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INFLUENCE OF FOLIAR ZINC AND IRON APPLICATION ON YIELD AND FRUIT QUALITY OF NAGPUR MANDARIN (*Citrus reticulata* blanco.) WITH CORRELATION AND REGRESSION ANALYSIS

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ABSTRACT

A field experiment was conducted at the Research Farm, School of Agriculture, Suresh Gyan Vihar University, Jagatpura, Jaipur (Rajasthan) during 2025-26 to evaluate the effect of foliar application of zinc (ZnSO_4) and iron (FeSO_4) on yield and quality parameters of six-year-old Nagpur Mandarin (*Citrus reticulata* Blanco.) trees, and to establish the correlation and regression relationship between fruit yield and quality attributes. The experiment was laid out in a Randomized Block Design (RBD) with ten treatments, comprising individual and combined foliar sprays of zinc (0.25, 0.50, 0.75%) and iron (0.25, 0.50, 0.75%) along with a water-spray control, replicated thrice. Foliar nutrition significantly improved all the yield attributing characters (number of fruits per tree, fruit length, fruit diameter and fruit weight), yield parameters (fruit yield per plant and per hectare) and quality parameters (total soluble solids, ascorbic acid content, reducing, non-reducing and total sugars) over the control, while titratable acidity declined significantly. The combined application of Zinc 0.75% + Iron 0.25% (T_9) was the most effective treatment, recording the highest fruit yield (23.78 kg/plant and 65.67 q/ha), the highest total soluble solids (10.85 °Brix), ascorbic acid (51.26 mg/100 ml) and total sugars (6.88%), and the lowest titratable acidity (0.44%). Correlation analysis revealed a very strong, highly significant positive association of fruit yield per plant with total soluble solids ($r = 0.9965$), ascorbic acid ($r = 0.9999$), reducing sugar ($r = 0.9962$), non-reducing sugar ($r = 0.9984$) and total sugar ($r = 0.9972$), and a very strong negative association with titratable acidity ($r = -0.9960$), all significant at the 1% level of probability. Linear regression equations fitted for each quality parameter against fruit yield per plant explained more than 99% of the variability ($R^2 = 0.992-1.000$) in every case, indicating that fruit quality attributes can be reliably predicted from, and are intrinsically linked to, the yield response of Nagpur Mandarin to zinc and iron nutrition. The results establish foliar spray of Zinc 0.75% + Iron 0.25% as an economically remunerative and physiologically effective practice for simultaneously enhancing yield and fruit quality of Nagpur Mandarin grown on alkaline, calcareous soils.

Key words: Nagpur Mandarin; Zinc; Iron; Foliar spray; Yield; Fruit quality; Correlation; Regression

Introduction

Citrus is one of the most economically important and widely cultivated fruit crops in the world, grown successfully across tropical, subtropical and favourable temperate agro-climatic zones. Among citrus species, Mandarin (*Citrus reticulata* Blanco.) occupies the

largest share of area in India, where citrus ranks as the third largest fruit industry after mango and banana. Nagpur Mandarin, one of the most iconic and commercially important mandarin groups of India, is cultivated across belts in Maharashtra, Madhya Pradesh and Rajasthan. In Rajasthan, Jhalawar district is the most important

Nagpur Mandarin-growing region, while Jaipur and adjoining districts, characterised by deep, calcium carbonate-rich, alkaline soils, are increasingly being brought under mandarin cultivation (Meena *et al.*, 2022).

Balanced nutrient management, particularly of micronutrients, plays a decisive role in determining the yield and fruit quality of perennial, nutrient-exhaustive crops such as Nagpur Mandarin. Among micronutrients, zinc (Zn) and iron (Fe) are of special significance, being directly involved in chlorophyll synthesis, enzyme activation, auxin metabolism and carbohydrate metabolism (Hamzah Saleem *et al.*, 2022), and respiratory and photosynthetic electron transport (Rout and Sahoo, 2015). In alkaline and calcareous soils, such as those of the Jaipur region, both Zn and Fe are rendered largely unavailable to plant roots due to precipitation and fixation reactions at higher soil pH, making soil application of these nutrients agronomically inefficient (Zekri and Obreza, 2003). Foliar application, by contrast, bypasses soil-based fixation constraints and allows rapid absorption of the nutrients through the leaf surface, and has been consistently reported to improve fruit set, yield and quality of citrus and other fruit crops (Fageria *et al.*, 2009).

While the individual effects of zinc and iron foliar nutrition on citrus growth, yield and quality have been documented in several earlier studies (Khan *et al.*, 2015; Aboutalebi and Hassanzadeh, 2013), information specifically quantifying the strength of association between fruit yield and the several fruit-quality attributes of Nagpur Mandarin under combined Zn-Fe foliar nutrition, through correlation and regression analysis, remains limited. Correlation and regression analysis is a valuable statistical tool that not only measures the degree and direction of association between yield and quality traits, but also permits prediction of one variable from another, thereby helping to identify the quality attributes that change most consistently and predictably with yield improvement. Accordingly, the present investigation was undertaken with the specific objectives of (i) evaluating the effect of foliar application of zinc and iron, alone and in combination, on the yield attributing characters, yield and fruit quality parameters of Nagpur Mandarin, and (ii) working out the correlation and regression relationship of fruit yield per plant with each of the fruit quality parameters recorded.

Materials and Methods

Experimental site and plant material

The present investigation was carried out at the Research Farm, School of Agriculture, Suresh Gyan Vihar University, Jagatpura, Jaipur (Rajasthan), during June

Table 1: Treatment details.

S.No.	Symbol	Treatment
1	T ₀	Control (water spray)
2	T ₁	Zinc 0.25%
3	T ₂	Zinc 0.50%
4	T ₃	Zinc 0.75%
5	T ₄	Iron 0.25%
6	T ₅	Iron 0.50%
7	T ₆	Iron 0.75%
8	T ₇	Zinc 0.25% + Iron 0.75%
9	T ₈	Zinc 0.50% + Iron 0.50%
10	T ₉	Zinc 0.75% + Iron 0.25%

2025 to January 2026, on three-year-old (six-year-old at the time of observation) Nagpur Mandarin (*Citrus reticulata* Blanco.) plants of cv. Nagpur, established at 6 × 6 m spacing in a square system of planting. The soils of the experimental site are alkaline in reaction with comparatively high pH, a condition known to restrict the bio-availability of zinc and iron to citrus plants.

Treatments and experimental design

The experiment was laid out in a Randomized Block Design (RBD) with three replications, comprising ten treatments involving individual and combined foliar sprays of zinc sulphate (ZnSO₄) and ferrous sulphate (FeSO₄) at varying concentrations, along with a water-spray control, as detailed in Table 1. The spray solutions were neutralized with lime (50%, overnight soaking) to avoid leaf scorch, and a few drops of Teepol were added as a surfactant. Sprays were applied during the first week of June 2025 using a battery-operated knapsack sprayer, ensuring uniform coverage of both leaf surfaces, in the early morning hours.

Yield attributing and yield parameters

At the time of fruit harvest (October 2025), the number of fruits per tree was counted from tagged plants; fruit length and equatorial fruit diameter were measured with Vernier calipers; and individual fruit weight was recorded on a digital balance. Fruit yield per plant (kg) was computed as the product of average fruit weight and number of fruits per tree, and yield per hectare (q) was estimated on the basis of yield per plant and planting density.

Fruit quality parameters

Total soluble solids (TSS, °Brix) were recorded with a hand-held digital refractometer following AOAC (2019). Titratable acidity (%) was estimated by titrating diluted fruit juice against standard 0.1 N NaOH using phenolphthalein indicator, and expressed as per cent citric acid (AOAC, 2019). Ascorbic acid content (mg/100 ml) was determined by the 2,6-dichlorophenol indophenol dye

Table 2: Effect of foliar spray of zinc and iron on yield attributing parameters of Nagpur Mandarin.

Treatment	FT	FL	FD	FW
T ₀ - Control	97.69	5.24	5.32	107.64
T ₁ - Zn 0.25%	102.51	5.49	6.35	124.76
T ₂ - Zn 0.50%	104.46	5.62	6.44	127.30
T ₃ - Zn 0.75%	109.01	5.91	6.67	133.03
T ₄ - Fe 0.25%	108.54	6.02	6.73	135.10
T ₅ - Fe 0.50%	115.78	6.60	7.20	146.77
T ₆ - Fe 0.75%	117.61	6.76	7.26	149.39
T ₇ - Zn0.25+Fe0.75%	122.85	7.09	7.52	156.02
T ₈ - Zn0.50+Fe0.50%	125.65	7.27	7.66	159.63
T ₉ - Zn0.75+Fe0.25%	129.41	7.53	7.83	164.50
SEm±	4.74	0.24	0.27	5.61
CD (P=0.05)	14.09	0.71	0.80	16.68

FT: Fruits/tree; FL: Fruit length (cm);
FD: Fruit diameter (cm); FW: Fruit weight (g)

titration method (Ranganna, 2010). Reducing sugars (%) were estimated by the Lane and Eynon (1923) volumetric method using Fehling's solution, non-reducing sugars (%) were calculated from the invert sugar obtained after acid hydrolysis, and total sugars (%) were computed as the sum of reducing and non-reducing sugars.

Statistical, correlation and regression analysis

Data on yield and quality parameters were subjected to analysis of variance (ANOVA) as applicable to RBD (Panse and Sukhatme, 1995), and treatment means were compared using the Critical Difference (CD) at the 5% level of significance, wherever the F-test was significant.

To examine the relationship between fruit yield and fruit quality, simple linear correlation and regression analysis was carried out between fruit yield per plant (Y, kg) and each of the six quality parameters (X): total soluble solids, titratable acidity, ascorbic acid content, reducing sugar, non-reducing sugar and total sugar, using the treatment mean values (n = 10 treatments). The Pearson correlation coefficient (r), coefficient of determination (R²), regression coefficient (b, slope), intercept (a) and the linear regression equation of the form $Y = a + bX$ were computed for each pair of variables. The significance of each correlation coefficient was tested using the t-test, with $t\text{-calculated} = r\sqrt{(n-2) / \sqrt{(1-r^2)}}$ at $(n-2) = 8$ degrees of freedom, against the tabulated t-values of 2.306 (5%) and 3.355 (1%).

Results and Discussion

Effect on yield attributing parameters

Foliar application of zinc and iron significantly influenced all the yield attributing characters of Nagpur Mandarin (Table 2). The number of fruits per tree

Table 3: Effect of foliar spray of zinc and iron on yield parameters of Nagpur Mandarin.

Treatment	Yield/plant (kg)	Yield/ha (q)
T ₀ - Control	16.32	45.23
T ₁ - Zn 0.25%	17.96	54.00
T ₂ - Zn 0.50%	18.34	56.56
T ₃ - Zn 0.75%	19.10	49.72
T ₄ - Fe 0.25%	19.48	55.20
T ₅ - Fe 0.50%	21.04	57.64
T ₆ - Fe 0.75%	21.61	59.82
T ₇ - Zn0.25+Fe0.75%	22.51	60.54
T ₈ - Zn0.50+Fe0.50%	23.04	63.69
T ₉ - Zn0.75+Fe0.25%	23.78	65.67
SEm±	0.50	2.28
CD (P=0.05)	1.49	6.78

increased progressively from 97.69 in the control (T₀) to a maximum of 129.41 under T₉ (Zinc 0.75% + Iron 0.25%), an increase of about 32.5 per cent, with treatments T₅-T₉ statistically at par with one another. Fruit length increased from 5.24 cm (T₀) to 7.53 cm (T₉), fruit diameter from 5.32 cm to 7.83 cm, and individual fruit weight from 107.64 g to 164.50 g, all following the same increasing trend with rising zinc and iron concentration and their combination. The consistent superiority of the combination treatments (T₇-T₉) over the corresponding single-nutrient treatments suggests an additive or synergistic influence of zinc and iron on cell division and cell enlargement during fruit development, zinc being essential for auxin synthesis and iron for the respiratory and photosynthetic electron-transport chain that sustains the energy supply required for fruit growth. Similar improvement in fruit number, size and weight under combined Zn-Fe foliar.

Effect on yield parameters

Fruit yield per plant and fruit yield per hectare were significantly and progressively enhanced by foliar zinc and iron nutrition (Table 3). Fruit yield per plant increased from 16.32 kg under control to a maximum of 23.78 kg under T₉, an increase of 45.7 per cent, while yield per hectare increased from 45.23 q to 65.67 q, an increase of about 45.2 per cent over control. Treatment T₉ was significantly superior to all other treatments in fruit yield per plant, and was at par with T₇ and T₈ in yield per hectare. The marked improvement in yield under combined Zn-Fe nutrition is consistent with the concurrent increase recorded in all yield attributing characters, since fruit yield is essentially the product of fruit number and mean fruit weight, both of which were maximised under T₉. A comparable yield response to zinc foliar nutrition has been reported by Kumar *et al.*, (2020) in Kinnor Mandarin and by Meshram *et al.*, (2025) in Nagpur

Table 4. Effect of foliar spray of zinc and iron on fruit quality parameters of Nagpur Mandarin.

Treatment	TSS (°Brix)	Acidity (%)	Ascorbic acid (mg/100ml)	Reducing sugar (%)	Non-red. sugar (%)	Total sugar (%)
T ₀ - Control	9.34	0.69	41.77	3.85	1.27	5.12
T ₁ - Zn 0.25%	9.54	0.65	43.87	3.99	1.38	5.37
T ₂ - Zn 0.50%	9.62	0.64	44.35	4.05	1.42	5.47
T ₃ - Zn 0.75%	9.81	0.62	45.35	4.17	1.49	5.66
T ₄ - Fe 0.25%	9.88	0.60	45.79	4.23	1.53	5.76
T ₅ - Fe 0.50%	10.25	0.55	47.79	4.49	1.67	6.16
T ₆ - Fe 0.75%	10.36	0.51	48.49	4.58	1.73	6.31
T ₇ - Zn0.25+Fe0.75%	10.57	0.49	49.64	4.73	1.82	6.55
T ₈ - Zn0.50+Fe0.50%	10.69	0.47	50.31	4.81	1.87	6.68
T ₉ - Zn0.75+Fe0.25%	10.85	0.44	51.26	4.93	1.94	6.88
SEm±	0.15	0.01	0.69	0.08	0.03	0.11
CD (P=0.05)	0.44	0.03	2.05	0.24	0.10	0.34

Mandarin under improved fertigation and micronutrient management.

Effect on quality parameters

All the fruit quality parameters studied were significantly improved by foliar application of zinc and iron, with the exception of titratable acidity, which declined progressively with treatment (Table 4). Total soluble solids increased from 9.34 °Brix (T₀) to a maximum of 10.85 °Brix under T₉, an increase of 16.2 per cent, while titratable acidity declined from 0.69% to 0.44%, a reduction of 36.2 per cent, the parallel and inverse trends of TSS and acidity being consistent with enhanced

conversion and utilisation of organic acids under improved carbohydrate metabolism. Ascorbic acid content rose from 41.77 to 51.26 mg/100 ml (an increase of 22.7%), a response attributable to the close biochemical linkage between sugar metabolism and ascorbic acid biosynthesis, for which zinc and iron together serve as essential enzymatic cofactors, a trend also reported by Muhammad *et al.*, (2010) in sweet orange cv. Blood Red and by Razzaq *et al.*, (2013) in Kinnow Mandarin. Reducing, non-reducing and total sugars increased by 28.1, 52.8 and 34.4 per cent respectively over the control, the comparatively larger relative gain in non-reducing sugar

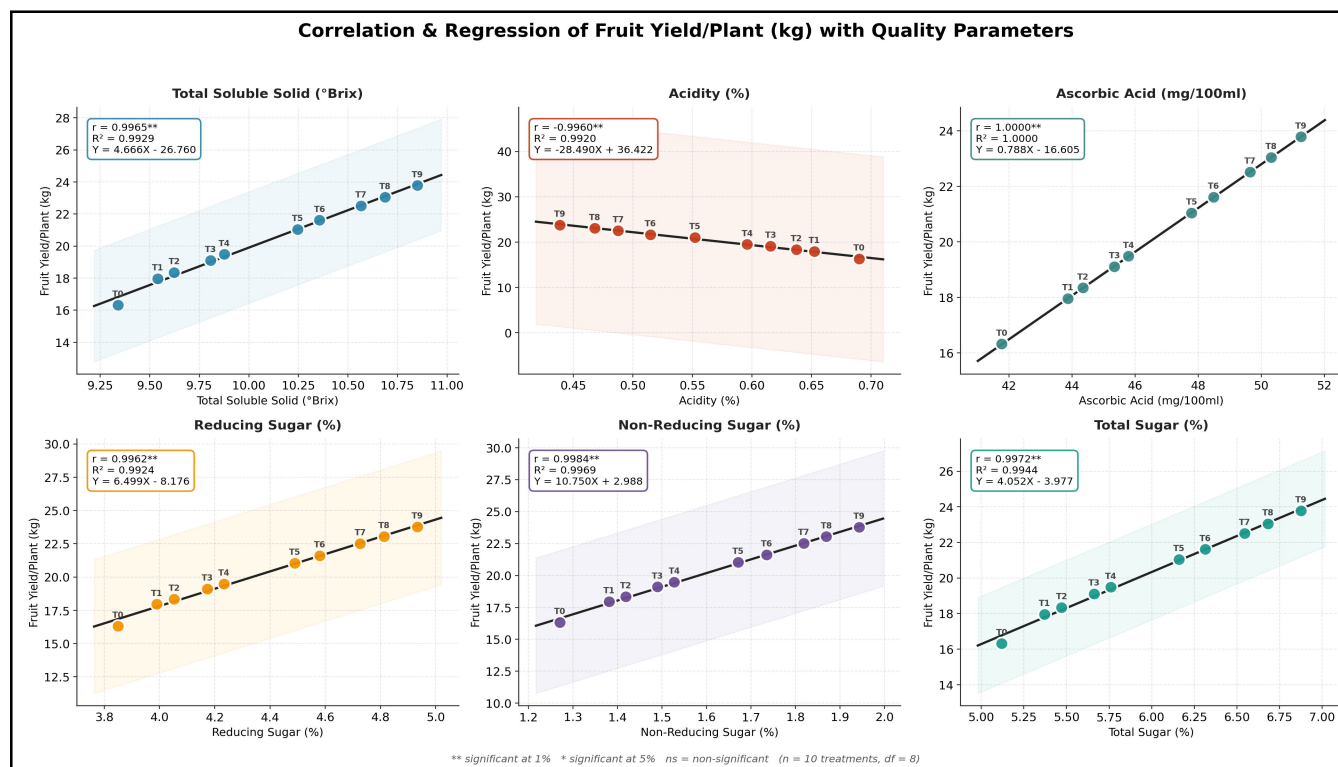


Fig. 1: Scatter plots with fitted linear regression lines and 95% confidence bands for fruit yield per plant against total soluble solids, titratable acidity, ascorbic acid content, reducing sugar, non-reducing sugar and total sugar of Nagpur Mandarin.

Table 5: Correlation and regression of fruit yield per plant (Y, kg) with fruit quality parameters (X) of Nagpur Mandarin (treatment means, n = 10, RBD).

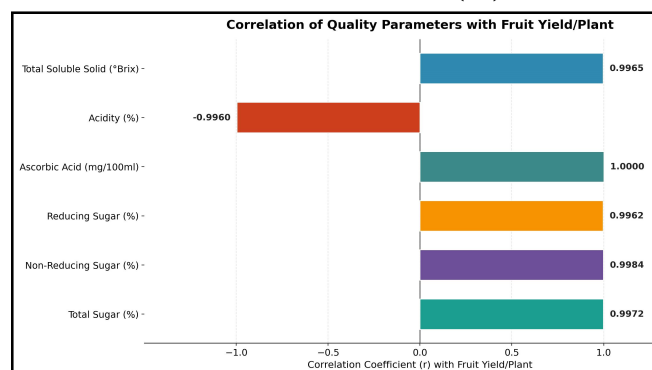
Quality parameter (X)	r	R ²	b (slope)	a (intercept)	Regression equation (Y = a + bX)	t-cal	Significance
Total soluble solids (°Brix)	0.9965	0.9929	4.6662	-26.7602	Y = -26.7602 + 4.6662X	33.544	** (1%)
Titrateable acidity (%)	-0.9960	0.9920	-28.4899	36.4223	Y = 36.4223 - 28.4899X	-31.510	** (1%)
Ascorbic acid (mg/100ml)	0.9999	0.9999	0.7879	-16.6049	Y = -16.6049 + 0.7879X	673.74	** (1%)
Reducing sugar (%)	0.9962	0.9924	6.4992	-8.1759	Y = -8.1759 + 6.4992X	32.326	** (1%)
Non-reducing sugar (%)	0.9984	0.9969	10.7503	2.9875	Y = 2.9875 + 10.7503X	50.719	** (1%)
Total sugar (%)	0.9972	0.9944	4.0516	-3.9767	Y = -3.9767 + 4.0516X	37.625	** (1%)

suggesting that the additional photosynthate generated under improved Zn-Fe nutrition was preferentially channelled towards sucrose synthesis and storage. In all cases, the combination treatments T₇, T₈ and T₉ were statistically at par with one another and significantly superior to the single-nutrient treatments, indicating a synergistic effect of combined zinc and iron nutrition on fruit quality, in agreement with Kumar *et al.*, (2020), El-Gioushy *et al.*, (2021).

Correlation and regression between fruit yield and quality parameters

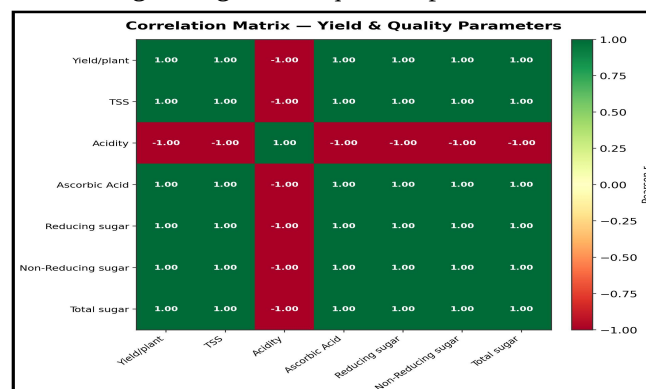
Simple linear correlation and regression analysis, carried out between fruit yield per plant and each of the six fruit quality parameters using the treatment mean values, revealed a very strong and highly significant relationship in every case (Table 5, Fig. 1-3). Fruit yield per plant was positively and very strongly correlated with total soluble solids (r = 0.9965), ascorbic acid content (r = 0.9999), reducing sugar (r = 0.9962), non-reducing sugar (r = 0.9984) and total sugar (r = 0.9972), and was negatively and very strongly correlated with titrateable acidity (r = -0.9960). All six correlation coefficients were significant at the 1% level of probability (t-calculated ranging from -31.51 to 673.74, against a tabulated t of 3.355 at 8 degrees of freedom), indicating that the observed associations were extremely unlikely to have arisen by chance.

The coefficients of determination (R²) for the fitted

**Fig. 2:** Pearson correlation coefficients (r) of fruit yield per plant with fruit quality parameters of Nagpur Mandarin.

regression equations ranged from 0.992 to 1.000, showing that between 99.2 and 100 per cent of the variation in fruit yield per plant among the ten treatments could be statistically accounted for by the corresponding variation in each individual quality

These extremely high correlation and regression coefficients reflect the fact that, in the present investigation, yield and all the quality attributes responded to the zinc and iron treatments along a common physiological pathway, namely the treatment-induced enhancement of chlorophyll synthesis, photosynthetic efficiency and carbohydrate metabolism brought about jointly by zinc (as a cofactor for carbon-fixing and sugar-interconverting enzymes) and iron (as an essential component of the respiratory and photosynthetic electron-transport chain). Because both yield and quality parameters increased monotonically and proportionately with increasing zinc and iron supply across the treatment gradient, from the control through to the most concentrated combination treatment (T₉), the resulting treatment means traced an almost perfectly linear relationship in each case. This finding is of direct practical significance, since it demonstrates that, under the conditions of the present study, the fruit-quality response of Nagpur Mandarin to foliar zinc and iron nutrition can be predicted with a very high degree of confidence directly from the corresponding yield response, and vice versa, using the regression equations presented in Table 5.

**Fig. 3:** Correlation matrix (Pearson r) among fruit yield per plant and fruit quality parameters of Nagpur Mandarin.

Conclusion

Foliar application of zinc and iron significantly improved the yield attributing characters, fruit yield and fruit quality of Nagpur Mandarin grown on alkaline, calcareous soils. Among all the treatments evaluated, the combined foliar spray of Zinc 0.75% + Iron 0.25% (T₉) was the most effective, producing the highest fruit yield (23.78 kg/plant, 65.67 q/ha) along with superior fruit size, maximum total soluble solids, ascorbic acid and sugar content, and minimum titratable acidity. Correlation and regression analysis further established that fruit yield per plant is very strongly and significantly associated with all the fruit quality parameters examined ($r = 0.996-1.000$; $R^2 = 0.992-1.000$), confirming that yield enhancement under zinc and iron foliar nutrition in Nagpur Mandarin is closely and predictably coupled with a simultaneous improvement in fruit quality, rather than occurring at its expense. Foliar spray of Zinc 0.75% + Iron 0.25% at fruit development stage may therefore be recommended as an agronomically effective and economically remunerative practice for enhancing both the yield and quality of Nagpur Mandarin grown under alkaline soil conditions.

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