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Foliar Micronutrients Application: A Promising Approach to Improve Reproductive Growth and Quality in *Citrus reticulata* Blanco

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Abstract
Micronutrients play a crucial role in plant metabolic processes, directly influencing growth and development. In Citrus, suboptimal nutritional practices often compromise fruit yield and quality. This study evaluated the effects of foliar application of zinc sulphate ($ZnSO_4$) and copper sulphate ($CuSO_4$) on the reproductive growth and quality attributes of *Citrus reticulata* Blanco (Kinnow mandarin). Treatments, including $ZnSO_4$ and $CuSO_4$ alone and in combination, were applied at the onset of new growth (first week of September 2021) and repeated after 15 days. Results indicated that foliar application of $ZnSO_4$ (0.5%) significantly enhanced the number of flowers (124.27), juice weight (66.87 g), juice percentage (49.1%), and vitamin C content (46.87 mg/100 mL). The highest fruit weight (149.67 g), peel weight (39.0 g), fruit diameter (75.64 mm), total soluble solids (12.58 °Brix), reducing sugars (4.57%), non-reducing sugars (6.73%) and total sugars (11.3%) were recorded with $ZnSO_4$ at 1–1.5%. However, the highest rag weight (44.4 g) was obtained at 1% $ZnSO_4$, followed by 0.5% $CuSO_4$ (42.07 g). The results also revealed that foliar applications of $CuSO_4$ have significantly improved fruit juice contents. Additionally, the fruit set percentage in the subsequent year was improved. Overall, the $ZnSO_4$ application alone proved more effective in enhancing reproductive growth and fruit quality compared to $CuSO_4$ or the control treatment.

Keywords: micronutrients; nutritional practices; kinnow mandarin; foliar application; zinc sulphate; fruit quality

Highlights
- Foliar application of zinc sulphate ($ZnSO_4$) and copper sulphate ($CuSO_4$) significantly enhanced reproductive growth and fruit quality in Kinnow mandarin.
- Low concentrations of $ZnSO_4$ improved key physical traits, including fruit diameter, fruit weight, juice weight, and juice percentage, along with biochemical attributes such as TSS, vitamin C, reducing sugars, non-reducing sugars, and total sugars, followed by similar results related to the Cu.
- The application of zinc proved more effective in enhancing fruit quality than other treatments.

1.0. Introduction
Citrus is a major fruit crop with significant economic importance in global fruit industries. Among Citrus, *Citrus reticulata* Blanco (Kinnow mandarin) dominates Pakistan's citrus sector, accounting for 91% of the total citrus-cultivated area and contributing 75% of overall citrus production (Usman et al., 2018; Nawaz et al., 2019; Sajid et al., 2021). However, citrus productivity is influenced by various abiotic factors, such as soil composition, climate, nutrition, and irrigation, as well as biotic factors, including insect pests, diseases, rootstocks, and cultivars (Iglesias et al., 2007; Ahmed et al., 2006, 2007). Among these, nutrition plays a crucial role in determining fruit quality, stress tolerance, disease resistance, and yield (Omaima and El-Metwally, 2007; Tariq et al., 2007).
Foliar nutrient application is known to be 10–20 times more effective than soil fertilization, enhancing nutrient uptake efficiency and plant response (Perveen and Rehman, 2000; Yaseen et al., 2004; Zaman and Schumann, 2006). However, environmental conditions and improper application schedules can reduce its effectiveness. Micronutrients such as zinc (Zn) and copper (Cu) are essential for plant growth and metabolism. Zinc plays a vital role in enzymatic processes and biological functions, as well as in improving fruit yield and quality. Its deficiency causes cytological and anatomical alterations, reducing flowering, fruit set, and overall fruit quality in Citrus (Marschner, 2012; Rehman et al., 2024). Copper, though required in small quantities, is equally crucial as it supports protein metabolism, activates enzymes, and contributes to lignin formation, photosynthesis and electron transport within plant systems (Henry, 2009; Somasundaram et al., 2011).
The combined application of magnesium, copper and zinc enhances plant height, canopy spread, stem girth, fruit yield and juice content in mandarins (Ram and Bose, 2000). Similarly, foliar application of Zn, Fe, and B in Citrus improved

ascorbic acid content, total sugars, non-reducing sugars, soluble sugars, fruit weight, fruit retention, and overall fruit production. These nutrients also increased zinc and iron concentrations in leaves (Ghosh and Basra, 2000; Khurshid et al., 2008). Moreover, foliar supplementation of potassium and zinc significantly improved fruit weight, yield, size, total soluble solids (TSS), acidity, and vitamin C content in Washington Navel orange (*Citrus sinensis* Osbeck) (Omaima and El-Metwally, 2007).

The soil of Pakistan is deficient in essential micronutrients such as copper, boron, manganese, and zinc (Shah et al., 2012). Furthermore, high soil pH (8–8.5) limits nutrient availability, particularly restricting zinc absorption by plants. Given these challenges, the foliar application of zinc and copper may serve as an effective strategy to meet plant nutritional requirements and enhance Citrus reticulata Blanco's growth, yield, and fruit quality. Therefore, this study aimed to evaluate the effects of foliar-applied zinc sulphate and copper sulphate on the reproductive growth and quality attributes of *Citrus reticulata* Blanco to determine the optimal application rates for maximizing fruit yield and quality.

2.0. Materials and Methods

A field study was conducted on ten-year-old *Citrus reticulata* Blanco cv. (Kinnow mandarin) trees grafted onto rough lemon (*Citrus jambheri* L.) rootstock. The experiment was conducted at a commercial citrus orchard in Kot Muhammad Yar, Tehsil Shahpur, District Sargodha, Pakistan. Trees selected for the study were healthy, disease-free, and uniform in canopy size. The orchard was managed under standard agronomic practices, with trees planted at a spacing of 15 × 15 feet. The analysis of the fruits was carried out at the Postharvest Research and Training Centre, Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan. Zinc sulphate and copper sulphate were applied in different concentrations alone and combination. In this study, water-sprayed plants were used as a control. Treatment consisted of control (water application), 0.5% $ZnSO_4$, 1% $ZnSO_4$, 1.5% $ZnSO_4$, 0.5% $CuSO_4$, 1% $CuSO_4$, 1.5% $CuSO_4$, 0.5% $ZnSO_4$+ 0.5% $CuSO_4$, 1% $ZnSO_4$+ 1% $CuSO_4$ and 1.5% $ZnSO_4$+ 1.5% $CuSO_4$. In this study, one tree was considered an experimental unit, and three replicates of each treatment were taken. This experiment was laid out in a randomized complete block design (RCBD). Reproductive parameters such as the number of flowers, fruit set percentage, and fruit drop percentage were determined during different growth stages. Similarly, the data for physical attributes of fruit, such as fruit size, per fruit weight, peel weight, rag weight, juice weight, and juice percentage was measured at the time of fruit harvesting.

2.1. Reproductive Parameters

Four branches, one from each of the four sides (East, West, South, and North), with a diameter of 1.5 to 2 inches, were chosen to measure the reproductive characteristics of the experimental trees. The average number of flowers per branch was determined by counting the number of blooms on tagged branches. The following formula was used to calculate the fruit set % after counting the total number of fruits at the button stage from each of the four chosen branches.

$$\text{Fruit set percentage} = \frac{\text{Number of fruits}}{\text{Total number of flowers}} \times 100$$

Fruit drop percentage was calculated using the following formula after the total number of fruits from each chosen branch was counted.

$$\text{Fruit drop percentage} = \frac{\text{Number of fruits retained}}{\text{Total number of fruits set}} \times 100$$

2.2. Physical Parameters

Ten fruits from each plant were harvested randomly from all four sides to determine physical parameters. Fruit diameter (mm) was calculated by a digital venire caliper (Incrome, Part number 2313). Fruit weight, peel weight, rag weight, and juice weight were measured using an electric balance. The average juice percentage was calculated using the formula:

$$\text{Juice percentage} = \frac{\text{Juice weight per fruit}}{\text{Average fruit weight}} \times 100$$

2.3. Biochemical Parameters

Juice extracted from ten fruits was used to calculate chemical parameters. One to two drops of fruit juice were placed on the prism of a digital refractometer (ATAGO, RX 5000, Tokyo, Japan) to measure TSS, which was then shown as Brix. By titrating the fruit juice with 0.1 N NaOH, the acidity of the juice was determined and expressed as a percentage. Phenolphthalein was used as an indicator during the titration.

The method of Ruck (1961) was used to determine the vitamin C content (mg/100 g) of the juice, whereas Lane and Eyon's (1923) method, as described by Hortwitz (1960), was used to estimate the reducing, non-reducing and total sugars.

2.4. Statistical analysis

The experiment was arranged in a Randomized Complete Block Design (RCBD) with three replications per treatment. Data were analyzed using R software, applying analysis of variance (ANOVA) to assess treatment effects. Mean comparisons were performed using the Least Significant Difference (LSD) test at a significance level of $p < 0.05$.

3.0. Results and Discussion

3.1. Reproductive Parameters

3.1.1. Number of Flowers per Branch

The results showed that foliar application of zinc sulphate ($ZnSO_4$) and copper sulphate ($CuSO_4$), both individually and in combination, significantly increased the number of flowers per branch compared to the control (Table 1). The highest number of flowers per branch (124.27) was observed in trees treated with 0.5% $ZnSO_4$, followed by those treated with 1.5% $ZnSO_4$. $CuSo_4$ application alone also showed better results than the combined application of $ZnSO_4$ and $CuSO_4$. $CuSO_4$ @ 0.5% induced better flowering and produced 100.13 flowers per branch. In contrast, the lowest flower count (73.57) was recorded in control trees (water spray).

The increase in flower production may be attributed to the essential role of zinc in plant development. Zinc is a critical component of Zn-finger transcription factors, which regulate floral tissue development, including anthers and pollen formation. Additionally, Zn plays a key role in the initiation of floral primordia, which later differentiate into flowers (Cheng and Zhao, 2007; Kobayashi et al., 1998). Similarly, copper is a cofactor for several enzymatic reactions, including polyphenol oxidase, cytochrome oxidase, and superoxide dismutase (SOD), involved in oxidative stress management and energy metabolism. These enzymes help to maintain cellular functions that are crucial for flower differentiation and development (Marschner, 2012). These findings align with the study by Singh and Maurya (2004), who reported that the application of micronutrients significantly increased the number of flowers in mango (*Mangifera indica* cv. Mallika).

Table 1: Foliar Application of $ZnSO_4$ and $CuSO_4$ influence on different reproductive and physical attributes of *Citrus reticulate* Blanco

Treatments	No. of flowers	Fruit set (%)	Fruit Drop (%)	Fruit Diameter (mm)	Weight (g)	Peel Weight (g)	Rag Weight (g)	Juice Weight (g)	Juice (%)
Control (Water spray)	73.57f	33.06e	56.37a	63.04b	115.6d	34.87	38abc	42.67e	36.99cd
0.5% $ZnSO_4$	124.27a	47.61 b	36.61de	74.41ab	135.67bc	32.07	36.87bc	66.87ab	49.1a
1% $ZnSO_4$	110.8b	53.26 a	32.96 e	75.64 a	149.67a	39	44.4a	66.67ab	44.53ab
1.5% $ZnSO_4$	117ab	47.87 ab	35.23 de	74.53 ab	146.93ab	36.53	41abc	69.67a	47.44a
0.5% $CuSO_4$	100.13c	39.78 cd	39.53 de	67.73 ab	135.93bc	35.13	42.07ab	58.93abc	43.35abc
1% $CuSO_4$	92.4cd	37.76 de	41.84 de	68.16 ab	133.8c	33.93	40.47abc	60abc	44.86ab
1.5% $CuSO_4$	83.53e	35.22 de	47.89 bc	67.54 ab	124.87cd	32.47	34.53c	57.47bcd	45.99ab
0.5% $ZnSO_4$ + 0.5% $CuSO_4$	95.83c	40.34cd	51.04ab	64.03ab	126.47cd	38.8	41.8ab	46.2de	36.52d
1% $ZnSO_4$ + 1% $CuSO_4$	84.2de	39.63cd	47.81bc	75.14ab	126.2cd	35.53	40.73abc	50.4cde	39.87bcd
1.5% $ZnSO_4$ + 1.5% $CuSO_4$	78.87ef	43.45bc	51.17ab	64.79ab	126.13cd	32.73	42.47ab	50.73cde	40.23 bcd

*Means in the column followed by similar letters are non-significant; means not followed by similar letters differ significantly at $P \leq 0.05$.

3.1.2. Fruit Set Percentage

The highest fruit set percentage (53.26%) was recorded in trees treated with 1% $ZnSO_4$, followed by 1.5% $ZnSO_4$ (47.87%) and 0.5% $ZnSO_4$ (47.61%) as depicted in Table (1). The application of $CuSO_4$ alone, as well as in combination with $ZnSO_4$, produced better results compared to the control group (water spray). The fruit set percentage increased to 39.78% with a 0.5% $CuSO_4$ application, whereas the control treatment resulted in 33.06%. The increase in fruit set percentage may be due to zinc, which improves reproductive success and fruit retention (Hafez and El-Metwally, 2007). Adequate copper supply also improves pollen viability and pollen tube growth, leading to better fertilization and fruit set. (Broadley et al., 2012). Previous studies have also reported that the application of calcium, boron, GA_3, and zinc significantly improved fruit sets in Washington Navel Orange (Abd-Allah, 2006; Eman et al., 2007).

3.1.3. Fruit Drop Percentage

Foliar application of 1% $ZnSO_4$ significantly reduced fruit drop to 32.96%, whereas in the case of $CuSO_4$ application, minimum fruit drop percentage was recorded in 0.5% $CuSO_4$ treatment, and the highest fruit drop (56.37%) was observed in the control group (water spray) (Table 1). The application of zinc alone effectively minimized fruit drop, reinforcing the inverse relationship between fruit set and fruit drop treatments, with the highest fruit set percentage exhibiting the lowest fruit drop percentage. In contrast, those with the lowest fruit set had the highest fruit drop.

The reduction in fruit drop may be attributed to zinc's role as a cofactor for dehydrogenase and proteinase enzymes, which are crucial for auxin synthesis. This, in turn, enhances photosynthetic efficiency and auxin balance, contributing to improved fruit retention (Venu et al., 2014). The reduction in fruit drop percentage may also be due to copper application as it reduces oxidative stress and enhances overall plant health, which consequently decreases floral abortion and premature fruit drop. This results in an increased number of flowers and improved fruit retention (Alloway, 2008). These findings align with those of Ashraf et al. (2012), who reported a significant reduction in fruit drop in *Citrus jambheri* L (*Citrus deliciosa* × Citrus nobilis) following the application of zinc and other essential minerals.

3.2. Physical Parameters

3.2.1. Fruit Diameter

Foliar application of zinc and copper significantly influenced fruit diameter. The largest fruit size (75.64 mm) was recorded in trees treated with 1% $ZnSO_4$, followed by 1% $ZnSO_4$ + 1% $CuSO_4$, 1.5% $ZnSO_4$ and 0.5% $ZnSO_4$. In contrast, the smallest fruit size (63.04 mm) was observed in the control group (Table 1). Additionally, zinc facilitates the transport of minerals and photosynthetic products from different plant parts to the fruit, ensuring adequate nutrient supply for fruit enlargement (Rawat et al., 2010). Furthermore, zinc plays a key role in tryptophan synthesis, which serves as a precursor for auxin biosynthesis. The increased auxin levels promote cell enlargement, leading to greater vesicle size, expanded locules, and, ultimately, more extensive and heavier fruit (Sheikh et al., 2021). The increase in fruit diameter may also be attributed to copper's role in cell wall metabolism and chlorophyll formation, both of which are crucial for photosynthesis and overall fruit development (Tripathi et al., 2015; Yruela, 2005). These findings are consistent with the results of Tariq et al. (2007), who reported that zinc foliar application significantly improved fruit weight in sweet oranges.

3.2.2. Fruit Weight

Foliar application of $ZnSO_4$ and $CuSO_4$ significantly increased fruit weight compared to the control (Table 1). The highest fruit weight (149.67 g) was recorded in trees treated with 1% $ZnSO_4$, followed by 1.5% $ZnSO_4$ and 0.5% $CuSO_4$, where fruit weight was recorded at 146.93 g and 135.93 g, respectively, while the lowest fruit weight (115.6 g) was observed in untreated trees (control). The increase in fruit weight may be attributed to zinc's role in enhancing chlorophyll content and boosting enzymatic activity, which is essential for photosynthesis and fruit development (Chermahini et al., 2010). Furthermore, the increase in fruit weight may result from the role of Cu in plastocyanin, a protein involved in photosynthesis that boosts carbohydrate production and its transport to developing fruits (Marschner, 2012). These findings align with those of Omaima and El-Metwally (2007), who reported a significant increase in the fruit weight of Washington Navel Orange following foliar application of GA_3, zinc, and potassium.

3.2.3. Peel Weight per Fruit

The peel weight differences among treatments were observed (Tabe 1). The highest peel weight (39 g) was observed in trees treated with 1% $ZnSO_4$, followed by combined application of $ZnSO_4$ and $CuSO_4$ at a concentration of 0.5%, while the lowest peel weight (32.07 g) was recorded for 0.5% $ZnSO_4$ application.). These findings are consistent with Khan et al. (2012), who reported that peel weight in Feutrell's Early (*Citrus reticulata* Blanco) remained unaffected by boron and zinc application, while our findings are in contrast with El-Gioushy et al., (2021), who reported that Zn and Cu potentially enhanced the peel weight of Washington Navel orange.

3.2.4. Rag Weight

Rag weight varied significantly among treatments (Table 1). The lowest rag weight (34.53 g) was recorded in fruits treated with 1.5% $CuSO_4$, while the highest rag weight (44.4 g) was observed in fruits sprayed with 1% $ZnSO_4$, followed by the 1.5% $ZnSO_4$ + 1.5% $CuSO_4$ combination. The increase in rag weight may be attributed to the synergistic effect of zinc and copper, which play a crucial role in the transport and distribution of nutrients and sugars during fruit development and maturation (Chandra and Singh, 2015). These findings align with the results of Tariq et al. (2007), who reported that foliar application of zinc and manganese influenced rag weight in sweet orange.

3.2.5. Juice Weight

The foliar application of $ZnSO_4$ and $CuSO_4$ individually had a significant impact on the juice weight of *Citrus reticulata* Blanco fruits (Table 1). The highest juice weight (69.67 g) was recorded in fruits treated with 1.5% $ZnSO_4$. Whereas the application of 1% $CuSO_4$ alone resulted in improved juice weight (60 g). However, the lowest juice weight (42.67 g) was observed in untreated fruits. These results are consistent with those of Sajid et al. (2012) and Ashraf et al. (2012), who reported that zinc and other micronutrients significantly enhanced fruit juice content in sweet orange and Kinnow, respectively.

3.2.6. Juice Percentage

The foliar application of $ZnSO_4$ and $CuSO_4$ significantly influenced the juice percentage of *Citrus reticulata* Blanco (Table 1). The highest juice percentage (49.1%) was observed in fruits treated with 0.5% $ZnSO_4$, followed by 1.5% $ZnSO_4$ (47.44 %) and 1.5% $CuSO_4$ (45.99%), respectively. These findings align with Sajid et al. (2012), who reported that foliar application of zinc and boron increased fruit juice percentage in sweet oranges.

3.3. Biochemical Parameters

3.3.1. Acidity Percentage

The data collected to evaluate fruit acidity in response to different Zn and Cu treatments showed statistically non-significant differences among treatments (Table 2). The acidity percentage in *Citrus reticulata* Blanco remained unaffected by all treatments. The highest acidity (1.06%) was recorded in untreated control fruits, followed by the application of 1% $ZnSO_4$ + 1% $CuSO_4$, whereas the lowest acidity was observed in fruits treated with 0.5% $ZnSO_4$ + 0.5% $CuSO_4$. The slight reduction in acidity in zinc-treated fruits may be attributed to zinc's role in enzyme activities involved in protein and acid metabolism. These findings are consistent with Abd-El-Motty et al. (2006) and Anees et al. (2011), who reported that micronutrients such as zinc, iron, boron, and manganese had no significant effect on acidity percentage in Valencia orange and mango, respectively.

3.3.2. Total Soluble Solids (TSS)

The findings revealed significant differences in TSS content among the treatments (Table 2). Compared to the control, all treatments resulted in a notable increase in TSS levels. However, zinc application was more effective than copper in enhancing total soluble solids (TSS) in *Citrus reticulata* Blanco juice. The highest TSS value (12.58 °Brix) was observed in fruits treated with 1.5% $ZnSO_4$, followed by the combined application of $ZnSO_4$ and $CuSO_4$ at 0.5% (11.87 °Brix), while the lowest (9.23 °Brix) was recorded in untreated fruits (Control). The increase in TSS content may be attributed to zinc's role in breaking down complex polysaccharides into simple sugars, leading to improved TSS levels in zinc-treated fruits (Rawat et al., 2010). These results are consistent with Eman et al. (2007) and Sajid et al. (2012), who reported that the foliar application of zinc and boron significantly enhanced TSS content in sweet orange and Washington Navel orange.

3.4. Vitamin C

The application of micronutrients significantly influenced the vitamin C content of *Citrus reticulata* Blanco fruits (Table 2). The highest vitamin C concentration (46.87 mg/100 g) was recorded in fruits treated with 0.5% $ZnSO_4$, followed by 1.5% $ZnSO_4$ (42.41 mg/100 g), 0.5% $CuSO_4$ (40.97 mg/100 g) and 1% $ZnSO_4$ (40.08 mg/100 g). The lowest vitamin C content (24.30 mg/100 g) was found in untreated fruits (Control). Interestingly, a lower concentration of $ZnSO_4$ (0.5%) was more effective in enhancing vitamin C levels compared to higher concentrations. Additionally, all zinc treatments outperformed copper sulphate applications and the control. This increase in vitamin C may be attributed to the role of Zn and Cu as cofactors for enzymes involved in the antioxidant defense system. Their presence enhances the activity of these enzymes, potentially promoting the synthesis and accumulation of ascorbic acid, a vital antioxidant in plants (Behtash et al., 2022). These findings are in line with Tariq et al. (2007), who reported that the foliar application of zinc and boron enhanced vitamin C levels in sweet oranges.

3.5. Sugar Contents

3.5.1. Total Sugars

The total sugar content of *Citrus reticulata* Blanco juice was significantly influenced by foliar applications of $ZnSO_4$ and $CuSO_4$ (Table 2). The highest total sugar content (11.3%) was recorded in fruits treated with 1.5% $ZnSO_4$, followed by 1% $ZnSO_4$ (10.72%), 1% $CuSO_4$ (10.38%) and 0.5% $ZnSO_4$ + 0.5% $CuSO_4$ (9.69%). In contrast, the lowest total sugar content (7.50%) was observed in the untreated control fruits. The increased total sugar content in response to zinc foliar application may be attributed to its role in activating aldolase, a key enzyme involved in sugar biosynthesis (Alloway, 2008). These findings are supported by Khan et al. (2012), who reported that foliar application of micronutrients, particularly zinc, significantly increased the total sugar content in Feutrell's Early fruit juice.

Table 2: Foliar Application of $ZnSO_4$ and $CuSO_4$ influence on different biochemical attributes of *Citrus reticulate* Blanco

Treatments	Acidity (%)	TSS (°Brix)	Vitamin C (mg/100ml)	Reducing Sugars (%)	Non-Reducing Sugars (%)	Total Sugars (%)
Control (Water spray)	1.06	9.23c	24.30f	2.8de	4.7c	7.50d
0.5% $ZnSO_4$	0.74	12.52a	46.87a	3.85abc	5.76abc	9.61bc
1% $ZnSO_4$	0.73	11.55ab	40.08bcd	4.49a	6.23ab	10.72ab
1.5% $ZnSO_4$	0.76	12.58a	42.41b	4.57a	6.73a	11.3a
0.5% $CuSO_4$	0.83	11.22ab	40.97bc	3.31cde	6.3ab	9.61bc
1% $CuSO_4$	0.77	10.95abc	40.08bcd	4.18ab	6.2ab	10.38ab
1.5% $CuSO_4$	0.80	10.42bc	39.65bcd	3.36bcde	5.94abc	9.30bc
0.5% $ZnSO_4$+ 0.5% $CuSO_4$	0.67	11.87ab	36.54d	3.59bcd	6.1ab	9.69bc
1% $ZnSO_4$+ 1% $CuSO_4$	0.89	10.27bc	37.76cd	2.66e	5.15bc	7.81d
1.5% $ZnSO_4$+ 1.5% $CuSO_4$	0.84	10.35bc	29.46e	3cde	5.86abc	8.86cd

*Means in the column followed by similar letters are non-significant; means not followed by similar letters differ significantly at $P \leq 0.05$.

3.5.2 Reducing Sugars

The findings on reducing sugars indicated significant differences among the various zinc sulphate ($ZnSO_4$) and copper sulphate ($CuSO_4$) treatments (Table 2). The highest reducing sugar content (4.57%) was recorded in fruits treated with 1.5% $ZnSO_4$, closely followed by 1% $ZnSO_4$ (4.49%) and 1% $CuSO_4$ (4.18%). However, the lowest reducing sugar content (2.66%) was observed in fruits treated with a combination of 1% $ZnSO_4$ + 1% $CuSO_4$. Notably, zinc alone exhibited a more pronounced effect in enhancing reducing sugars compared to copper or their combination. An increase in $ZnSO_4$ concentration from 0.5% to 1.5% resulted in a progressive rise in reducing sugar content from 3.85% to 4.57%, whereas the control fruits had a significantly lower content (2.80%). Interestingly, the application of Zn and Cu together at higher concentrations led to a decrease in reduced sugar content, suggesting a possible antagonistic interaction between the two micronutrients at elevated levels (Table 2).

3.5.3 Non-Reducing Sugars

Non-reducing sugars were calculated by subtracting reducing sugars from total sugars and were subsequently analyzed statistically (Table 2). The highest non-reducing sugar content (6.73%) was recorded in fruits treated with 1.5% $ZnSO_4$, followed by 0.5% $CuSO_4$ (6.3%), 1% $ZnSO_4$ (6.23%) and 1% $CuSO_4$ (6.2%). Conversely, the lowest non-reducing sugar content (4.70%) was observed in fruits from untreated plants (Control). Both $ZnSO_4$ and $CuSO_4$ treatments significantly increased non-reducing sugars compared to the control. However, the combination of Zn and Cu resulted in a lower non-reducing sugar content than their separate applications. This may be attributed to a possible antagonistic effect between the two micronutrients on sugar accumulation. Notably, zinc application proved more effective than copper in enhancing non-reducing sugar content in Kinnow fruit juice (Table 2). These findings align with those of Sajid et al. (2012), who reported that zinc foliar spray significantly enhanced the non-reducing sugar content in sweet orange.

4.0. Conclusion

This study highlights the significant impact of foliar zinc sulphate ($ZnSO_4$) application on the reproductive and fruit quality attributes of *Citrus reticulate* Blanco. The results indicate that applying $ZnSO_4$ at different concentrations positively influenced various growth and fruit attributes. Specifically, a 0.5% $ZnSO_4$ application proved most effective in enhancing flower production, juice percentage, and vitamin C content. Higher concentrations, notably 1% and 1.5% $ZnSO_4$, significantly improved fruit set percentage, fruit diameter, fruit weight, rag weight, juice weight, total soluble solids (TSS), reducing sugars, non-reducing sugars and total sugars compared to copper alone or in combination with zinc. The findings of this study provide a strong foundation for precision nutrient management, paving the way for improved citrus production through scientifically backed fertilization practices.

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