of strawberry cv. Winter Dawn was affected by the different doses of nano-ZnO and FeO, as presented in tables and figures, respectively. Maximum plant height (12.2 cm) was observed in T_{15} significantly at 110 DAT, followed by T_{11}, having a value of 11.7 cm. In comparison, the minimum plant height was recorded as T_0, having a value of (9.9 cm) as shown in table 1 and figure 1. Readings on stem girth of strawberry cv. Winter Dawn significant variations were found between different treatments. The data showed that maximum stem girth (26.62 mm) was observed in T_{15}, and minimum stem girth (13.37 mm) was recorded in T_0. Maximum count of leaves (15.00) was noted in T_{15} followed by T_{12} (12.00) at 110 DAT, minimum number of leaves (9.33) was noted in T_0 as shown in table 2 and figure 2. Maximum leaf area (73.11 cm^2) was recorded in T_{15} followed by the T_{10} having leaf area (72.12 cm^2), minimum leaf area (68.62 cm^2) recorded in T_0. Leaf length was observed maximum (5.7 cm) in the T_{15}, and minimum (3.3 cm) was noted in T_0.

According to data obtained related to chlorophyll content in leaves of the crop, significant variations were found after 30 days of transplanting; maximum chlorophyll content (55.47 μmol/m^2) was recorded in T_{15} on the upper leaves of plants, while minimum chlorophyll content (46.03 μmol/m^2) was noted in control. Significant variations were found among all the treatments on the 30^{th}, 60^{th}, 90^{th}, and 110^{th} DAT regarding the spreading of the plant; maximum plant spreading

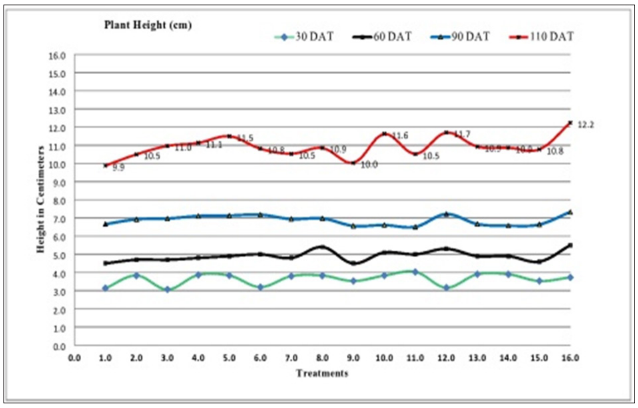

Figure 1: Performance at different concentrations of ZnO and FeO on plant height (cm) strawberry (*Fragaria* × *ananassa* Duch) cv. Winter Dawn.

Table 1: Performance of ZnO and FeO on plant height, stem girth, leaf area, number of leaves, leaf length and chlorophyll content of strawberry (*Fragaria* × *ananassa* Duch) cv. Winter Dawn.

Treatments	Plant height (cm)				Stem girth (mm)	Leaf area (cm^2)	Number of leaves				Leaf length (cm)	Chlorophyll content (μmol/m^2)
	30 DAT	60 DAT	90 DAT	120 DAT			30 DAT	60 DAT	90 DAT	120 DAT		
T_0	3.1	4.5	6.7	2.7	5	6	2.67	5	6	9.33	3.3	46.03
T_1	3.8	4.7	6.9	4	5.67	6.33	4	5.67	6.33	11.33	3.6	48.57
T_2	3.1	4.7	7	3	5.33	6.33	3	5.33	6.33	11.67	3.9	51.27
T_3	3.9	4.8	7.1	3.7	5.33	6.67	3.67	5.33	6.67	12	4.2	52.97
T_4	3.8	4.9	7.1	4.3	6.33	8	4.33	6.33	8	13	3.8	53.9
T_5	3.2	5	7.2	5	6.33	8	5	6.33	8	12.67	4.5	54
T_6	3.8	4.8	6.9	4.3	5.67	6.67	4.33	5.67	6.67	12	4.6	51.13
T_7	3.8	5.4	7	5.7	6.33	7	5.67	6.33	7	10.33	4.5	51.4
T_8	3.5	4.5	6.6	5.3	6.67	8	5.33	6.67	8	11	4.6	51.77
T_9	3.8	5.1	6.6	5	7.33	8.67	5	7.33	8.67	13.67	5.2	50.48
T_{10}	4	5	6.5	3.3	5.33	7	3.33	5.33	7	11.67	5.4	54.2
T_{11}	3.2	5.3	7.2	5	6.67	7.67	5	6.67	7.67	13.33	4.8	51.44
T_{12}	3.9	4.9	6.7	4.3	5.33	7.33	4.33	5.33	7.33	14	5.4	49.71
T_{13}	3.9	4.9	6.6	5.3	6	7.33	5.33	6	7.33	13.67	4.4	50.71
T_{14}	3.5	4.6	6.6	4.7	5	8	4.67	5	8	12.67	4.8	51.14
T_{15}	3.7	5.5	7.3	4.7	7.67	9.33	4.67	7.67	9.33	15	5.7	55.47
C.D.	0.277	0.563	0.467	1.4	1.308	1.358	1.37	1.308	1.358	1.851	0.747	2.26
SE(m)	0.096	0.194	0.161	0.5	0.451	0.468	0.472	0.451	0.468	0.638	0.257	0.779
SE(d)	0.135	0.275	0.227	0.7	0.638	0.662	0.667	0.638	0.662	0.902	0.364	1.101

T_0 (100% RDF), T_1 (50 ppm ZnO), T_2 (100 ppm ZnO), T_3 (150 ppm ZnO), T_4 (50 ppm FeO), T_5(100 ppm FeO), T_6 (150 ppm FeO), T_7 (50 ppm ZnO + 50 ppm FeO), T_8 (50 ppm ZnO + 100 ppm FeO), T_9 (50 ppm ZnO + 150 ppm FeO), T_{10} (100 ppm ZnO + 50 ppm FeO), T_{11} (100 ppm ZnO + 100 ppm FeO), T_{12} (100 ppm ZnO + 150 ppm FeO), T_{13} (150 ppm ZnO + 50 ppm FeO), T_{14} (150 ppm ZnO + 100 ppm FeO), T_{15} (150 ppm ZnO + 150 ppm FeO).

Table 2: Performance of ZnO and FeO on plant spreading, petiole length, number of flowers per plant, days to flower initiation and duration of flowering of strawberry (*Fragaria × ananassa* Duch) cv. Winter Dawn.

Treatments	Plant spreading (cm) (E-W)				Plant spreading (cm) (N-S)				Petiole length (cm)	Number of flowers per plant				Days to flowers initiation	Duration of flowering
	30 DAT	60 DAT	90 DAT	120 DAT	30 DAT	60 DAT	90 DAT	120 DAT		60 DAT	80 DAT	100 DAT	115 DAT		
T_0	7.73	9.71	15.55	21.98	51	52.33	15.88	20.77	7.27	3.33	8.33	6.33	2.67	51	52.33
T_1	7.86	10.38	16.4	22.09	48	53	16.21	21.4	6.33	3.67	8.67	6.67	3.67	48	53
T_2	7.42	10.53	16.63	22.2	49	54.67	16.48	21.48	7.47	4.33	9	7	3.33	49	54.67
T_3	7.7	10.44	16.71	22.19	48	53	16.55	21.77	7.2	4.33	9.33	7	3.67	48	53
T_4	7.45	10.57	17.03	22.45	48.7	53	16.84	22.1	7.63	4.67	9.33	7.33	3.33	48.7	53
T_5	7.56	10.62	16.99	22	47.7	52.67	16.87	22.19	7.5	4.67	8	7.67	3.67	47.7	52.67
T_6	7.54	10.47	16.63	23.03	48	53	16.42	21.44	7.5	3.67	9	6.33	3.33	48	53
T_7	7.91	10.58	16.59	22.57	48	52.67	16.37	21.64	8.23	4.33	8.67	7	4.33	48	52.67
T_8	7.97	10.35	16.93	22.94	48	52.67	16.1	21	8.33	4.33	9	6.67	4.67	48	52.67
T_9	7.87	10.42	16.84	22.54	47.7	53.67	16.35	22.55	8.43	4.67	9.67	7.33	4	47.7	53.67
T_{10}	7.91	10.85	17.26	23.5	49.3	53.67	17.24	22.23	9.57	3.67	10	7.67	5.33	49.3	53.67
T_{11}	7.92	10.43	17	22.34	47	53.33	17.35	22.29	9.27	4.33	9	7.67	3.67	47	53.33
T_{12}	7.47	10.84	17.01	22.16	49	53	16.86	22.26	8.27	3.67	8.33	7	5	49	53
T_{13}	7.98	10.93	16.74	22.91	49.7	53	16.74	21.98	8.87	3.67	10	6.67	3.67	49.7	53
T_{14}	8.04	10.77	17.31	23.09	48	53.33	17.58	22.33	9.1	3.67	9	5.67	5	48	53.33
T_{15}	8.02	11.23	17.71	23.18	50	55	17.96	22.99	9.43	5.33	11	8.33	5.33	50	55
C.D.	0.221	0.466	0.679	0.438	1.536	1.431	0.79	0.95	1.14	0.997	1.499	1.269	1.076	1.536	1.431
SE(m)	0.076	0.161	0.234	0.151	0.529	0.493	0.272	0.327	0.393	0.344	0.516	0.437	0.371	0.529	0.493
SE(d)	0.108	0.227	0.331	0.213	0.748	0.697	0.385	0.463	0.555	0.486	0.73	0.618	0.524	0.748	0.697

T_0 (100% RDF), T_1 (50 ppm ZnO), T_2 (100 ppm ZnO), T_3 (150 ppm ZnO), T_4 (50 ppm FeO), T_5 (100 ppm FeO), T_6 (150 ppm FeO), T_7 (50 ppm ZnO + 50 ppm FeO), T_8 (50 ppm ZnO + 100 ppm FeO), T_9 (50 ppm ZnO + 150 ppm FeO), T_{10} (100 ppm ZnO + 50 ppm FeO), T_{11} (100 ppm ZnO + 100 ppm FeO), T_{12} (100 ppm ZnO + 150 ppm FeO), T_{13} (150 ppm ZnO + 50 ppm FeO), T_{14} (150 ppm ZnO + 100 ppm FeO), T_{15} (150 ppm ZnO + 150 ppm FeO).

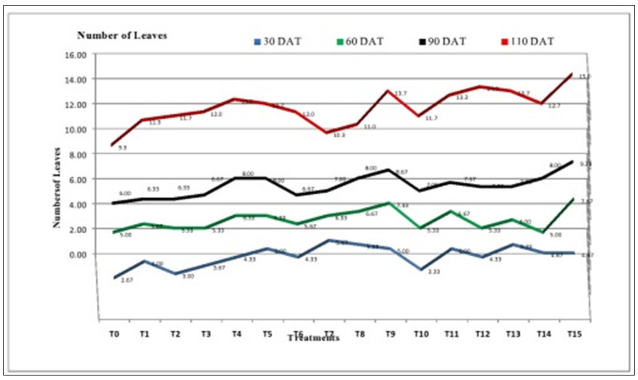

Figure 2: Performance at different concentrations of ZnO and FeO on number of leaves per plant of strawberry (*Fragaria × ananassa* Duch) cv. Winter Dawn.

(23.50 cm) in the East-West direction was observed in T_{15} and North-South direction maximum spreading (22.99 cm) of the plant was noted in T_{10} followed by T_{15} (23.18 cm). Maximum petiole length (9.57 cm) was noted in T_{10}, followed by T_{15} (9.43 cm), and minimum petiole length (7.27 cm) was noted down in the T_0, as shown in table 3 and figure 3, respectively.

Effect on flowering of the plants

With the flowering phase of the crop, significant variations were found among all the treatments, respectively. Minimum days to flower initiation were noted in T_{11} (47.0 days), and maximum days for flowering were recorded in T_0 (51 days), as shown in table 2 and figure 4. Concerning the flowering, variations were found amongst all the treatments concerning total number of flowers per plant. Maximum flowers per plant (5.33) was recorded in T_{15} at 60 DAT, after 80 days of transplanting the runners, maximum flowers (11.00) was noted in T_{15} while in T_0 (8.00), After 100 DAT maximum number (8.33) of flowers was noted down in T_{15} and after 115 DAT maximum number of flowers (5.33) was also higher in T_{15} as comparison with the other treatments as shown in table 2 and figure 5. Total duration of flowering was also observed maximum that is 55 days in T_{15} and minimum (52.33) in control.

Table 3: Performance of ZnO and FeO on days for fruit maturity, number of fruits per plant, yield per plant (g), duration of harvesting and number of harvesting of strawberry (*Fragaria × ananassa* Duch) cv. Winter Dawn.

Treatments	Days for fruit maturity	Number of fruits per plant				Yield per plant (g)	Duration of harvesting (Days)	Number of harvesting
		80 DAT	95 DAT	110 DAT	125 DAT			
T_0	29	4.67	6.67	4.33	1.67	174.7	45	3.33
T_1	28	5.33	7.33	5.67	2	176.7	47.67	4.33
T_2	28	5.67	7.67	5.67	2	176	46.67	4
T_3	28.33	5.67	8	6	2.33	185	49	4.67
T_4	26.33	6	8	6.33	2.33	196	49.33	3.67
T_5	27.67	5.67	8.67	6.67	2.67	202.7	49.67	3.67
T_6	27	5	7.33	5.67	2	199.7	51.33	4.67
T_7	26.33	7	6.67	5.67	3.33	214.3	53.67	3.67
T_8	25.67	5.33	7	6	1.67	227.3	55.67	4.67
T_9	27	6.33	6.67	6.67	2.33	223.7	51	5
T_{10}	25.33	6.33	8.33	7	3	257.7	54	5.67
T_{11}	27.33	6	7.33	5.67	3.33	228.7	51	4.67
T_{12}	28	6	7.33	7	2	240.7	53.33	4
T_{13}	27.33	6.67	6.33	6.67	3	270	55.67	4.33
T_{14}	28	6.33	7.33	6.67	3	246.7	55.33	4
T_{15}	25	7.33	9.67	7.67	4	299	57.33	6
C.D.	1.374	0.999	1.02	1.013	0.981	33.056	2.813	1.073
SE(m)	0.473	0.344	0.352	0.349	0.338	11.39	0.969	0.37
SE(d)	0.669	0.487	0.497	0.493	0.478	16.108	1.371	0.523

T_0 (100% RDF), T_1 (50 ppm ZnO), T_2 (100 ppm ZnO), T_3 (150 ppm ZnO), T_4 (50 ppm FeO), T_5(100 ppm FeO), T_6 (150 ppm FeO), T_7 (50 ppm ZnO + 50 ppm FeO), T_8 (50 pm ZnO + 100 ppm FeO), T_9 (50 ppm ZnO + 150 ppm FeO), T_{10} (100 ppm ZnO + 50 ppm FeO), T_{11} (100 ppm ZnO + 100 ppm FeO), T_{12} (100 ppm ZnO + 150 ppm FeO), T_{13} (150 ppm ZnO + 50 ppm FeO), T_{14} (150 ppm ZnO + 100 ppm FeO), T_{15} (150 ppm ZnO + 150 ppm FeO).

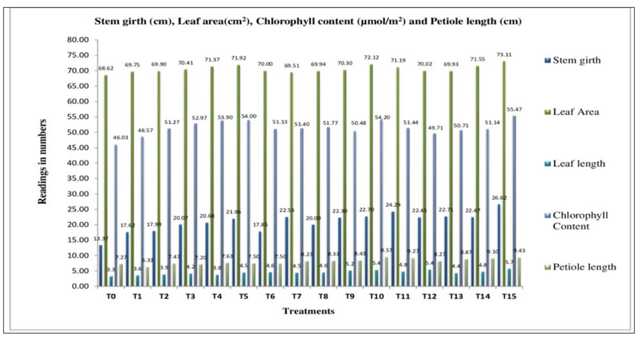

Figure 3: Performance at different concentrations of ZnO and FeO on stem girth (cm), leaf area (cm²), chlorophyll content (μmol/m²) and petiole length (cm) of strawberry (*Fragaria × ananassa* Duch) cv. Winter Dawn.

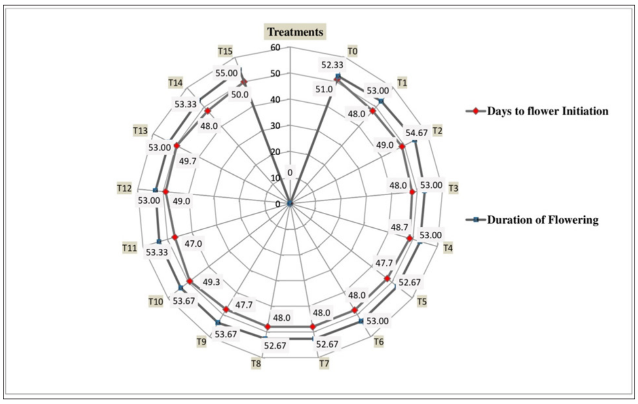

Figure 4: Performance at different concentrations of ZnO and FeO on days to flower initiation and duration of flowering of strawberry (*Fragaria × ananassa* Duch) cv. Winter Dawn.

Effect on yield of the crop

Crop yield parameters, e.g., number of fruit per plant, total days taken for fruit maturity, total yield per plant (g), total number of harvesting, and duration of harvesting, significant variations were found among various treatments. Firstly, the total number of fruits was recorded as a maximum (9.67) in T_{15}. The lowest fruiting (6.67) was recorded in T_0, as shown in table 3 and figure 6. The plants treated with T_{15} show minimum days (25.00) to fruit maturity while maximum days (29) for fruit maturity were noted in the T_0. Yield per plant (g) was maximum (299.00 g) under T_{15}, and minimum yield per plant (174.7 g) was noted in T_0, as shown in table 3 and figure 7. Number of harvesting recorded maximum (6.00) in T_{15}. The

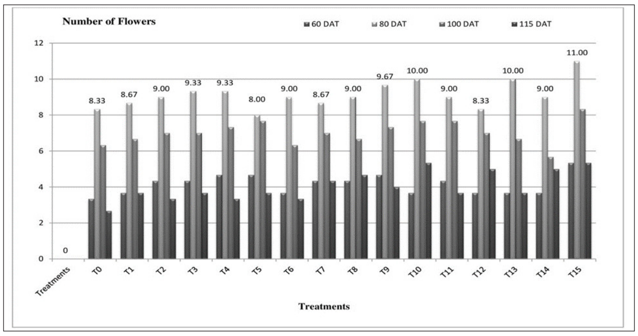

Figure 5: Performance at different concentrations of ZnO and FeO on number of leaves of strawberry (*Fragaria × ananassa* Duch) cv. Winter Dawn.

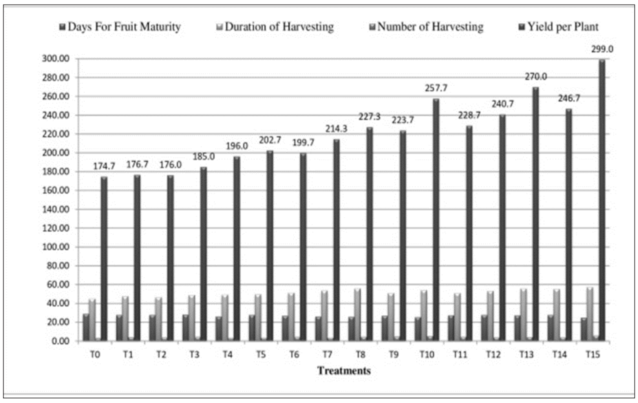

Figure 6: Performance at different concentrations of ZnO and FeO on days to fruit maturity, duration of harvesting and number of harvesting and yield per plant (g) of strawberry (*Fragaria × ananassa* Duch) cv. Winter Dawn.

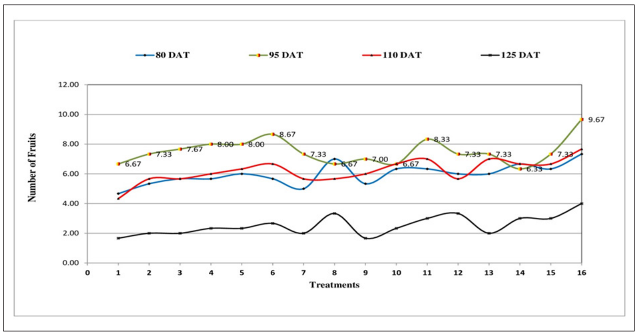

Figure 7: Performance at different concentrations of ZnO and FeO on number of fruits per plant at different days of interval of strawberry (*Fragaria × ananassa* Duch) cv. Winter Dawn.

Figure 8: (**a**) Runners of strawberry (**b**) Transplanting of runners (**c**) Flower initiation (**d**) During first harvesting (**e**) During second harvesting (**f**) During third harvesting (**g**) During manual weeding and (**h**) During final harvesting.

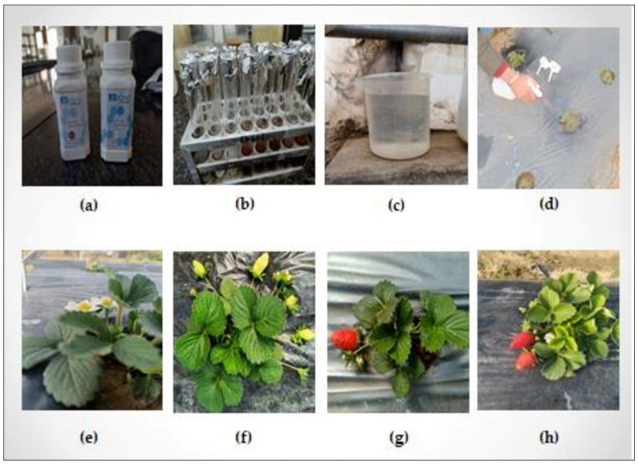

Figure 9: (**a**) Nano-Zinc oxide and Iron oxide (**b**) Preparation of stock solution (**c**) Mix stock in distilled water (**d**) Foliar application of ZnO and FeO (**e**) After foliar application flower initiation stage (**f**) After foliar application fruiting stage (**g**) Fruit ripening stage and (**h**) Harvesting stage.

total duration of harvesting was observed to be higher (57.33) in T_{15} and lowest (45.00) in T_0, as shown in table 3 and figure 8, figure 9, respectively.

Discussion

Numerous studies observed that applying Zn and Fe significantly influences various crops' plant growth, development, and productivity. For instance, the same findings were demonstrated by Laware and Raskar in onions [6], which observed that lower concentrations of ZnO NPs had a significant impact on the germination of seeds. However, higher doses of ZnO were found to impair seed germination. Furthermore, NPs role in germination can vary depending on the specific concentrations and plant species [16]. The increased height of plants, the total number of leaves per plant, and the production of runners and other growth parameters are due to the application of zinc sulphate (Zn SO_4), which might impute the availability of the appropriate quantity of Zn within the system of plants as the element elevates ribosome and ribonucleic acid [17]. Bagali et al. revealed that applying $ZnSO_4$ in the guava crop boosts plant growth parameters and yields contributing characters at various concentrations [17]. A study by Raliya and Tarafdar observed that various concentrations of NPs were applied to cucumber, alfalfa, and tomato to increase the germination of seeds in the crops [5, 18]. Based on a study, it was noted that the simultaneous application of Zn and Fe NPs at different concentrations led to enhanced growth and increased yield of strawberry crops at various concentrations. Zinc sulphate at a lower concentration enhances the production of heavier berries; on the other hand, $ZnSO_4$ in higher doses reduces the weight of fruits in blood red, orange, and strawberry [19].

Paydas et al. [10] observed that maximum fruits per plant, total yield (g), and fruit quality attributes were higher with ferrous sulphate at the concentration of 0.2 %, followed by 0.4 %, while the toxicity occurred with higher doses. Sanz et al. [19] discovered that $ZnSO_4$ by foliar application method in papaya plants enhanced the number of leaves, reduced leaf loss, and accelerated blooming in the papaya plants. Iron's influence on the soluble solids by the foliar application may be related to its availability and involvement in photosynthesis, which boosts the photosynthetic rate in the plant. Zaiter et al. [20] found that foliar application of $FeSO_4$ on strawberries improved performance by increasing the total fruits per plant [21]. Iron has a favorable influence on chlorophyll synthesis and activity, improving plants' photosynthesis. The ability to photosynthesize and create more available nutrients for the plant helps boost its generative strength, allowing it to hold more fruits. Zn is an essential component that contributes to the formation of cell membranes, cell walls, fruit's development, growth, and overall quality of fruit [4]. Zn is also an essential element for plants since it functions as a metal component of many enzymes, a functional, structural cofactor in photosynthesis, synthesis of proteins, division of cells, synthesis of auxin, maintenance of functioning, sexual fertilization, and structure of membranes [22]. Brittenham [23] found that $ZnSO_4$ at 0.2% and 0.4% boosted strawberry leaf number, plant height, petiole length, stem girth, and other characteristics in the cultivars 'Pajaro' and 'Trakia'.

Conclusion

Based on the current research study conducted in 2022-23, It can be concluded consecutively that treatments T_{15} Z_3F_3 (150 ppm ZnO NPs + 150 ppm FeO NPs) and $T_{11}Z_2F_2$ (100 ppm ZnO NPs + 100 ppm FeO NPs) in which simultaneously application of ZnO and FeO was found bests in terms of growth, flowerings, and the yield parameters of the strawberry cv. Winter Dawn. Zn is an ingredient of carbonic anhydrase, as well as numerous dehydrogenases and the formation of auxin, all of which contribute to the elongation process. Iron is a cofactor for about 140 enzymes, which plays a significant role in catalyzing specific biological reactions. In the combination of ZnO and FeO, ZnO@150 ppm plays numerous essential functions in plant growth and development, and FeO@150 ppm such as chlorophyll production, thylakoid synthesis, and chloroplast. To summarize, combining ZnO and FeO (150 ppm) shows considerable results in strawberry cv. Winter Dawn under the Punjab region of India.

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Conflict of Interest

The authors declared that they have no conflict of interest.

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