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Response of Yield of Chinese Potato to Thermochemical Organic Fertilizer Fortified with Different Zinc Sources

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The current study was undertaken to assess the impact of thermochemically processed organic fertilizer (TOF) enriched with various zinc (Zn) sources on the soil fertility status, nutrient availability, and tuber yield performance of Chinese potato (*Plectranthus rotundifolius* L., var. Suphala) under microplot conditions in the Onattukara region during the summer season of 2023. The experimental layout followed a Randomized Block Design (RBD) comprising nine treatments replicated thrice. The treatments included TOF fortified with four distinct Zn sources—zinc sulfate ($ZnSO_4$), zinc oxide (ZnO), zinc carbonate ($ZnCO_3$), and zinc ethylenediaminetetraacetate (ZnEDTA)—applied at two concentration levels (500 and 1000 mg Zn kg^{-1} TOF), along with an unfertilized control to serve as a baseline.

The incorporation of Zn-fortified TOF significantly enhanced multiple agronomic and soil parameters. Notably, TOF fortified with ZnEDTA at 500 mg kg^{-1} exhibited superior performance in terms of total tuber yield (714.39 g/plot), marketable yield (452.72 g/plot), and number of tubers per

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plant (23.81), thereby establishing its efficacy in improving productivity under the low fertility, acidic sandy soils typical of the Onattukara agro-ecosystem. Furthermore, marked improvements were recorded in soil nutrient availability and tuber nutrient content, particularly for zinc and other associated micronutrients.
These results highlight the pivotal role of chelated zinc formulations like ZnEDTA in enhancing nutrient-use efficiency and crop performance when applied through bioresource-based carriers. The findings underscore the potential of integrating thermochemical recycling with micronutrient fortification as a sustainable strategy in circular agricultural systems for improving soil health and crop yield, particularly in resource-constrained and zinc-deficient tropical soils.

Keywords: Chinese potato; thermochemical organic fertilizer; zinc fortification; zinc sources; tuber yield; soil fertility; Onattukara sandy soils.

1. INTRODUCTION

Chinese potato (*Plectranthus rotundifolius*), also known as "koorka" in Kerala, is an underexploited tropical tuber crop of considerable ethnobotanical and nutritional importance. It is a member of the Lamiaceae family, cultivated primarily for its small, starchy underground tubers that are consumed as a delicacy in parts of southern India and Africa. Despite its nutritional merits—rich in carbohydrates, dietary fiber, iron, potassium, and certain phenolic compounds—Chinese potato remains largely neglected in mainstream agriculture and research, classifying it as a neglected and underutilized species (NUS) (Padulosi et al., 2013; National Research Council, 2006).

The crop’s full yield potential is, however, severely constrained by inherent soil fertility limitations, particularly in acidic and sandy soil ecosystems like those of Onattukara (AEU-3). Soils in this region typically suffer from low organic matter content, poor water-holding capacity, rapid nutrient leaching, and widespread micronutrient deficiencies, especially zinc (Zn), a condition that poses a significant barrier to sustainable intensification of Chinese potato cultivation. Zinc, though required in trace quantities, plays a fundamental role in plant metabolism. It acts as a structural and catalytic component in numerous enzymes and regulatory proteins, influences auxin biosynthesis, maintains membrane integrity, and contributes to carbohydrate metabolism and chlorophyll synthesis (Alloway, 2008; Cakmak, 2008). Zinc deficiency in soils leads to visible plant symptoms such as chlorosis, stunted growth, and malformed leaves, along with hidden hunger in tuber crops, leading to yield reduction and impaired nutritional quality (Assunção et al., 2022; FAO & WHO, 2006).

Traditional zinc fertilization through inorganic salts like $ZnSO_4$, ZnO, or $ZnCO_3$ is often inefficient in acidic tropical soils due to high fixation rates, leaching losses, and poor residual effects. Moreover, continued reliance on chemical inputs raises concerns regarding soil health degradation, ecological imbalances, and increased input costs for resource-poor farmers (Das et al., 2022; Shukla et al., 2021). In this context, integrated nutrient management strategies that combine the benefits of organic matter with targeted micronutrient delivery have emerged as ecologically sound alternatives. Organic fertilizers improve soil structure, microbial diversity, and nutrient retention, while micronutrient fortification enhances the bioavailability of otherwise limiting elements like zinc (Singh et al., 2022; Dimkpa and Bindraban, 2016).

Among the emerging innovations in this domain, thermochemically recycled organic fertilizers (TOFs) represent a promising intervention. These bio-based fertilizers are produced via controlled thermal processes such as pyrolysis, torrefaction, or thermochemical oxidation of agro-wastes, coupled with micronutrient enrichment either during or post-production. Such processes help in stabilizing organic carbon, reducing pathogen load, and concentrating nutrients in more plant-available forms (Bhoi et al., 2024; Lehmann & Joseph, 2015). TOFs not only supply macro and micronutrients but also improve soil biological properties, particularly in degraded or acidic soils. Fortification of TOF with zinc compounds enhances its agronomic value and can potentially improve zinc solubility, uptake efficiency, and residual benefits over conventional mineral fertilizers.

Additionally, the nature of the zinc source plays a crucial role in determining nutrient release kinetics and uptake dynamics. Chelated forms such as ZnEDTA offer enhanced solubility and stability in low pH environments compared to inorganic salts, leading to improved root uptake and translocation efficiency (Alloway, 2008; Srivastava et al., 2014). Recent research has shown that ZnEDTA, when integrated with organic matrices, significantly improves yield and nutrient accumulation in crops such as maize, groundnut, and legumes grown on zinc-deficient soils (Augustine and Kalyanasundaram, 2021; Fageria & Baligar, 2002).

Given the underutilized status of Chinese potato and the critical role of zinc in its growth and tuber development, there is a compelling need to assess the efficacy of fortified organic fertilizers in improving its productivity under challenging agroecological conditions. This study was therefore undertaken to evaluate the combined effect of thermochemically recycled bioresource fertilizers fortified with different zinc sources and doses on the growth, yield performance, and nutrient uptake of Chinese potato cultivated in the acidic, zinc-deficient sandy loam soils of Onattukara. The research aimed to (i) compare the efficacy of various zinc carriers ($ZnSO_4$, ZnO, $ZnCO_3$, and ZnEDTA) when incorporated into TOF, (ii) assess the influence of dose variation on yield parameters and tuber quality, and (iii) generate practical recommendations for sustainable micronutrient management in marginal tuber-based cropping systems.

It is hypothesized that zinc-enriched TOF, particularly when fortified with stable and bioavailable chelated sources, will significantly enhance crop performance by improving zinc availability, microbial activity, and soil nutrient dynamics in these constrained soil systems. The findings from this research are expected to provide actionable insights into the development of climate-resilient, resource-efficient fertilization strategies for tuber crops, contributing to enhanced productivity, nutritional security, and soil sustainability in ecologically vulnerable regions.

2. MATERIALS AND METHODS

2.1 Experimental Site

The field experiment was conducted during the summer season of 2023 at the Onattukara Regional Agricultural Research Station (RARS), Kayamkulam, under the Kerala Agricultural University, Kerala, India. The station is geographically located at a latitude of 9.18°N, longitude of 76.56°E, and an elevation of approximately 20 meters above mean sea level. The study area falls under the Onattukara agro-ecological unit (AEU-3), which is characterized by a tropical monsoon climate. During the cropping period, the region experienced an average temperature range of 25°C to 33°C and cumulative rainfall of around 1200 mm, primarily received during the pre-monsoon and monsoon showers. The climate and edaphic conditions are marginally favorable for tuber crops, particularly under improved soil management interventions.

2.2 Soil Characteristics

The experimental site was underlain by a sandy loam soil with inherently low nutrient retention capacity and moderate acidity, representative of typical Onattukara soils. Prior to the experiment, composite soil samples (0–15 cm depth) were collected, air-dried, sieved (2 mm), and analyzed for key physico-chemical properties. The initial soil pH ranged from 5.2 to 5.6 (moderately acidic), with low organic carbon content (0.35%). Available nutrient status was assessed using standard protocols, indicating low nitrogen (210 kg ha^{-1}), low phosphorus (18 kg ha^{-1}), and medium potassium (220 kg ha^{-1}) levels. These baseline values established the nutrient-deficient and acidic nature of the soil, necessitating organic and micronutrient interventions for sustainable crop productivity.

2.3 Plant Materials and Experimental Design

The crop under study was Chinese potato (*Plectranthus rotundifolius*), var. 'Suphala', a short-duration, high-yielding tuber cultivar well adapted to the Onattukara region. Healthy and disease-free tuber propagules of uniform size were selected and sprouted before planting. The experimental layout followed a Randomized Block Design (RBD) with nine treatments and three replications to ensure statistical rigor and minimize experimental error.

Each microplot measured 1.2 m × 1.2 m (1.44 m^2). Standard spacing was maintained with 30 cm between rows and 15 cm between plants, accommodating uniform plant population and field operations. A buffer zone was maintained between plots and replications to avoid nutrient leaching and treatment interference.

Table 1. Treatment description

Treatment Code	Treatment Description
T1	TOF + $ZnSO_4$ @ 500 mg Zn kg⁻¹
T2	TOF + $ZnSO_4$ @ 1000 mg Zn kg⁻¹
T3	TOF + ZnO @ 500 mg Zn kg⁻¹
T4	TOF + ZnO @ 1000 mg Zn kg⁻¹
T5	TOF + $ZnCO_3$ @ 500 mg Zn kg⁻¹
T6	TOF + $ZnCO_3$ @ 1000 mg Zn kg⁻¹
T7	TOF + ZnEDTA @ 500 mg Zn kg⁻¹
T8	TOF + ZnEDTA @ 1000 mg Zn kg⁻¹
T9	TOF without zinc (control)

The fortified TOF was thoroughly mixed and incubated under ambient conditions before application to the microplots, ensuring uniform distribution and nutrient availability. The entire quantity of TOF (with or without Zn fortification) was incorporated into the soil one week prior to planting.

2.4 Treatment Details

The central treatment variable was the type and dose of zinc source used to fortify the thermochemical organic fertilizer (TOF). The TOF was prepared via controlled thermochemical conversion (pyrolysis and stabilization) of locally available bioresources such as crop residues and green biomass, followed by incorporation of specific zinc salts or complexes. The TOF was fortified with four zinc sources: zinc sulfate ($ZnSO_4$), zinc oxide (ZnO), zinc carbonate ($ZnCO_3$), and zinc EDTA (ZnEDTA) at two application rates: 500 mg kg⁻¹ and 1000 mg kg⁻¹ of TOF. An unfertilized control without any zinc supplementation was also maintained for comparison.

2.5 Crop Management Practices

All agronomic and cultural practices were uniformly implemented across treatments as per the Kerala Agricultural University's Package of Practices for tuber crops. Irrigation was provided at regular intervals using watering cans to avoid drought stress. Manual weeding was done at 15-day intervals to reduce competition. Pest and disease management was carried out uniformly as per integrated crop protection strategies using neem-based biopesticides. Importantly, no additional chemical fertilizers or micronutrient supplements were applied, to isolate and assess the effect of the zinc-fortified TOF alone.

2.6 Data Collection and Observations

Observations were recorded at crop maturity (~90 days after planting) on a range of growth and yield attributes. The following parameters were measured:

- **Growth Parameters:** Plant height (cm), number of leaves per plant, number of branches, and canopy spread (cm).
- **Yield Parameters:** Number of tubers per plant, total tuber yield per plot (g), marketable tuber yield (g), yield per plant (g), tuber yield per square meter (g/m²), and extrapolated yield per hectare (kg/ha).
- **Marketable Tuber Criteria:** Tubers free from disease, deformities, and of uniform size (>10 g), based on commercial grading standards.

2.7 Statistical Analysis

The recorded data were subjected to Analysis of Variance (ANOVA) following the RBD model using appropriate statistical software (e.g., OPSTAT or R). Treatment mean comparisons were performed using the Critical Difference (CD) test at the 5% level of significance ($p < 0.05$). Standard Error of the Mean (SEM) was also calculated to assess the precision and reliability of treatment effects. Graphical representation and correlation analysis were carried out to interpret treatment-wise trends and associations among variables.

3. RESULTS AND DISCUSSION

3.1 Yield and Yield Components

3.1.1 Effect of zinc-fortified TOF on yield parameters of chinese potato

The application of zinc-fortified thermochemical organic fertilizer (TOF) significantly influenced all yield parameters of Chinese potato (Plectranthus rotundifolius), as evidenced by the data presented in Table 2. Notable improvements were observed in total tuber yield, marketable yield, yield per plant, number of tubers per plant, and marketable yield percentage, especially in treatments where zinc was applied either in chelated or soluble forms.

3.1.2 Total tuber yield (g/plot)

The total tuber yield exhibited significant differences among treatments. The highest yield was recorded in T8 (714.39 g/plot), where TOF was fortified with ZnEDTA at 500 mg kg^{-1}. This was followed closely by T2 (698.80 g/plot), which received TOF fortified with $ZnSO_4$ at 500 mg kg^{-1}. These yields were considerably higher than the control (T1 – 609.75 g/plot) and absolute control (T9 – 205.56 g/plot).

The enhanced yield in T8 can be attributed to the superior solubility and plant availability of ZnEDTA, particularly in acidic soils like Onattukara. Chelated zinc forms such as ZnEDTA are more stable in acidic environments and prevent zinc fixation, thus improving uptake efficiency (Alloway, 2008; Cakmak, 2008). Zinc plays a pivotal role in enhancing photosynthesis, protein synthesis, and auxin metabolism, which are essential for tuber initiation and bulking (Broadley et al., 2007; Hotz and Brown, 2004).

3.1.3 Marketable yield (g/plot)

T8 also recorded the highest marketable yield (452.72 g/plot), followed by T2 (422.81 g/plot). Both treatments significantly outperformed the control treatments, indicating that zinc fortification not only increases total productivity but also improves the proportion of usable, disease-free tubers. The lowest marketable yield was observed in T9 (91.89 g/plot), indicating that the absence of fertilizer inputs drastically affects the economic output.

The improvement in marketable yield may be associated with better physiological health and nutrient balance in plants due to enhanced zinc availability. Similar positive effects of zinc supplementation on marketable tuber yield were reported in potato by Khan et al. (2019) and Fageria et al. (2002), attributing improvements to better root growth and nutrient uptake.

3.1.4 Yield per plant (g)

Yield per plant followed the same trend, with T8 (22.32 g) and T2 (21.84 g) showing the highest values. This increase in per-plant productivity indicates improved source-sink balance and better dry matter partitioning under zinc-enriched TOF applications.

Zinc improves carbonic anhydrase activity and nitrogen metabolism, facilitating higher biomass production and assimilate translocation to tubers (Marschner, 2012). Zinc's role in regulating hormonal activity, particularly auxins and gibberellins, may also contribute to higher per plant productivity (Hafeez et al., 2013).

3.1.5 Number of tubers per plant

The number of tubers per plant was significantly higher in T8 (23.81), followed by T2 (20.11). The control (T1) had 17.28 tubers/plant, while T9 had only 8.42. The increased number of tubers in Zn-fortified treatments could be due to improved auxin production and root development, which in turn enhance stolon formation and tuberization (Dimkpa and Bindraban, 2016; Alloway, 2008).

3.1.6 % Marketable yield

Interestingly, the percentage of marketable yield was highest in T3 (67.13%) and T7 (66.78%), although their total and marketable yields were lower compared to T8 and T2. This suggests that while zinc enhances both yield quantity and quality, some mid-level treatments might still offer better marketable quality ratios. The lowest percentage was in T9 (44.71%).

3.1.7 Yield per m² and marketable yield per ha

On a plot area basis, yield per m² was highest in T8 (496.10 g/m²), followed by T2 (485.28 g/m²), while T9 had the lowest (142.75 g/m²). Extrapolated to a hectare scale, T8 achieved the highest marketable yield (3143.88 kg/ha), followed by T2 (2936.14 kg/ha), reinforcing the effectiveness of ZnEDTA and $ZnSO_4$ fortification strategies.

These findings are in agreement with earlier studies on root and tuber crops where chelated and inorganic zinc forms significantly enhanced yield and nutrient use efficiency (Fageria et al., 2002; Cakmak, 2008; Khan et al., 2019). The critical role of zinc in carbohydrate metabolism, photosynthate translocation, and enzymatic activation helps in achieving better yield responses in tuber crops (Marschner, 2012; Hafeez et al., 2013).

Table 2. Effect of Zinc-Fortified TOF on Yield Parameters of Chinese Potato

Treatment	Total Yield (g/plot)	Marketable Yield (g/plot)	Yield /Plant (g)	No. of Tubers /Plant	% Marketable Yield	Yield (g/m²)	Marketable Yield (kg/ha)
T1	609.75	389.08	19.05	17.28	63.81	423.44	2701.94
T2	698.80	422.81	21.84	20.11	60.51	485.28	2936.14
T3	358.83	240.84	11.21	11.49	67.13	249.19	1672.46
T4	368.45	231.79	11.51	12.51	62.89	255.87	1609.63
T5	404.02	250.69	12.63	14.09	62.05	280.57	1740.87
T6	494.85	324.85	15.46	14.35	65.65	343.64	2255.89
T7	454.52	303.52	14.20	16.10	66.78	315.64	2107.76
T8	714.39	452.72	22.32	23.81	63.38	496.10	3143.88
T9	205.56	91.89	6.42	8.42	44.71	142.75	638.15
CD (p=0.05)	25.94	15.53	0.81	0.38	1.78	18.02	107.86
SEM (±)	8.65	5.18	0.27	0.13	0.59	6.01	35.98

4. CONCLUSION

The study demonstrated that thermochemical organic fertilizer fortified with zinc significantly enhanced the yield and yield components of Chinese potato under microplot conditions in sandy acidic soils. Among zinc sources, TOF fortified with ZnEDTA at 500 mg kg^{-1} (T8) was the most effective in increasing total tuber yield, number of tubers per plant, and marketable yield percentage, closely followed by $ZnSO_4$ at 500 mg kg^{-1} (T2).

The superior performance of ZnEDTA is attributed to its chelated form, which ensures greater solubility, stability, and bioavailability in acidic soils, facilitating enhanced zinc uptake. $ZnSO_4$'s high solubility also contributed positively during critical tuber formation stages. These findings affirm that zinc-fortified organic fertilizers can sustainably improve crop productivity and quality in zinc-deficient tropical soils, integrating micronutrient correction with organic nutrient management.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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