

Pineapple (*Ananas comosus* (L.) Merr.) plant growth and nutrient concentration enhancement on mineral soil using different rates of copper-zinc chelated foliar spray content

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Abstract

Pineapple (*Ananas comosus* (L.) Merr.) ranks second in the four major fresh tropical fruits in terms of importance in global production. However, copper and zinc deficiencies have become an issue and are widespread in all pineapple-growing countries, including Malaysia. The impact of foliar fertilisation with chelated copper-zinc on plant growth and development has garnered significant attention due to its profound effects. This study was designed to determine pineapple plant growth and nutrient concentration enhancement on mineral soil using different rates of copper-zinc chelated foliar spray. The selected rates of Cu-Zn fertiliser and NPK were applied for 6 months on pineapple plants. The treatments that were used in this study consisted of T0: control, T1: NPK, T2: NPK with Cu-Zn 6,407 ppm, T3: NPK with Cu-Zn 7,208 ppm, and T4: NPK with Cu-Zn 8,009 ppm. The pineapple cultivation was conducted in Parit Nipah, Batu Pahat, Johor, with the coordinates 1.842907, 103.145727. About fifteen pineapple suckers were planted in a polybag with a double row spacing system with 45 cm × 60 cm × 90 cm. The plants were arranged according to a randomised complete block design (RCBD) with three replications. The plant growth parameters such as plant fresh weight, plant root weight, plant leaf length, plant root length and plant chlorophyll content were collected after 6 months of transplanting. The plant nutrient was analysed using ICP-OES and CHNS analyser for macronutrient and micronutrient content. All the collected data were subjected to analysis of variance (ANOVA) and followed by the Tukey-B post hoc test for data interpretation. Differences at the 95% level are considered significant. The plant growth parameters showed treatment T4 exhibited the highest plant fresh weight (437 g) and root weight (36.50 g) compared to the other treatments at $p < 0.05$. For the plant nutrient analysis, treatment T4 showed the highest copper concentration (6.47 mg kg⁻¹) and (442.3 mg kg⁻¹), respectively, compared to the other treatments. As a conclusion, the chelated zinc-copper foliar spray has influenced pineapple plant fresh weight, root weight and copper nutrient content. These findings underscore the potential of foliar fertilisation with chelated copper-zinc as a valuable strategy in modern agriculture, promising enhanced plant growth and yield.

1. Introduction

Agricultural systems worldwide are facing unprecedented challenges as they strive to meet the growing demand for food in a sustainable and efficient manner. Among the diverse range of crops cultivated globally, pineapple (*Ananas comosus*) holds a distinctive place due to its economic importance and nutritional richness. As the agricultural landscape evolves, the

imperative to enhance crop productivity becomes increasingly pressing, necessitating innovative approaches to address the intricate complexities of plant growth and nutrient acquisition. In this context, the proposed research delves into the intricate relationship between pineapple plants and essential micronutrients, specifically copper and zinc, within the framework of foliar spray fertilisation.

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Mineral soils, though abundant, often lack an adequate concentration of micronutrients essential for optimal plant development (Shu-zhuan *et al.*, 2022). Traditional soil-based fertilisation methods may not efficiently address this deficiency, leading researchers to explore alternative strategies that offer targeted nutrient delivery. The advent of foliar spray fertilisation presents a promising avenue to supplement micronutrients directly to plant foliage, bypassing potential soil limitations (Naeem *et al.*, 2021). Within this context, the role of Cu and Zn, as critical micronutrients, emerges as a focal point of investigation for their influence on various physiological processes crucial for pineapple growth. The scarcity of comprehensive studies focusing on the interplay between copper, zinc, and pineapple plants, especially in mineral soil environments, underscores the significance of this research endeavour. The multifaceted impact of these micronutrients on enzymatic activities, hormone synthesis, and overall plant health demands meticulous examination. By addressing this research gap, the study aims to contribute not only to the advancement of knowledge in pineapple cultivation but also to the broader field of sustainable agriculture.

A key dimension of this research involves the selection of suitable mixtures of copper and zinc concentrations in conjunction with NPK fertiliser, guided by considerations of pH and electrical conductivity (EC). This foundational step aligns with the overarching goal of achieving a balanced nutrient profile that maximises the availability of essential elements for pineapple plants while maintaining optimal soil conditions (Prakash *et al.*, 2022). The outcome of this investigation holds promise not only for pineapple cultivation but also for informing fertilisation practices in other crops. Thus, the objective of this study is to determine pineapple (*Ananas comosus*) plant growth and nutrient uptake enhancement on mineral soil using different rates of copper-zinc chelated foliar spray. The findings of this study have the potential to reshape existing paradigms in pineapple cultivation practices and offer a blueprint for enhancing the efficiency and sustainability of agriculture in mineral soil environments.

2. Materials and methods

2.1 Treatment used

There are five treatments used in the study. Treatment one served as the control, which means no substances were applied to the plants. Treatment 1 involved providing the plants with only nitrogen fertiliser. Treatment 2 involved applying nitrogen fertiliser, copper, and zinc at a concentration of 6,407 ppm. Treatment 3 involved applying nitrogen fertiliser,

copper, and zinc at a concentration of 7,208 ppm. Treatment 4 involved applying nitrogen fertiliser, copper, and zinc at a concentration of 8,009 ppm. All these fertilisers were sprayed every month for a duration of 6 months. The fertiliser was applied using a foliar spraying method, which means it was sprayed onto the surface of the leaves only. Fertilisation was carried out in the late afternoon because the stomata of pineapple plants open during the late afternoon until early morning.

2.2 Experiment design

This study was conducted in Parit Nipah, Johor, at coordinates 1.842907, 103.145727. Pineapple plants of the Millie Dillard 2 (MD2) variety were used and planted in 16 in × 16 in polybags, using mineral soil sourced from the surrounding area with the same coordinates. In each treatment, there were three plants. The study utilised the Randomised Complete Block Design (RCBD) method, consisting of three blocks, with each block containing each treatment.

2.3 Determination of plant growth parameters

Pineapple trees were planted in polybags for 6 months. Each treatment had three pineapple trees, making 15 MD2-type pineapple trees used in this study. Plant height, plant weight, root weight, root length and chlorophyll content were recorded as pineapple growth parameters. First, the pineapple tree was uprooted, and the soil attached to the roots was cleaned using water. Then, the pineapple tree was air-dried for 4 hours. Then, the pineapple roots were cut using secateurs that had been sterilised using alcohol. Next, the pineapple tree is weighed using an analytical balance. Then, the pineapple roots were also weighed by using an analytical balance, plant and root height were measured using a measuring tape from the base of the plant to the top of the plant. Next, four leaves from the crown, namely D leaf, were cut using secateurs to analyse leaf nutrients and chlorophyll content. The chlorophyll content was measured using a SPAD-502 plus chlorophyll meter from Konica Minolta.

2.4 Plant nutrient analysis

Plant nutrient analysis is a crucial tool for understanding the nutritional status of plants and optimising their growth and development. One popular technique for assessing plant nutrition is acid digestion followed by inductively coupled plasma mass spectrometry (ICP-MS) to ascertain the concentrations of specific components. In the case of copper and zinc analysis, the use of hydrochloric acid (HCl) and nitric acid (HNO₃) can be effective. To analyse the nutrient content of plants, particularly copper (Cu) and zinc (Zn), using ICP-MS, a combination of HCl and nitric acid can

be used for sample preparation. The use of HCl and nitric acid for the digestion and extraction of elements is a common method called the double acid method. The total amount of Cu and Zn can be determined by microwave acid extraction with ICP-AES.

Figure 1 shows that the experiment has been conducted. First, leaf samples were collected and cleaned by wiping them with a damp cloth or tissue paper. Then, the samples were oven-dried at 60°C for 24 to 48 h until a constant weight was obtained. Next, the dried leaves were ground into a fine powder using a sample grinder. About 0.5 g was collected of the ground sample and it was placed in a crucible. The sample was burned till ash at 300°C for 1 h, then the temperature was increased to 550°C and continued to be heated for 6-7 h.

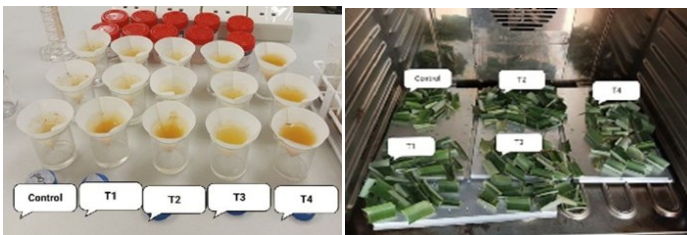


Figure 1. Experiment has been conducted.

Afterwards, the sample was moistened by adding a few drops of distilled water. Around 2 mL of concentrated HCl was added and it was evaporated on a hot plate. Following this, 10 mL of 20% HNO₃ was added and prepared (by mixing 200 mL concentrated HNO₃ with 1000 mL distilled water). Then, the crucible containing the mixture was heated in a water bath at 100°C for 30 min. After that, the sample was diluted in the crucible to a final volume of 100 mL using a volumetric flask. Finally, the resulting solution into a 100 mL-vial was filtered through 1 mm filter paper into plastic container. The nutrient content of the sample in the plastic container was analysed using an Inductively Coupled Plasma (ICP) instrument.

The use of acid digestion with hydrochloric acid and nitric acid, followed by ICP-MS, is a reliable method for analysing the concentration of copper and zinc in plant samples. This approach allows for accurate measurement of these elements and provides valuable insights into their uptake, accumulation, and distribution in plants.

2.5 Data analysis

Data analysis was conducted using the Statistical Package for the Social Sciences (SPSS) version 13. Data obtained from the Inductively Coupled Plasma (ICP) analysis has been entered into SPSS for analysis. This study employed Analysis of Variance (ANOVA) to determine whether the means of two or more groups are significantly different from each other. Furthermore, the study used Tukey's post hoc test to identify significant

differences between multiple groups or treatments. Through this analysis, researchers have been able to pinpoint specific groups that exhibited significant differences, providing valuable insights into the effects of different treatments or interventions. The results of this research are presented in the results and discussion section.

3. Results

The results of this study consist of data reading from the ICP for copper micronutrient and data reading from the ICP for zinc micronutrient. Data from ICP providing results on the absorption of copper and zinc foliar fertilisers on pineapple trees. In this study, 5 treatments were used to see the absorption of Cu-Zn by pineapple trees.

3.1 Absorption of copper and zinc

The results of this study consist of data reading from ICP for copper micronutrient and data reading from ICP for zinc micronutrient, as shown in Table 1. The result of Treatment T4, showcasing a significantly higher copper concentration of 442.23 mg kg⁻¹ compared to other treatments, underscores the remarkable impact of copper supplementation on MD2 pineapple plants at P<0.05. This finding elucidates a fascinating dose-dependent relationship, where higher doses of copper chelated foliar spray, as observed in Treatments 2, 3, and 4 (T2, T3, and T4), correspond to increased copper accumulation within the pineapple tissues. This dose-dependent response not only highlights the efficacy of copper supplementation in enhancing copper uptake by the plants but also hints at the potential for fine-tuning copper application rates to optimise nutrient levels and promote healthier plant growth.

Table 1. Copper-Zinc micronutrient in pineapple plant tissue analysis

Treatments	Copper Concentration (mg kg ⁻¹)	Zinc Concentration (mg kg ⁻¹)
T0: Control Plant	35.68±10.47 ^d	54.16±23.72 ^a
T1: NPK	10.96±0.63 ^d	13.56±10.16 ^b
T2: NPK + 6,407 ppm Cu-Zn	78.05±20.71 ^c	7.41±2.67 ^b
T3: NPK + 7,208 ppm Cu-Zn	195.23±4.38 ^b	8.90±3.08 ^b
T4: NPK + 8,009 ppm Cu-Zn	442.23±13.27 ^a	6.98±1.03 ^b

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different using Tukey's test (p<0.05).

Despite the significant influence of copper supplementation on copper concentration, no significant

differences were observed in zinc concentration among the treatment groups at $P < 0.05$. Research on the effects of copper foliar sprays on the growth and yield of broad bean (*Vicia faba* L.) demonstrated that copper spraying improved growth and yield attributes such as nitrogen content in leaves, chlorophyll content, plant height, and the number of branches (Alhasany *et al.*, 2019). These results underline the necessity of optimising copper levels in foliar sprays to boost plant growth and productivity. Similarly, studies on the response of broccoli hybrids to foliar spraying with copper nanoparticles showed positive impacts on vegetative growth characteristics and yield, highlighting copper's role in enhancing plant performance (Al-Shammari and Abbas, 2023).

Several studies have demonstrated that plants can absorb copper through foliar application. Pérez-Labrada *et al.* (2019) explored how tomato plants respond to foliar application of copper nanoparticles under saline stress, showing their effectiveness in delivering copper and affecting stress responses. Similarly, Karamanos *et al.* (2004) found that foliar applications can correct copper deficiency in crops during the growing season, confirming successful copper uptake through leaves. Furthermore, Elshazly (2020) showed that foliar application of micronutrients, including copper, can improve mineral uptake and metabolism in plants. The relationship between zinc and copper is marked by antagonism, as evidenced by multiple studies. Ebbs and Kochian (1997) found that copper inhibited lateral root elongation in Brassica species, whereas zinc primarily reduced lateral root diameter, highlighting the antagonistic interaction between the metals. Similarly, Hughes and Samman (2006) noted that zinc supplementation can lower the activity of copper-zinc superoxide dismutase, underscoring the antagonism between high zinc intake and copper absorption. Kaur *et al.* (2014) reported that copper supplementation enhances the conjugation of zinc with large molecules, reducing the ratio of zinc bound to smaller molecules, further indicating antagonism. Franklin *et al.* (2002) showed that adding copper to a zinc-containing solution decreased zinc adsorption by algae due to competitive binding, reinforcing the antagonistic relationship. Additionally, Takahashi (2022) emphasised that zinc antagonises divalent cations like copper during absorption, corroborating their antagonistic interaction. These studies collectively demonstrate that zinc and copper exhibit antagonistic behaviour, influencing various physiological processes and interactions within biological systems.

3.2 Absorption of macronutrient N, P, K, Ca, Mg

The macronutrient analysis of pineapple plant tissue

is tabulated in Table 2. Treatment 2 demonstrated a significant positive impact on N levels, with a concentration of approximately 34.84 mg kg^{-1} , suggesting enhanced nitrogen uptake compared to other treatments at $p < 0.05$. Similarly, research on the effects of nitrogen fertigation rate and foliar urea spray on Encore Azalea 'Chiffon' showed changes in nutrient uptake, such as increased copper levels, highlighting the importance of urea spray in nutrient management (Li *et al.*, 2022). Additionally, a study on the impact of foliar nitrogen applications, including urea, on chickpea seed yield and protein content revealed that urea foliar application positively affected nitrogen content and crop productivity, particularly under water deficit conditions (Palta *et al.*, 2005). Furthermore, research on the combined use of humic substances and urea for improving foliar nitrogen efficiency in sugarcane found that various foliar applications, including urea, can enhance nitrogen uptake and utilisation, resulting in better growth and productivity (Wells and Brock, 2014).

The control plant has a significant phosphorus concentration of approximately $2193.67 \text{ mg kg}^{-1}$ compared to the other treatments at $p < 0.05$ (Table 2). It seems that the type and concentration of fertiliser treatments have varying effects on phosphorus levels. Treatment T1 positively influences phosphorus levels, while Treatments T2, T3, and T4 have negative effects, with Treatment T4 having the most substantial negative impact. While for potassium concentration, there is no significant difference among all treatments at $p < 0.05$. The application of copper and zinc treatments appears to have a negative impact on calcium and magnesium levels. The control group has the highest calcium and magnesium concentration levels, while the treatments (T1, T2, T3, T4) all lead to significantly lower calcium levels at $p < 0.05$.

Based on Table 2, the control group has the highest average calcium level, at approximately $9067.67 \text{ mg kg}^{-1}$. This level represents the baseline or typical calcium concentration. T1 has a significantly lower average calcium level, around $2359.33 \text{ mg kg}^{-1}$, suggesting that the application of N fertiliser leads to a reduction in calcium levels compared to the control. T2 has an even lower average calcium level of approximately $1401.10 \text{ mg kg}^{-1}$. This indicates that T2 has a more pronounced negative impact on calcium levels compared to T1. T3 shows a calcium level of about $2340.67 \text{ mg kg}^{-1}$. While it's higher than T2, it's still significantly lower than the control, suggesting that T3 has a negative impact on calcium levels. T4 also results in a low average calcium level of about $1363.67 \text{ mg kg}^{-1}$, indicating that it has a negative effect on calcium levels similar to T2 and T3. The application of copper and zinc treatments appears to

Table 2. Macronutrient analysis of pineapple plant tissue.

Treatments	Nitrogen (mg kg ⁻¹)	Phosphorus (mg kg ⁻¹)	Potassium (mg kg ⁻¹)	Calcium (mg kg ⁻¹)	Magnesium (mg kg ⁻¹)
T0: Control Plant	21.56±0.92 ^d	2193.67±88.66 ^a	13506.67±2878.65 ^{ab}	9067.67±3729.92 ^a	2305.00±152.04 ^a
T1: NPK	26.62±0.20 ^c	2911.3±102.43 ^b	16296.67±73.71 ^a	2359.33±128.76 ^b	1885.67±30.02 ^b
T2: NPK + 6,407 ppm Cu-Zn	34.84±1.28 ^a	1044.37±236.90 ^c	9736.00±2779.37 ^{bc}	1401.10±460.10 ^b	972.17±220.59 ^d
T3: NPK + 7,208 ppm Cu-Zn	31.11±0.38 ^b	-1495.67±213.23 ^d	5606.00±672.02 ^c	2340.67±1011.70 ^b	1661.33±71.86 ^{bc}
T4: NPK + 8,009 ppm Cu-Zn	31.87±0.09 ^b	-6374.67±425.50 ^c	7333.33±214.70 ^c	1363.67±68.06 ^b	1406.67±27.21 ^c

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different using Tukey's test (p<0.05).

have a negative impact on calcium levels. The control group has the highest calcium and magnesium concentration levels, while the treatments (T1, T2, T3, T4) all lead to significantly lower calcium levels.

Excessive nitrogen application has been linked to reduced calcium uptake in plants, suggesting a potential antagonistic relationship between these two essential nutrients. Studies by Gołab-Bogacz *et al.* (2021) have highlighted the negative effects of excessive nitrogen on plant physiology, including disruptions in nitrogen metabolism and the production of reactive oxygen and nitrogen species. This imbalance caused by excess nitrogen can decrease calcium uptake, adversely affecting plant health and growth. Additionally, research by Fritz *et al.* (2014) showed that nitrogen fertilisation significantly impacts calcium uptake in plants, with nitrogen application influencing the uptake rates of various nutrients, including calcium. These findings indicate that nitrogen availability can affect calcium uptake and utilisation in plants, potentially leading to nutrient imbalances and issues in plant development. Similarly, research on the effects of nitrogen fertilisers on plant growth has shown that they can influence nutrient uptake and growth through various mechanisms, highlighting the importance of sustainable nutrient management strategies (Adesemoye *et al.*, 2009).

3.3 Other micronutrient absorption Fe and B

The plants treated with different combinations of copper and zinc micronutrients (T2, T3, and T4) also had lower average iron concentrations compared to the control group, but generally higher than the T1 group at P<0.05, as shown in Table 3. This suggests that the addition of copper and zinc micronutrients had varying effects on iron content, with some treatments leading to higher iron concentrations compared to treatment 1 (T1). The control plant had the highest average concentration of boron micronutrient at 24.73 mg kg⁻¹. The plants treated with nitrogen (T1) had a slightly lower average boron concentration at 24.34 mg kg⁻¹ compared to the

control group at P<0.05. This indicates that nitrogen treatment had a minor impact on boron content. The plants treated with different combinations of copper and zinc micronutrients (T2, T3, and T4) generally had lower average boron concentrations compared to the control group, with T2 having the lowest concentration. This suggests that these micronutrient treatments had a suppressing effect on boron levels.

Table 3. Iron and boron micronutrients in plant nutrient analysis.

Treatments	Iron Concentration (mg kg ⁻¹)	Boron Concentration (mg kg ⁻¹)
T0: Control Plant	375.80±170.59 ^a	24.73±2.01 ^a
T1: NPK	122.66±43.80 ^b	24.34±1.02 ^a
T2: NPK + 6,407 ppm Cu-Zn	117.00±28.19 ^b	20.85±1.84 ^a
T3: NPK + 7,208 ppm Cu-Zn	139.23±61.99 ^b	21.34±0.55 ^a
T4: NPK + 8,009 ppm Cu-Zn	183.93±81.68 ^{ab}	23.04±3.44 ^a

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different using Tukey's test (p<0.05).

The finding that Cu-Zn fertiliser does not increase iron uptake in plants can be explained by the complex interactions between these metallic elements in plant nutrition. Copper (Cu) and zinc (Zn) are known to compete with iron (Fe) for plant uptake, which can limit iron absorption (Jouvin *et al.*, 2012). Similarly, the lack of increased boron uptake with Cu-Zn fertiliser can be attributed to the intricate interactions between these metallic elements and their influence on nutrient absorption. Boron uptake in plants can be affected by the presence of other metallic nutrients like copper and zinc (Khan *et al.*, 2013). Studies have demonstrated a negative correlation between zinc and copper uptake in rice plants, indicating an antagonistic effect of zinc on copper bioaccumulation, which may also apply to other metallic nutrients like boron (Khan *et al.*, 2013).

3.4 Plant growth parameter

3.4.1 Effect of Zn-Cu foliar fertiliser on pineapple plant weight

The findings of the effects of Zn-Cu foliar fertiliser treatments on pineapple plant growth are described in Figure 2. Treatment T2, T3 and T4 show significantly higher plant fresh weight at 383 g, 421.5 g, and 437 g, respectively, compared to T0 and T1 at $p < 0.05$. Treatment groups T2, T3, and T4 displayed similar and significantly higher fresh weights compared to both the control group and Treatment 1 (T1). Figure 2 shows a bar chart for pineapple plant weight from different rates of Cu-Zn mix with NPK fertiliser. This observation suggests a positive and consistent effect on plant growth resulting from the specific composition or concentrations of Cu and Zn present in these treatments. Notably, the consistency in the outcomes across treatments 2, 3, and 4 indicates a robust response of pineapple plants to the applied copper-zinc chelated foliar spray fertilisation. This underscores the efficacy of copper-zinc chelated foliar spray fertilisation in enhancing the fresh weight of pineapple plants grown on mineral soil.

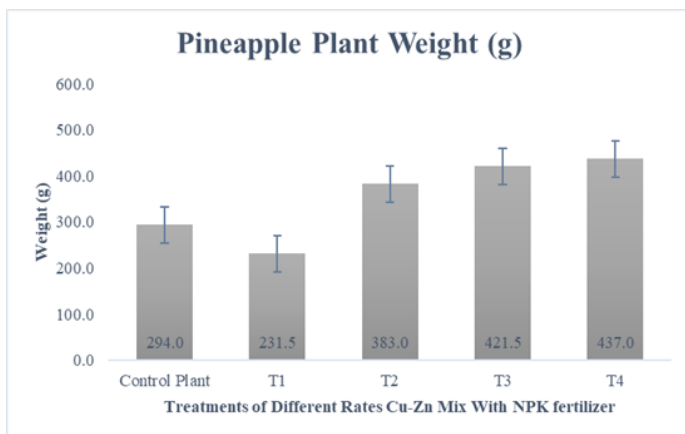


Figure 2. Pineapple plant weight from different rates of Cu-Zn mix with NPK fertiliser.

Foliar spray fertilisation with copper-zinc chelates has shown promise in enhancing the fresh weight of Egyptian cotton (*Gossypium barbadense* L.) plants grown on mineral soil. Studies have indicated that foliar application of zinc, especially in chelated form, can significantly increase plant growth and yield by improving nutrient uptake efficiency (El-Shazly, 2020). The application of zinc through foliar spraying has been found to enhance growth parameters such as fresh and dry weights of plants, seed production, and seed yield on satureja khuzistanica jamzad plant (Mumivand *et al.*, 2021). Additionally, the use of zinc oxide nanoparticles in foliar spraying has been shown to increase root fresh weight and leaf dry weight in cucumber plants, indicating a positive impact on plant growth (Li *et al.*, 2022). Furthermore, the efficacy of copper supplementation in enhancing copper uptake by plants

has been demonstrated in various studies. The application of nano chelates micronutrients, including copper, has been reported to significantly improve plant growth and yield on artichoke plants (*Cynara cardunculus*), highlighting the importance of micronutrient supplementation for plant development (Saadoun and Al-Juthery, 2019). Additionally, foliar application of copper nanoparticles has been shown to positively influence the growth and yield of broccoli hybrids, further emphasising the role of copper in promoting plant productivity (Al-Shamry and Abbas, 2023). Moreover, the use of zinc and other micronutrients in foliar sprays has been linked to improvements in plant growth under stress conditions. Studies have reported that foliar application of zinc on Fenugreek plant (*Trigonella foenum*) can significantly enhance root and shoot length, as well as fresh and dry weights of plants under salinity stress (Khan *et al.*, 2024). Similarly, foliar spraying with zinc has been found to improve growth characteristics and yield of broccoli hybrids, indicating the potential of micronutrient foliar applications in enhancing plant performance (Al-Shammari and Abbas, 2023).

3.4.2 Effects of Cu-Zn foliar fertiliser on pineapple plant root weight

Treatment T4 exhibited a significantly higher root weight (36.50 g) of plant roots compared to the other treatments, indicating a pronounced effect on root growth at $P < 0.05$. This finding suggests that the specific composition or concentrations of nutrients in T4, which may include copper and zinc, played a crucial role in promoting root development. Notably, the observed increase in root fresh weight in T4 highlights the importance of micronutrient management in influencing below-ground plant structures. This underscores the importance of optimising nutrient composition and application methods to maximise root growth and, consequently, overall plant health and productivity. Figure 3 shows pineapple root weight from different rates of Cu-Zn mix with NPK fertiliser.

Additionally, Vos *et al.* (1991) emphasised that

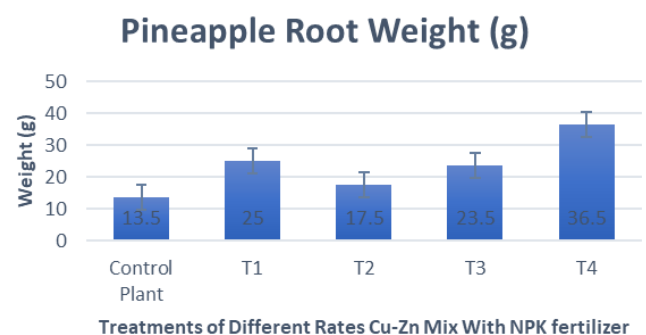


Figure 3. Pineapple root weight from different rates of Cu-Zn mix with NPK fertiliser.

copper-induced damage predominantly targets the plasmalemma of root cells, resulting in inhibited growth and root damage. Freitas *et al.* (2017) observed that copper toxicity can lead to root senescence and necrosis, thereby reducing plant biomass. Marques *et al.* (2018) investigated the effects of excessive copper on *Hymenaea courbaril L.* and found that copper toxicity impacts root morphology. Rossi *et al.* (2004) reported that significant copper levels generally inhibit root growth in non-tolerant plants.

The results of this study reveal a significant impact of copper-zinc chelated foliar spray fertilisation on the root weight. Treatment T4, characterised by a specific composition or concentration of nutrients, including copper and zinc, demonstrated a marked increase in root fresh weight compared to the other treatments. The observed significant difference in root fresh weight in Treatment T4 suggests that the nutrient composition in this treatment has a pronounced effect on root development.

Copper and zinc are known to play essential roles in various physiological processes, including root elongation, lateral root formation, and nutrient uptake (Hotegni, 2014). The observed increase in root fresh weight underscores the importance of micronutrient management in promoting root growth and overall plant health. The study by Khan *et al.* (2024) showed that foliar application of zinc on wheat plants enhanced shoot length and root weight under salinity stress, indicating a beneficial effect of zinc on root development. Furthermore, the study by Lemes *et al.* (2015) on fenugreek (*Trigonella foenum-graecum*) discovered that coating seeds with zinc sulfate increased seedling dry weight and zinc content in roots, emphasising zinc's potential to enhance root growth.

The significance of Treatment T4 in promoting root development has practical implications for pineapple cultivation. Robust root systems are critical for optimising nutrient and water uptake, anchorage, and plant stability. By enhancing root growth, farmers can improve the resilience of pineapple plants to environmental stresses, such as drought and nutrient deficiencies, thereby enhancing yield potential and crop quality.

3.4.3 Effects of Cu-Zn foliar fertiliser on pineapple plant leaf length

Treatment groups T2, T3, and T4 exhibited similar and significantly longer leaf lengths compared to the control group and Treatment T1, as shown in Figure 4. This consistent finding suggests that the application of copper and zinc in a foliar spray form has a distinct and

pronounced impact on pineapple leaf length. The observed increase in leaf length in response to copper-zinc foliar spray fertilisation indicates a stimulatory effect on leaf elongation and development. Statistical analysis revealed a significant difference in leaf length between the copper-zinc foliar spray treatments (T2, T3, T4) and the control and NPK treatments at a significance level of $P < 0.05$. This underscores the effectiveness of copper-zinc chelated foliar spray fertilisation in promoting leaf elongation and growth in pineapple plants.



Figure 4. Differences in leaf length from control plant (left) and treated plant

3.4.4 Effects of Cu-Zn foliar fertiliser on pineapple root length

There are no significant differences observed at the $P < 0.05$ level among the treatment groups; there are noticeable variations in pineapple root length across different treatments (Table 4).

Research on the impact of excessive zinc on sugarcane growth parameters revealed growth depression, reduced root number and length, and a significant decrease in root mitotic activity due to high zinc doses (Jain *et al.*, 2010). Similarly, a study on barley's early growth stages exposed to varying forms and concentrations of zinc showed reduced root length, except for bulk ZnO, which positively affected root growth (Nemček *et al.*, 2020).

Table 4. Weight pineapple plant leaf length and root length.

Treatments	Pineapple Leaf Length (cm)	Pineapple Root Length (cm)
T0: Control Plant	56.05±0.55 ^b	53.60±8.20 ^b
T1: NPK	51.50±11.30 ^b	101.55±29.95 ^a
T2: NPK + 6,407 ppm Cu-Zn	70.85±1.45 ^a	62.00±0.60 ^{ab}
T3: NPK + 7,208 ppm Cu-Zn	68.60±1.80 ^a	71.15±19.95 ^{ab}
T4: NPK + 8,009 ppm Cu-Zn	71.00±0.20 ^a	55.80±2.40 ^b

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different using Tukey's test ($p < 0.05$).

Studies have demonstrated that excess copper can cause growth inhibition, root damage, and changes in root morphology in wheat (*Triticum aestivum*) and trumpet tree (*Handroanthus heptaphyllus*) plants (Gao et al., 2018; Kuinchtner et al., 2023). High copper concentrations have been linked to reduced root length, biomass, and chlorophyll biosynthesis on the West Indian locust plant (*Hymenaea courbaril*) (Marques et al., 2018). Moreover, copper toxicity can lead to complete growth inhibition, root elongation disturbances, and damage to root cells and membranes in the annual oil seed plant (*Crambe abyssinica*) (Hu et al., 2015). Copper exposure has also been shown to decrease root length, increase root compactness, and alter root colour, reflecting physiological changes in the roots (Sharma et al., 2017; Turchetto et al., 2022). Additionally, copper treatments have been associated with reduced root length, as well as decreased biomass (Li et al., 2015). Conversely, a study on maize (*Zea mays* L.) showed zinc has varying effects on root length, with some studies reporting reduced root length with excess zinc exposure (Romdhane et al., 2021). Zinc application can result in decreased root length and biomass, along with reduced chlorophyll and carotenoid content in plants. Zinc treatments have also been linked to decreased root length, root biomass, and shoot biomass, indicating zinc's potential negative impact on root development.

The lack of statistically significant differences in pineapple root length may indicate that the effects of copper-zinc chelated foliar spray fertilisation on root growth are subtle and may require longer-term monitoring to detect. It is possible that root growth responses to nutrient treatments may manifest over extended periods, reflecting delayed or cumulative effects that may not be immediately evident in short-term studies (Johnson et al., 2018).

3.4.5 Effects of Cu-Zn foliar fertiliser on pineapple plant chlorophyll content

SPAD meters were used to determine chlorophyll content, as shown in Figure 5. Significant differences in chlorophyll content were observed between the control group and the treated groups (NPK with varying concentrations of Cu and Zn). Treatment groups T1, T2, T3, and T4, as shown in Table 5, exhibited substantially higher mean chlorophyll content compared to the control, indicating a stimulatory effect of copper-zinc chelated foliar spray fertilisation on chlorophyll synthesis. The observed increase in chlorophyll content across the treated groups suggests enhanced photosynthetic activity and overall plant health in response to the specific nutrient treatments. Chlorophyll is a key pigment involved in photosynthesis, and higher

chlorophyll content is indicative of improved photosynthetic efficiency.

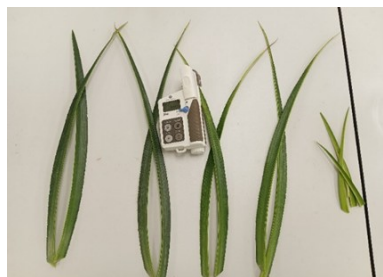


Figure 5. SPAD meters were used to determine chlorophyll content.

Table 5. Pineapple plant SPAD value.

Treatments	SPAD Value
T0: Control Plant	46.1±6.69 ^b
T1: NPK	73.07±5.61 ^a
T2: NPK + 6,407 ppm Cu-Zn	68.77±7.44 ^a
T3: NPK + 7,208 ppm Cu-Zn	74.77±14.73 ^a
T4: NPK + 8,009 ppm Cu-Zn	75.03±9.79 ^a

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different using Tukey's test ($p < 0.05$).

4. Conclusion

The experiment primarily focused on the application of Co-Zn spray in combination with N fertiliser and its effect on plant growth parameters. However, to fully assess the impact on plant nutrient contents, more detailed nutrient analyses, such as concentrations of Copper (Cu), Zinc (Zn), and Nitrogen (N), should be conducted. These specific nutrient measurements can provide valuable insights into how Co-Zn spray affects the nutritional content of plants.

In conclusion, our findings demonstrate that Co-Zn spray, when combined with N fertiliser, has the potential to enhance plant growth parameters, particularly plant weight and leaf length. However, it may negatively affect root weight. The specific effects on root length vary depending on the concentration and combination of nutrients. Further studies and nutrient analyses are recommended to gain a comprehensive understanding of how Co-Zn spray influences plant nutrient contents. These results offer valuable insights for optimising fertiliser treatments to achieve desired outcomes in plant growth and nutrient management.

Conflict of interest

The authors declare no conflict of interest.

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References

- Adesemoye, A.O., Torbert, H.A. and Kloepper, J.W. (2009). Plant growth-promoting rhizobacteria allow reduced application rates of chemical fertilizers. *Microbial Ecology*, 58(4), 921-929. <https://doi.org/10.1007/s00248-009-9531-y>
- Alhasany, A.R., Noaema, A.H. and Alhmadi, H.B. (2019). The role of spraying copper and zinc on the growth and yield of *Vicia faba* L. *IOP Conference Series: Materials Science and Engineering*, 571(1), 012048. <https://doi.org/10.1088/1757-899x/571/1/012048>
- Al-Shammari, A.M.A. and Abbas, D.K. (2023). Response of growth characteristics and yield of broccoli hybrids to foliar spraying with copper nanoparticles. *IOP Conference Series: Earth and Environmental Science*, 1158(4), 042064. <https://doi.org/10.1088/1755-1315/1158/4/042064>
- Ebbs, S.D. and Kochian, L.V. (1997). Toxicity of zinc and copper to Brassica species: implications for phytoremediation. *Journal of Environmental Quality*, 26(3), 776-781. <https://doi.org/10.2134/jeq1997.00472425002600030026x>
- Franklin, N.M., Stauber, J.L., Lim, R.P. and Petocz, P. (2002). Toxicity of metal mixtures to a tropical freshwater alga (*Chlorella* sp.): the effect of interactions between copper, cadmium, and zinc on metal cell binding and uptake. *Environmental Toxicology and Chemistry*, 21(11), 2412. [https://doi.org/10.1897/1551-5028\(2002\)0212.0.co;2](https://doi.org/10.1897/1551-5028(2002)0212.0.co;2)
- Freitas, F.D., Lunardi, S., Souza, L.B., Osten, J.S.C.V.D., Arruda, R., Andrade, R.L.T.D. and Battirola, L.D. (2017). Accumulation of copper by the aquatic macrophyte *Salvinia biloba* Raddi (Salviniaceae). *Brazilian Journal of Biology*, 78(1), 133-139. <https://doi.org/10.1590/1519-6984.166377>
- Fritz, C., Lamers, L.P.M., Riaz, M., van den Berg, L.J. and Elzenga, J.T.M. (2014). Sphagnum mosses - masters of efficient N-uptake while avoiding intoxication. *PLoS ONE*, 9(1), e79991. <https://doi.org/10.1371/journal.pone.0079991>
- Gao, X., Avellan, A., Laughton, S., Vaidya, R., Rodrigues, S., Casman, E.A. and Lowry, G.V. (2018). CuO nanoparticle dissolution and toxicity to wheat (*Triticum aestivum*) in rhizosphere soil. *Environmental Science and Technology*, 52(5), 2888-2897. <https://doi.org/10.1021/acs.est.7b05816>
- Gołab-Bogacz, I., Helios, W., Kotecki, A., Kozák, M. and Jama-Rodzeńska, A. (2021). Content and uptake of ash and selected nutrients (K, Ca, S) with biomass of *Miscanthus × giganteus* depending on nitrogen fertilisation. *Agriculture*, 11(1), 76. <https://doi.org/10.3390/agriculture11010076>
- Hotegni, V.N. (2014). Using agronomic tools to improve pineapple quality and its uniformity in Benin. Wageningen University, The Netherlands: PhD Thesis.
- Hu, J., Deng, Z., Wang, B., Zhi, Y., Pei, B., Zhang, G. and Huang, B. (2015). Influence of heavy metals on seed germination and early seedling growth in *Crambe abyssinica*, a potential industrial oil crop for phytoremediation. *American Journal of Plant Sciences*, 6(1), 150-156. <https://doi.org/10.4236/ajps.2015.61017>
- Hughes, S. and Samman, S. (2006). The effect of zinc supplementation in humans on plasma lipids, antioxidant status and thrombogenesis. *Journal of the American College of Nutrition*, 25(4), 285-291. <https://doi.org/10.1080/07315724.2006.10719537>
- Jain, R., Srivastava, S., Solomon, S., Shrivastava, A.K. and Chandra, A. (2010). Impact of excess zinc on growth parameters, cell division, nutrient accumulation, photosynthetic pigments and oxidative stress of sugarcane (*Saccharum* spp.). *Acta Physiologiae Plantarum*, 32(5), 979-986. <https://doi.org/10.1007/s11738-010-0487-9>
- Jouvin, D., Weiss, D., Mason, T.F.D., Bravin, M., Louvat, P., Zhao, F. and Benedetti, M.F. (2012). Stable isotopes of Cu and Zn in higher plants: evidence for Cu reduction at the root surface and two conceptual models for isotopic fractionation processes. *Environmental Science and Technology*, 46(5), 2652-2660. <https://doi.org/10.1021/es202587m>
- Karamanos, R.E., Pomarenski, Q., Goh, T.B., and Flore, N.A. (2004). The effect of foliar copper application on grain yield and quality of wheat. *Canadian Journal of Plant Science*, 84(1), 47-56. <https://doi.org/10.4141/p03-090>
- Kaur, K., Gupta, R., Saraf, S.A. and Saraf, S.K. (2014). Zinc: the metal of life. *Comprehensive Reviews in Food Science and Food Safety*, 13(4), 358-376. <https://doi.org/10.1111/1541-4337.12067>
- Khan, A., Bibi, S., Javed, T., Mahmood, A., Mehmood, S., Javaid, M.M. and Malik, T. (2024). Effect of salinity stress and surfactant treatment with zinc and boron on morpho-physiological and biochemical indices of fenugreek (*Trigonella foenum-graecum*). *BMC Plant Biology*, 24, 138. <https://doi.org/10.1186/s12870-024-04800-7>

- Khan, S., Cai, C., Waqas, M., Arp, H.P.H. and Zhu, Y. (2013). Sewage sludge biochar influence upon rice (*Oryza sativa*) yield, metal bioaccumulation and greenhouse gas emissions from acidic paddy soil. *Environmental Science and Technology*, 47(15), 8624-8632. <https://doi.org/10.1021/es400554x>
- Kuinchtner, C.C., Aguilar, M.V.M., Senhor, D.F., Birck, T.P., Brunetto, G. and Tabaldi, L.A. (2023). Morpho-physiological and biochemical mechanisms of copper tolerance in *Handroanthus heptaphyllus*. *Ciência e Agrotecnologia*, 47, e013322. <https://doi.org/10.1590/1413-7054202347011322>
- Lemes, E.S., Tunes, L.V.M.D., Almeida, A.D.S., Meneghello, G.E., Oliveira, S.D. and Muniz, M.F.B. (2015). Response of wheat seeds to zinc application during storage. *Ciencia e Investigación Agraria*, 42 (1), 21-22. <https://doi.org/10.4067/s0718-16202015000100011>
- Li, H., Xu, L., Li, J., Lyu, X., Li, S., Wang, C. and Yan, C. (2022). Multi-omics analysis of the regulatory effects of low-phosphorus stress on phosphorus transport in soybean roots. *Frontiers in Plant Science*, 13, 992036. <https://doi.org/10.3389/fpls.2022.992036>
- Li, S., Zhang, G., Gao, W., Zhao, X., Deng, C. and Longdou, L. (2015). Plant growth, development and change in GSH level in safflower (*Carthamus tinctorius* L.) exposed to copper and lead. *Archives of Biological Sciences*, 67(2), 385-396. <https://doi.org/10.2298/abs140910006l>
- Marques, D.J., Júnior, V.V., Silva, A.B.D., Mantovani, J.R., Magalhães, P.C. and Souza, T.C.D. (2018). Copper toxicity on photosynthetic responses and root morphology of *Hymenaea courbaril* L. (Caesalpinioideae). *Water, Air, and Soil Pollution*, 229(5), 172. <https://doi.org/10.1007/s11270-018-3769-2>
- Mumivand, H., Khanizadeh, P., Morshedloo, M.R., Sierka, E., Żuk-Golaszewska, K., Horaczek, T., and Kalaji, H.M. (2021). Improvement of growth, yield, seed production and phytochemical properties of *Satureja khuzistanica* Jamzad by foliar application of boron and zinc. *Plants*, 10(11), 2469. <https://doi.org/10.3390/plants10112469>
- Naeem, A., Aslam, M., Ahmad, M., Asif, M., Yazici, M.A., Cakmak, I., and Rashid, A. (2021). Biofortification of diverse Basmati rice cultivars with iodine, selenium, and zinc by individual and cocktail spray of micronutrients. *Agronomy*, 12(1), 49. <https://doi.org/10.3390/agronomy12010049>
- Nemček, L., Šebesta, M., Urík, M., Bujdoš, M., Dobročka, E. and Vávra, I. (2020). Impact of bulk ZnO, ZnO nanoparticles and dissolved Zn on early growth stages of barley—a pot experiment. *Plants*, 9 (10), 1365. <https://doi.org/10.3390/plants9101365>
- Palta, J.A., Nandwal, A.S., Kumari, S. and Turner, N.C. (2005). Foliar nitrogen applications increase the seed yield and protein content in chickpea (*Cicer arietinum* L.) subject to terminal drought. *Australian Journal of Agricultural Research*, 56(2), 105-112. <https://doi.org/10.1071/ar04118>
- Pérez-Labrada, F., López-Vargas, E.R., Ortega-Ortiz, H., Cadenas-Pliego, G., Benavides-Mendoza, A., and Juárez-Maldonado, A. (2019). Responses of tomato plants under saline stress to foliar application of copper nanoparticles. *Plants*, 8(6), 151. <https://doi.org/10.3390/plants8060151>
- Romdhane, L., Panozzo, A., Radhouane, L., Cortivo, C.D., Barion, G. and Vamerli, T. (2021). Root characteristics and metal uptake of maize (*Zea mays* L.) under extreme soil contamination. *Agronomy*, 11 (1), 178. <https://doi.org/10.3390/agronomy11010178>
- Rossi, G., Figliolia, A. and Socciarelli, S. (2004). Zinc and copper bioaccumulation in *Brassica napus* at flowering and maturation. *Engineering in Life Sciences*, 4(3), 271-275. <https://doi.org/10.1002/elsc.200420028>
- Saadoun, S.F., and Al-Juthery, H.W.A. (2019). Fertilizer use efficiency of nano fertilizers of micronutrients foliar application on Jerusalem artichoke. *Al-Qadisiyah Journal for Agriculture Sciences*, 9(1), 16–25. <https://doi.org/10.33794/qjas.2019.162661>
- Sharma, P., Sirhindi, G., Singh, A.K., Kaur, H. and Mushtaq, R. (2017). Consequences of copper treatment on pigeon pea photosynthesis, osmolytes and antioxidants defense. *Physiology and Molecular Biology of Plants*, 23(4), 809-816. <https://doi.org/10.1007/s12298-017-0461-8>
- Shu-zhuan, W., Xu, L., and Hao, M. (2022). Impacts of long-term micronutrient fertilizer application on soil properties and micronutrient availability. *International Journal of Environmental Research and Public Health*, 19(23), 16358. <https://doi.org/10.3390/ijerph192316358>
- Takahashi, A. (2022). Role of zinc and copper in erythropoiesis in patients on hemodialysis. *Journal of Renal Nutrition*, 32(6), 650-657. <https://doi.org/10.1053/j.jrn.2022.02.007>
- Vos, C.H.R.D., Schat, H., Waal, M.A.M.D., Vooijs, R. and Ernst, W.H.O. (1991). Increased resistance to copper-induced damage of the root cell plasmalemma in copper tolerant *Silene cucubalus*. *Physiologia Plantarum*, 82(4), 523-528. <https://doi.org/10.1034/j.1399-3054.1991.820407.x>
- Wells, L. and Brock, J. (2014). Effects of foliar sulfur sprays on pecan independent of pecan scab control. *HortScience*, 49(4), 434-437. <https://doi.org/10.21273/hortsci.49.4.434>