Effect of nano zinc and nano iron on the vegetative growth of guava (*Psidium guajava* L.) cv. Allahabad Safeda

Abstract

In June 2023, the Department of Horticulture at Lovely Professional University in Jalandhar, Punjab conducted a field experiment. The experiment utilized a factorial Randomized Block Design with 9 treatments and 3 replications, covering a total of 27 plants. The experiment ran from June 2023 to December 2023. Regarding the individual effect of nano zinc, it was found that the application of n~~N~~ano z~~Z~~inc at a concentration of 200 ppm resulted in significant increases in various vegetative parameters. The maximum plant height increased by 18.06%, canopy spread increased by 30.16% East to West and 30.31% North to South, canopy volume increased by 121.34%, leaf length increased by 119.25%, leaf width increased by 110.94%, and leaf area increased by 363.27%. However, the increase in stem diameter was not significant compared to other treatments. Similarly, the individual effect of nano iron was also studied. The application of Nano Iron at a concentration of 150 ppm resulted in significant increases in various vegetative parameters. The maximum plant height increased by 17.26%, canopy spread increased by 27.63% East to West and 27.78% North to South, canopy volume increased by 109.42%, leaf length increased by 113.28%, leaf width increased by 107.08%, and leaf area increased by 343.06%. However, the increase in stem diameter was not significant compared to other treatments. The experiment revealed that among various treatment combinations, the application of Nano Zinc @ 200ppm + Nano Iron @ 150ppm (nZn+$_2$nFe$_2$) was observed significantly superior and maximum maximum plant height increased by 19.98%, canopy spread increased by 34.69% East to West and 34.88% North to South, canopy volume increased by 144.72%, leaf length increased by 130.89%, leaf width increased by 120.56% and leaf area increased by 409.25% over other treatments about vegetative parameters except stem diameter compared to other treatments.

Keywords: Fertilizer, Iron, Nano, Vegetative parameters and Zinc

Introduction

In India, the guava (*Psidium guajava* L.) is considered to be one of the largest and most extensively developed tropical groups within the Myrtaceae family having diploid chromosome number 2n=22 (Darlington and Janaki, 1945). The guava plant thrives in tropical, sub-tropical, and certain arid regions across the globe. Its origins can be traced back to tropical America, specifically within a geographical range spanning from Mexico to Peru (Chandler, 1958). There is a wide variety of cultivars found in India, yet only a select few such as Allahabad Safeda, Apple colour, Sardar guava, and others dominate the majority of the cultivated land (Rajan *et. al*.,2005). The majority of guava cultivars are diploid and contain seeds, which can negatively impact the quality of the fruit. However, there are also known instances of both natural and artificially created triploids, which primarily yield seedless fruits (Chohan and Dhaliwal, 1994). It serves as a unique source of L-ascorbic acid and gelatin, while also containing a rich package of calcium. Due to these attributes, guava is widely utilized in the production of jam. Notably, guava is a commercially cultivated fruit crop on a global scale, with India being a major contributor. In India alone, guava is cultivated across an expansive area of 308,000 hectares, resulting in a production of 4,582,000 metric tons and Panjab ranked 6th ~~th~~ with the production of 219.85 metric tons during the year 2020-21 (Anon,2021).

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The available literature on this subject is rather limited, and the technology of nano-fertilizers is relatively new. In the field of agriculture, nanotechnology has made significant strides in the last decade due to substantial public funding. However, despite the vast scope of disciplines within agriculture, the pace of progress remains sluggish (De Rosa *et al*., 2010). Nanotechnology, a contemporary technology, encompasses a wide array of applications, such as the production of particles within the nanoscale range. It is recognized as an advanced discipline that encompasses the creation, development, and utilization of various installations, devices, and systems composed of minuscule units. The concept of nanotechnology originated from the Greek term "Nano," which translates to "dwarf," as nanoparticles are characterized as individual particles with dimensions no larger than 100 nanometers (Alalaf *et. al*., 2020). Nanotechnology can be employed for horticulture produce production, processing product manufacture, storage, packing, and transportation. (Mousavi and Rezai, 2011). The imbalanced problem of nutrient deficiency, decrease in the use of organic matter, and low use of fertilizer in soil to feed the growing global population. For which multipurpose nano-based fertilizer formulation should evolve. To improve soil fertility and increase crop productivity huge amounts of fertilizer are required (Dubey and Mailapalli, 2016). Fertilizers can be enclosed in nanoparticles to improve nutrient uptake. The greatest option for persistent eutrophication issues may be nano fertilizers, which also improve nutrient usage efficiency to lessen macro- and micronutrient deficiencies (Shukla *et al*., 2019).

Zinc is a crucial nutritional element that enhances the growth of seedlings by promoting increased absorption and faster transmission within the plant. It also prevents deposition on the surfaces of calcareous soil colloids. Additionally, zinc plays a vital role in the production and activation of chlorophyll, as well as in the synthesis of carbohydrates, proteins, and enzymes. Moreover, zinc is essential for the formation of important plant hormones, such as auxins, and contributes significantly to enhancing plant resistance against various pathogens. Iron is widely recognized as one of the most crucial elements due to its pivotal role in the formation and activation of chlorophyll pigment. This is achieved through its incorporation into the Porphyrin compounds that constitute chlorophyll. Additionally, iron is an essential component of the cytochrome, which is responsible for the respiration process in plants. Moreover, iron actively participates in the synthesis of chloroplasts, chloroplast proteins, and the formation of plant proteins. Furthermore, iron plays a vital role in the synthesis of numerous enzymes, including Catalase, Peroxidase, and Cytochrome oxidase. These enzymes are instrumental in activating various vital processes within the plant, particularly oxidative reactions, as iron facilitates the transfer of electrons in oxidation reactions. Reduction, on the other hand, assumes a significant function in cell metabolism (Alalaf *et. al*., 2020).

Materials and Method

Experimental Location

The experiment was conducted at farms at Department of Horticulture, Lovely Professional University, Phagwara, Panjab. The area of the experiment is suited at altitude of 232 meter above mean sea level, the latitude and longitude are 31.244604 ^{0}N and 75.701022 ^{0}E respectively. Punjab (Phagwara area), located in Northeastern India, it is part of the central plain zones. The annual rainfall in Punjab varies from 250 to 1000 mm/year. In the winter, the temperature drops to 5 ^{0}C at night and rises to 12 to 15 ^{0}C in the morning. The highest temperature throughout the summer is greater than 40 ^{0}C.

Treatment Details

The experimental block encompassed an area of $972m^2$, with each plant occupying a space of 6m*6m. Within this area, a total of 27 guava trees were present. The treatments applied in this study involved two factors: nano zinc and nano iron. The total number of treatments are 9 with 3 replications.

Table 1 Treatment Details

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Treatment	Treatment combination
nZn+$_0$nFe) $_0$Control)	Nano Zinc 0ppm+ Nano Iron 0ppm
nZn+$_0$nFe$_1$	Nano Zinc 0ppm+ Nano Iron 50ppm
nZn+$_0$nFe$_2$	Nano Zinc 0ppm+ Nano Iron 150ppm
nZn+$_1$nFe$_2$	Nano Zinc 100ppm+ Nano Iron 0ppm
nZn+$_1$nFe$_1$	Nano Zinc 100ppm+ Nano Iron 50ppm
nZn+$_1$nFe$_2$	Nano Zinc 100ppm+ Nano Iron 150ppm
nZn+$_2$nFe$_0$	Nano Zinc 200ppm+ Nano Iron 0ppm
nZn+$_2$nFe$_1$	Nano Zinc 200ppm+ Nano Iron 50ppm
nZn+$_2$nFe$_2$	Nano Zinc 200ppm+ Nano Iron 150ppm

Plant Growth Parameters Measurement

Growth parameters were monitored every two months throughout the duration of the study. The height of the guava tree was assessed using a measuring tape, while the diameter of the plant stem was measured with a vernier caliper. The canopy spread in both the east-west and north-south directions was determined using a measuring scale. Leaf length and width were measured using a scale, and leaf area was calculated using the formula proposed by Montgomery (1911): Area = Length x Width. Additionally, the canopy volume was calculated based on the observed data, including plant height and canopy spread in both the east-west and north-south directions, using the following formula (Arora and Singh 2006).

$$\text{Plant volume} = \frac{\text{East to West} + \text{North to South})^2 \times \tfrac{1}{2}\ \text{Plant height}}{4} \times 4.19$$

Result

Plant h~~H~~eight

From Table 2, it appeared that among treatments of nano zinc, the maximum percent increase (18.06%) was observed in treatment nZn_2 (n~~N~~ano z~~Z~~inc 200 ppm) and it was significantly ($p \leq 0.05$) superior over other treatments while minimum percent increase (12.37%) was found in treatment nZn_0 (Nano Zinc 0ppm). In the individual effect of nano iron, the maximum percent increase (17.26%) was observed in treatment nFe_2 (Nano Iron 150ppm) which was found significantly ($p \leq 0.05$) superior over other treatments of nano iron. However, a minimum percent increase (13.33%) was noticed with treatment nFe_0 (Nano Iron 0ppm). Among the interaction effect of nano zinc and nano iron, the maximum percent increase in plant height (19.98%) was observed in treatment $nZn+_2nFe_2$ (Nano Zinc 200ppm+ Nano Iron 150ppm). The treatment was thought significantly ($p \leq 0.05$) superior over all other combination treatments. The minimum increase (9.74%) was found in $nZn+_0nFe$ ~~$_0$~~(n~~N~~ano z~~Z~~inc 0ppm+ n~~N~~ano i~~I~~ron 0ppm) at the end of the experiment.

Stem d~~D~~iameter

From Table 3, it appeared that among the treatment of nano zinc, the maximum percent increase (0.38%) was observed in treatment nZn_2 (Nano Zinc 200 ppm) and it was non-significantly ($p \leq 0.05$) superior over other treatments of nano zinc while minimum percent increase (0.28%) was found in treatment nZn_0 (Nano Zinc 0ppm). In the individual effect of nano iron, the maximum percent increase (0.37%) was observed in treatment nFe_2 (Nano Iron 150ppm) which was non-significantly ($p \leq 0.05$) superior over other treatments of nano iron. However, a minimum percent increase (0.30%) was noticed with treatment nFe_0 (Nano Iron 0ppm). Among the interaction of nano zinc and nano iron, the maximum per cent increase in plant stem diameter (0.40%) was observed in treatment $nZn+_2nFe_2$ (Nano Zinc 200ppm+ Nano Iron 150ppm). The treatment was thought non-significantly ($p \leq 0.05$) superior over all other combination treatments. The minimum increase (0.24%) was found in $nZn+_0nFe_0$(Nano Zinc 0ppm+ Nano Iron 0ppm) at the end of the experiment.

Canopy s~~S~~pread

From Table 4, it appeared that among treatment of nano zinc, maximum percent increase (30.16%- E-W and 30.31%- N-S) was observed in treatment nZn2 (nano zinc 200 ppm) and it was significantly ($p \leq 0.05$) superior over other treatment of nano zinc while minimum percent increase (17.94%- E-W and 18.04 %- N-S) was found in treatment nZn0 (Nano Zinc 0ppm). In the individual effect of nano iron, the maximum percent increase (27.63%- E-W and 27.28%- N-S) was observed in treatment nFe2 (Nano Iron 150ppm) which was significantly ($p \leq 0.05$) superior over other treatments of nano iron. However, a minimum per cent increase (19.90%- E-W and 20.11%- N-S) was noticed with treatment nFe0 (Nano Iron 0ppm). Among the interaction of nano zinc and nano iron, the maximum per cent increase in plant canopy spread (34.69%- E-W and 34.88%-N-S) was observed in treatment nZn2+nFe2 (Nano Zinc 200ppm+ Nano Iron 150ppm). The treatment was thought significantly ($p \leq 0.05$) superior over all other combination treatments. The minimum increase (14.79%- E-W and 14.84%- N-S) was found in nZn0+nFe0 (Nano Zinc 0ppm+ Nano Iron 0ppm) at the end of the experiment.

Canopy vVolume

From Table 5, it appeared that among the treatments of nano zinc, the maximum percent increase (121.3%) was observed in treatment nZn_2 (nano zinc 200 ppm) and it was significantly ($p \leq 0.05$) superior over other treatments of nano zinc while minimum percent increase (64.4%) was found in treatment nZn_0 (Nano Zinc 0ppm). In the individual effect of nano iron, the maximum percent increase (109.4%) was observed in treatment nFe_2 (Nano Iron 150ppm) which was significantly ($p \leq 0.05$) superior over other treatments of nano iron. However, a minimum percent increase (73.4%) was noticed with treatment nFe_0 (Nano Iron 0ppm). Among the interaction of nano zinc and nano iron, the maximum percent increase in plant canopy volume (144.7%) was observed in treatment $nZn+_2nFe_2$ (Nano Zinc 200ppm+ Nano Iron 150ppm). The treatment was thought significantly ($p \leq 0.05$) superior over all other combination treatments. The minimum increase (51.3%) was found in $nZn+_0nFe\ _0$(Nano Zinc 0ppm+ Nano Iron 0ppm) at the end of the experiment.

Leaf lLength

From Table 6, it appeared that among the treatment of nano zinc, the maximum percent increase (119.2%) was observed in treatment nZn2 (nano zinc 200 ppm) and it was significantly ($p \leq 0.05$) superior over other treatments of nano zinc while minimum per cent increase (95.3%) was found in treatment nZn0 (Nano Zinc 0ppm). In individual effect of nano iron, the maximum percent increase (113.2%) was observed in treatment nFe2 (Nano Iron 150ppm) which was significantly ($p \leq 0.05$) superior over other treatments of nano iron. However, minimum per cent increase (95.3%) was noticed with treatment nFe0 (Nano Iron 0ppm). Among the interaction of nano zinc and nano iron, the maximum percent increase in plant leaf length (130.8%) was observed in treatment nZn2+nFe2 (Nano Zinc 200ppm+ Nano Iron 150ppm). The treatment was thought significantly ($p \leq 0.05$) superior over all other treatments of combination. The minimum increase (85.4%) was found in nZn0+nFe0 (Nano Zinc 0ppm+ Nano Iron 0ppm) at the end of experiment.

Leaf w~~W~~idth

From Table 7, it appeared that among treatment of nano zinc, maximum percent increase (110.9%) was observed in treatment nZn_2 (nano zinc 200 ppm) and it was significantly ($p \leq 0.05$) superior over other treatment of nano zinc while minimum per cent increase (87.9%) was found in treatment nZn_0 (Nano Zinc 0ppm). In the individual effect of nano iron, the maximum percent increase (107.0%) was observed in treatment nFe_2 (Nano Iron 150ppm) which was significantly ($p \leq 0.05$) superior over other treatment of nano iron. However, minimum per cent increase (91.5%) was noticed with treatment nFe_0 (Nano Iron 0ppm). Among the interaction of nano zinc and nano iron, the maximum per cent increase in plant leaf width (120.5%) was observed in treatment $nZn+_2nFe_2$ (Nano Zinc 200ppm+ Nano Iron 150ppm). The treatment was thought significantly ($p \leq 0.05$) superior over all other treatments of combination. The minimum increase (80.4%) was found in $nZn+_0nFe\ _0$(Nano Zinc 0ppm+ Nano Iron 0ppm) at the end of experiment.

Leaf a~~A~~rea

From table 8, it appeared that among treatment of nano zinc, maximum per cent increase (363.2%) was observed in treatment nZn2 (nano zinc 200 ppm) and it was significantly ($p \leq 0.05$) superior over other treatment of nano zinc while minimum per cent increase (260.4%) was found in treatment nZn0 (Nano Zinc 0ppm). In individual effect of nano iron, the maximum per cent increase (343.0%) was observed in treatment nFe2 (Nano Iron 150ppm) which was significantly ($p \leq 0.05$) superior over other treatment of nano iron. However, minimum per cent increase (274.9%) was noticed with treatment nFe0 (Nano Iron 0ppm). Among the interaction of nano zinc and nano iron, the maximum per cent increase in plant leaf area (409.2%) was observed in treatment nZn2+nFe2 (Nano Zinc 200ppm+ Nano Iron 150ppm). The treatment was thought significantly ($p \leq 0.05$) superior over all other treatments of combination. The minimum increase (234.6%) was found in nZn0+nFe0 (Nano Zinc 0ppm+ Nano Iron 0ppm) at the end of experiment.

Table 2 Effect of nano zinc and nano iron on plant height of guava (*Psidium guajava* L.) cv Allahabad Safeda

Months / Treatments	Height of plant (cm)			
	June (Initial values)	**August**	**October**	**December**
nZn_0	438.98	3.920 (456.27)	9.819 (482.30)	12.377 (793.65)
nZn_1	409.96	5.058 (430.65)	12.344 (460.34)	15.601 (473.74)
nZn_2	411.17	6.547 (437.84)	14.819 (471.81)	18.061 (485.05)
SE (m) ±		0.049	0.088	0.096
CD at 5 %		0.148	0.265	0.291
nFe_0	427.66	4.273 (445.97)	10.769 (473.76)	13.334 (484.77)
nFe_1	419.96	5.164 (441.60)	12.202 (471.11)	15.442 (484.68)
nFe_2	412.50	6.087 (437.20)	14.011 (469.57)	17.262 (482.98)
SE (m) ±		0.148	0.088	0.096
CD at 5 %		0.049	0.265	0.291
nZn+$_0$nFe) $_0$Control)	424.60	3.19 (438.07)	8.38 (460.03)	9.74 (465.97)
nZn+$_0$nFe$_1$	425.83	3.76 (441.80)	9.47 (466.17)	12.64 (479.63)
nZn+$_0$nFe$_2$	466.53	4.81 (488.97)	11.61 (520.70)	14.75 (535.37)
nZn+$_1$nFe$_2$	420.20	4.32 (438.43)	10.69 (464.93)	13.89 (478.50)
nZn+$_1$nFe$_1$	415.83	5.25 (437.63)	12.57 (467.97)	15.86 (481.63)
nZn+$_1$nFe$_2$	393.87	5.59 (415.90)	13.77 (448.13)	17.06 (461.10)
nZn+$_2$nFe$_0$	438.20	5.30 (461.43)	13.24 (496.33)	16.38 (509.87)
nZn+$_2$nFe$_1$	418.23	6.48 (445.37)	14.57 (479.20)	17.83 (492.80)
nZn+$_2$nFe$_2$	377.10	7.86 (406.73)	16.65 (439.90)	19.98 (452.50)
SE (m) ±		0.084	0.151	0.166
CD at 5 %		0.253	0.454	0.499

Note:

1. Data in parentheses indicate increase in plant height in percentage and cm.
2. CD (Critical Ddifference) has been calculated based on per cent increase values.

Table 3 Effect of nano zinc and nano iron on plant stem diameter of guava (*Psidium guajava* L.) cv Allahabad Safeda

Months / Treatments	Plant Stem Diameter (cm)			
	June (Initial values)	**August**	**October**	**December**
nZn_0	12.60	0.095 (12.17)	0.249 (12.18)	0.282 (12.19)
nZn_1	13.22	0.160 (13.24)	0.299 (13.26)	0.337 (13.26)
nZn_2	12.20	0.230 (12.29)	0.333 (12.30)	0.385 (12.31)
SE (m) ±		0.051	0.080	0.097
CD at 5 %		N/S	N/S	N/S
nFe_0	12.06	0.114 (12.07)	0.266 (12.09)	0.300 (12.10)
nFe_1	13.17	0.166 (13.19)	0.294 (13.21)	0.334 (13.21)
nFe_2	12.41	0.206 (12.43)	0.321 (12.45)	0.370 (12.45)
SE (m) ±		0.051	0.080	0.097
CD at 5 %		N/S	N/S	N/S
$nZn+_0nFe$) $_0$Control)	12.56	0.05 (12.57)	0.22 (12.59)	0.24 (12.59)
$nZn+_0nFe_1$	11.53	0.09 (11.54)	0.24 (11.56)	0.27 (11.56)
$nZn+_0nFe_2$	12.38	0.14 (12.40)	0.29 (12.41)	0.34 (12.42)
$nZn+_1nFe_2$	13.22	0.11 (13.24)	0.26 (13.25)	0.29 (13.26)
$nZn+_1nFe_1$	14.63	0.16 (14.66)	0.31 (14.68)	0.34 (14.68)
$nZn+_1nFe_2$	11.83	0.20 (11.85)	0.33 (11.86)	0.37 (11.87)
$nZn+_2nFe_0$	10.41	0.18 (10.43)	0.32 (10.44)	0.36 (10.45)
$nZn+_2nFe_1$	13.37	0.24 (13.39)	0.34 (13.41)	0.39 (13.41)
$nZn+_2nFe_2$	13.03	0.27 (13.06)	0.34 (13.07)	0.40 (13.08)
SE (m) ±		0.088	0.139	0.168
CD at 5 %		N/S	N/S	N/S

Note:

1. Data in parentheses indicate increase in plant stem diameter in percentage and cm.
2. CD (Critical difference) has been calculated based on per cent increase values.

Table 4 Effect of nano zinc and nano iron on plant canopy spread (East- West) of guava (*Psidium guajava* L.) cv Allahabad Safeda

Month / Treatments	Plant Canopy Spread (East- West) (cm)							
	June (Initial values)		August		October		December	
nZn_0	534.55	543.45	7.451 (574.3)	7.317 (582.8)	15.850 (619.1)	16.158 (630.63)	17.949 (630.3)	18.042 (640.75)
nZn_1	515.8	513.18	9.412 (564.3)	9.357 (561.2)	19.582 (616.7)	19.750 (614.41)	23.099 (634.8)	23.297 (632.55)
nZn_2	519.14	528.71	11.735 (579.8)	11.721 (590.3)	23.899 (642.8)	23.933 (654.68)	30.160 (675.3)	30.317 (668.25)
SE (m) ±			0.064	0.087	0.087	0.065	0.065	0.076
CD at 5 %			0.195	0.262	0.262	0.197	0.197	0.230
nFe_0	535.64	554.67	8.107 (579.0)	8.026 (599.0)	16.973 (626.5)	17.151 (649.37)	19.905 (642.3)	20.117 (665.63)
nFe_1	517.33	524.43	9.515 (566.6)	9.416 (573.8)	19.789 (619.8)	19.949 (629.15)	23.666 (640.0)	23.754 (649.21)
nFe_2	516.41	506.24	10.977 (572.7)	10.954 (561.5)	22.569 (632.3)	22.742 (621.20)	27.637 (658.1)	27.785 (646.71)
SE (m) ±			0.064	0.087	0.087	0.065	0.065	0.076
CD at 5 %			0.195	0.262	0.262	0.197	0.197	0.230
$nZn+_0nFe_0$)Control)	552.73	589.00	6.10 (586.4)	6.08 (624.8)	13.22 (625.8)	13.51 (668.60)	14.79 (634.5)	14.84 (676.4)
$nZn+_0nFe_1$	513.57	530.07	7.61 (552.6)	7.31 (568.8)	16.18 (596.5)	16.63 (618.23)	18.16 (606.8)	18.58 (628.6)
$nZn+_0nFe_2$	537.37	511.30	8.65 (583.8)	8.55 (554.9)	18.16 (635.0)	18.34 (605.07)	20.89 (649.7)	20.70 (617.3)
$nZn+_1nFe_2$	516.13	524.97	7.95 (557.2)	7.81 (566.1)	17.20 (605.0)	17.39 (616.33)	19.43 (616.5)	19.60 (627.9)
$nZn+_1nFe_1$	511.57	507.63	9.43 (559.9)	9.58 (556.2)	19.20 (609.7)	19.61 (607.20)	22.54 (626.7)	22.52 (622.0)
$nZn+_1nFe_2$	519.37	506.97	10.85 (575.7)	10.68 (561.1)	22.35 (635.6)	22.25 (619.70)	27.33 (661.5)	27.77 (647.8)
$nZn+_2nFe_0$	538.07	550.07	10.27 (593.3)	10.18 (606.0)	20.50 (648.8)	20.55 (663.20)	25.49 (676.0)	25.91 (692.6)
$nZn+_2nFe_1$	526.87	535.60	11.50 (587.5)	11.36 (596.4)	23.99 (653.2)	23.61 (662.03)	30.30 (686.6)	30.16 (697.1)
$nZn+_2nFe_2$	492.50	500.47	13.43 (558.6)	13.62 (568.6)	27.21 (626.4)	27.64 (638.83)	34.69 (663.3)	34.88 (675.1)
SE (m) ±			0.112	0.150	0.150	0.113	0.113	0.132
CD at 5 %			0.335	0.450	0.450	0.338	0.338	0.395

Note:

1. Data in parentheses indicate increase in plant canopy spread in percentage and cm.
2. CD (Critical difference) has been calculated based on per cent increase values.

Table 5 Effect of nano zinc and nano iron on plant canopy volume of guava (*Psidium guajava* L.) cv Allahabad Safeda

Month / Treatments	Canopy Volume (cm^3)			
	June (Initial values)	**August**	**October**	**December**
nZn_0	3296.37	23.936 (4075.68)	56.040 (5121.54)	64.442 (5349.04)
nZn_1	2942.52	30.968 (3853.50)	71.395 (5040.94)	87.228 (5502.45)
nZn_2	3052.60	39.541 (4240.70)	90.540 (5777.04)	121.348 (6702.74)
SE (m) ±		0.198	0.443	0.666
CD at 5 %		0.599	1.338	2.013
nFe_0	3415.10	26.345 (4356.10)	60.609 (5536.26)	73.418 (5979.33)
nFe_1	2966.87	31.315 (3901.25)	72.447 (5125.67)	90.175 (5663.54)
nFe_2	2873.53	36.785 (3912.53)	84.919 (5277.58)	109.424 (5956.36)
SE (m) ±		0.198	0.443	0.666
CD at 5 %		0.599	1.338	2.013
nZn+$_0$nFe) $_0$Control)	3777.97	19.42 (4511.26)	45.51 (5499.00)	51.34 (5717.6)
nZn+$_0$nFe$_1$	2965.50	24.25 (3686.10)	57.40 (4664.17)	65.58 (4908.6)
nZn+$_0$nFe$_2$	3145.64	28.15 (4029.73)	65.21 (5201.43)	76.41 (5556.0)
nZn+$_1$nFe$_2$	3122.19	25.65 (3930.64)	61.25 (5041.44)	70.59 (5333.5)
nZn+$_1$nFe$_1$	2796.79	31.25 (3671.15)	69.94 (4750.26)	83.95 (5139.3)
nZn+$_1$nFe$_2$	2908.62	36.01 (3958.70)	82.99 (5331.15)	107.15 (6034.5)
nZn+$_2$nFe$_0$	3453.13	33.97 (4626.43)	75.07 (6068.35)	98.33 (6886.9)
nZn+$_2$nFe$_1$	3138.32	38.45 (4346.56)	90.00 (5962.57)	120.99 (6942.7)
nZn+$_2$nFe$_2$	2566.38	46.20 (3749.17)	106.55 (5300.16)	144.72 (6278.6)
SE (m) ±		0.343	0.767	1.153
CD at 5 %		1.038	2.318	3.486

Note:

1. Data in parentheses indicate increase in plant canopy volume in percentage and cm^3.
2. CD (Critical difference) has been calculated based on per cent increase values

Table 6 Effect of nano zinc and nano iron on plant leaf length of guava (*Psidium guajava* L.) cv Allahabad Safeda

Month / Treatments	Leaf Length (cm)			
	June (Initial values)	**August**	**October**	**December**
nZn_0	8.31	27.44 (10.59)	80.54 (15.00)	91.56 (15.92)
nZn_1	8.24	32.05 (11.12)	88.41 (15.86)	102.24 (17.02)
nZn_2	8.32	37.11 (11.41)	98.90 (16.55)	119.25 (18.25)
SE (m) ±		0.818	0.231	0.338
CD at 5 %		0.548	0.691	1.021
nFe_0	8.35	28.45 (10.72)	83.45 (15.32)	95.34 (16.31)
nFe_1	8.37	32.53 (11.10)	88.78 (15.82)	104.41 (17.13)
nFe_2	8.32	35.65 (11.29)	95.58 (16.28)	113.28 (17.76)
SE (m) ±		0.818	0.231	0.338
CD at 5 %		0.548	0.691	1.021
$nZn+_0nFe)$ $_0$Control)	8.46	22.57 (10.37)	75.47 (14.85)	85.45 (15.70)
$nZn+_0nFe_1$	8.18	28.65 (10.53)	80.43 (14.77)	91.03 (15.64)
$nZn+_0nFe_2$	8.29	31.12 (10.87)	85.73 (15.40)	98.19 (16.43)
$nZn+_1nFe_2$	8.46	29.14 (10.93)	83.22 (15.51)	95.23 (16.52)
$nZn+_1nFe_1$	8.60	32.18 (11.37)	87.29 (16.11)	100.67 (17.26)
$nZn+_1nFe_2$	8.21	34.84 (11.07)	94.72 (15.99)	110.77 (17.30)
$nZn+_2nFe_0$	8.14	33.64 (10.88)	91.76 (15.61)	105.34 (16.71)
$nZn+_2nFe_1$	8.35	36.77 (11.42)	98.65 (16.59)	121.53 (18.50)
$nZn+_2nFe_2$	8.47	40.92 (11.94)	106.30 (17.48)	130.89 (19.56)
SE (m) ±		0.314	0.408	0.585
CD at 5 %		0.950	1.209	1.768

Note:

1. Data in parentheses indicate increase in plant leaf length in percentage and cm.
2. CD (Critical difference) has been calculated based on per cent increase values.

Table 7 Effect of nano zinc and nano iron on plant leaf width of guava (*Psidium guajava* L.) cv Allahabad Safeda

Month / Treatments	Leaf Width (cm)			
	June (Initial values)	**August**	**October**	**December**
nZn_0	3.53	27.87 (4.51)	75.48 (6.20)	87.98 (6.64)
nZn_1	3.56	32.27 (4.70)	83.55 (6.53)	98.72 (4.07)
nZn_2	3.55	36.99 (4.86)	93.21 (6.86)	110.94 (7.49)
SE (m) ±		0.129	0.219	0.275
CD at 5 %		0.389	0.661	0.830
nFe_0	3.55	29.07 (4.58)	78.17 (6.33)	91.59 (6.80)
nFe_1	3.55	32.53 (4.71)	84.11 (6.54)	98.98 (7.07)
nFe_2	3.53	35.52 (4.79)	89.97 (6.72)	107.08 (7.33)
SE (m) ±		0.129	0.219	0.275
CD at 5 %		0.389	0.331	0.830
$nZn+_0nFe)$ $_0$Control)	3.55	24.15 (4.40)	70.39 (6.04)	80.46 (6.40)
$nZn+_0nFe_1$	3.55	28.10 (4.54)	75.66 (6.23)	88.16 (6.67)
$nZn+_0nFe_2$	3.51	31.37 (4.61)	80.42 (6.33)	95.34 (6.85)
$nZn+_1nFe_2$	3.57	29.53 (4.62)	78.13 (6.35)	92.24 (6.86)
$nZn+_1nFe_1$	3.55	32.74 (4.72)	83.41 (6.52)	98.60 (7.06)
$nZn+_1nFe_2$	3.56	34.55 (4.79)	89.14 (6.73)	105.34 (7.31)
$nZn+_2nFe_0$	3.55	33.55 (4.74)	86.00 (6.60)	102.07 (7.17)
$nZn+_2nFe_1$	3.56	36.76 (4.87)	93.27 (6.89)	110.20 (7.49)
$nZn+_2nFe_2$	3.55	40.66 (4.99)	100.38 (7.11)	120.56 (7.83)
SE (m) ±		0.223	0.379	0.476
CD at 5 %		0.674	1.145	1.438

Note:

1. Data in parentheses indicate increase in plant leaf width in percentage and cm.
2. CD (Critical difference) has been calculated based on per cent increase values.

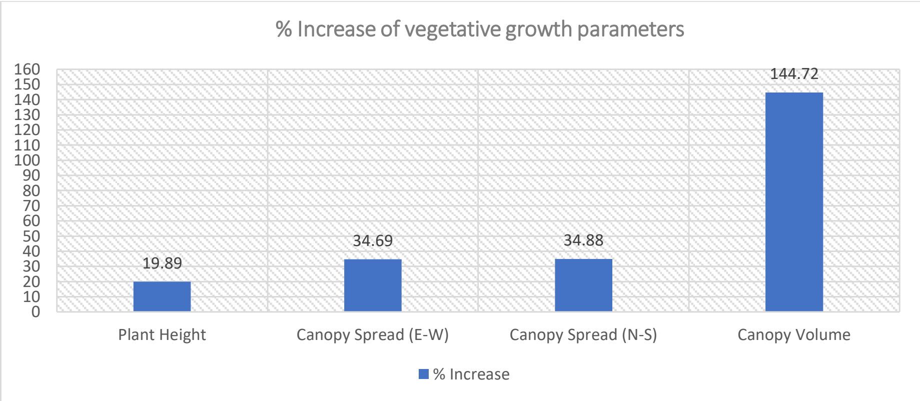
Table 8 Effect of nano zinc and nano iron on plant leaf area of guava (*Psidium guajava* L.) cv Allahabad Safeda

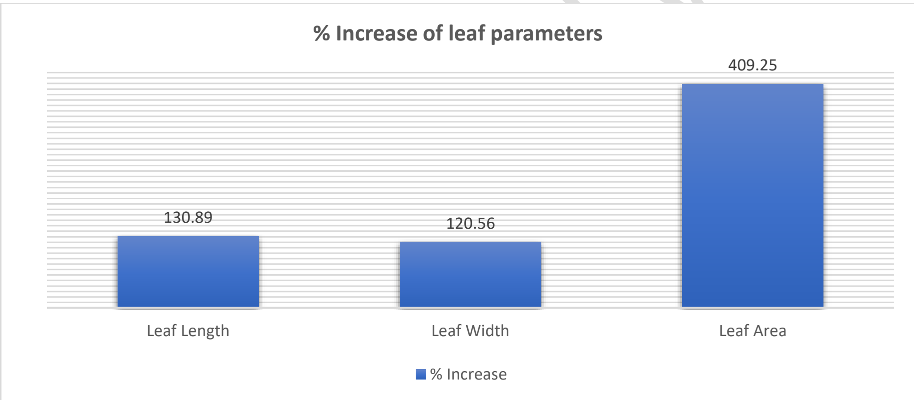
Month / Treatments	Leaf Area (cm^2)			
	June (Initial values)	**August**	**October**	**December**
nZn_0	29.37	63.07 (47.86)	217.00 (93.05)	260.42 (105.78)
nZn_1	29.98	74.71 (52.37)	246.05 (103.70)	302.21 (120.51)
nZn_2	29.56	87.91 (55.59)	284.65 (113.84)	363.27 (137.16)
SE (m) ±		0.284	0.559	0.808
CD at 5 %		0.859	1.690	2.442
nFe_0	29.69	56.97 (49.23)	227.34 (97.08)	274.97 (111.17)
nFe_1	29.78	75.77 (52.36)	248.12 (103.73)	307.87 (121.54)
nFe_2	29.45	83.96 (54.23)	272.25 (109.79)	343.06 (130.73)
SE (m) ±		0.284	0.559	0.808
CD at 5 %		0.859	1.690	2.442
nZn+$_0$nFe) $_0$Control)	30.02	52.17 (45.69)	198.99 (89.76)	234.67 (100.47)
nZn+$_0$nFe$_1$	29.03	64.81 (47.84)	216.95 (92.00)	259.44 (104.34)
nZn+$_0$nFe$_2$	29.07	72.25 (50.07)	235.09 (97.41)	287.15 (112.55)
nZn+$_1$nFe$_2$	30.19	67.28 (50.50)	226.37 (98.52)	275.33 (113.30)
nZn+$_1$nFe$_1$	30.56	75.45 (53.61)	243.49 (104.96)	298.53 (121.76)
nZn+$_1$nFe$_2$	29.22	81.42 (53.02)	268.30 (107.63)	332.78 (126.48)
nZn+$_2$nFe$_0$	28.86	78.48 (51.51)	256.68 (102.96)	314.92 (119.76)
nZn+$_2$nFe$_1$	29.76	87.05 (55.66)	283.92 (114.24)	365.66 (138.55)
nZn+$_2$nFe$_2$	30.08	98.21 (59.62)	313.38 (124.34)	409.25 (153.18)
SE (m) ±		0.492	0.968	1.399
CD at 5 %		1.488	2.928	4.230

Note:

1. Data in parentheses indicate increase in plant leaf area in percentage and cm^2.

2. CD (Critical difference) has been calculated based on per cent increase values.





Discussion

In the current research, guava plants treated with nano zinc and nano iron displayed a notable increase in vegetative growth. The enhanced growth parameters observed with the application of nZn_2 + nFe_2 (Nano Zinc 200ppm + Nano Iron 1500ppm) could be attributed to the adequate supply of nano zinc through foliar spray, which plays a crucial role in cellular mechanisms and respiration (Reed, 1946; Raj *et al.,* 2024). The presence of nano zinc in chloroplast cells is believed to contribute to the improved growth indicators such as plant height, canopy spread (E-W and N-S), canopy volume, leaf length, leaf width, and leaf area (Wood and Sibley, 1950). Additionally, nano iron applied as a foliar treatment is essential for key plant metabolic functions including chlorophyll synthesis, enzymatic reactions, respiration, and photosynthesis, ultimately enhancing plant growth (Ram and Bose, 2000). The significant benefits of foliar application of nano zinc and nano iron in increasing the nutrient content of guava leaves may be attributed to their high absorption due to a large surface area, leading to improved photosynthetic efficiency. Nano iron's role in chlorophyll pigment synthesis, photosynthesis, and enzyme activity such as catalase, cytochrome oxidase, and peroxidase contributes to various vital processes that enhance plant growth (Hewitt, 1951).

Conclusion

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The current study's results indicate that utilizing the application nZn_2+nFe_2 (Nano Zinc 200ppm+ Nano Iron 150ppm) via foliar spray has a notable influence on different vegetative characteristics like plant height, canopy spread, canopy volume, leaf length, leaf width, and leaf area. These characteristics displayed the most significant values compared to all other treatments, with the control group representing the least effect.

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