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Response of Nutrient Enriched Compost and Zinc on Quality, Nutrient Uptake and Profitability of Maize (*Zea mays* L.) in South-West Rajasthan, India

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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

A field experiment was conducted during kharif 2020 at the Instructional Farm (Agronomy), Rajasthan College of Agriculture, Udaipur, to study the effects of nutrient-enriched compost (NEC) and zinc application on the quality, nutrient uptake and profitability of maize (*Zea mays L.*) cultivar PM-9 in the sub-humid Southern Plain and Aravalli Hill region of Rajasthan. The treatments comprised four levels of NEC, namely control (NEC0), 2.0 t NEC ha-1 (NEC1), 4.0 t NEC ha-1 (NEC2) and 6.0 t NEC ha-1 (NEC3), and four zinc (Zn) application treatments, namely control (Zn0), 10 kg ZnSO4 ha-1 as basal + 0.5% ZnSO4 foliar spray (Zn1), 15 kg ZnSO4 ha-1 as basal + 0.5% ZnSO4 foliar spray (Zn2) and 20 kg ZnSO4 ha-1 as basal + 0.5% ZnSO4 foliar spray (Zn3), arranged in a factorial randomised block design with three replications. Increasing

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levels of nutrient-enriched compost and zinc up to 4 t ha-1 and 15 kg ZnSO4 ha-1 + 0.5% ZnSO4 foliar spray significantly (P=0.05) increased protein content, nutrient content and uptake (N, P, K and Zn) by seed and stover, net return and the BC ratio of maize. The application of NEC2 increased zinc content in seed and stover by 14.90 and 13.50 per cent, respectively, compared with the control (NEC0), while Zn2 increased zinc content in seed and stover by 13.98 and 13.42 per cent, respectively, compared with the control (Zn0). Based on the statistical inference, nutrient-enriched compost @ 4 t ha-1, along with basal application of 15 kg ZnSO4 ha-1 plus foliar application of 0.5% ZnSO4, emerged as the optimum treatment for improving maize quality, nutrient uptake by seed and stover, and profitability in the sub-humid Southern Plain region of Rajasthan.

Keywords: Maize; nutrient-enriched compost; zinc; protein content; nutrient uptake; seed quality; stover; net return; benefit-cost ratio; South-West Rajasthan.

1. Introduction

Maize (*Zea mays L.*) is one of the most important cereal crops in the world and is used as human food, animal feed, fodder and industrial raw material. Maize productivity is high because of the C4 nature of the plant, which enables efficient conversion of solar energy into dry matter production. The crop has high genetic yield potential and is therefore referred to as the Miracle Crop and the "Queen of Cereals". In India, maize occupies 9.03 m ha, with a production of 28.64 million tonnes and a productivity of 3.07 t ha-1 (FAI, 2020). In Rajasthan, it covers an area of 0.85 m ha and has a productivity of 2.24 t ha-1 (FAI, 2019-20). Recent field evidence also indicates that foliar zinc-based fortification can improve nutrient content and uptake in maize, while cultivar and location may influence the magnitude of grain micronutrient enrichment (Vishal et al., 2024; Xue et al., 2023).

Nutrient-enriched composting is primarily a microbiological process carried out through the combined activity of bacteria, actinomycetes, fungi and protozoa, which are either present in the composting material or introduced externally to accelerate composting and enrich the compost. As a result, the substrate breaks down to form an amorphous brown to dark-brown mixture known as compost. Waste material with adequate water content undergoes intensive decomposition from low to high temperature in heaps or pits for approximately 4 to 8 months. Compost is considered a valuable organic fertiliser, as it supplies nutrients to crops and can therefore reduce part of the requirement for mineral fertilisers (Erhart et al., 2005). Nutrient-enriched compost is used as a soil conditioner because it contains organic matter, diverse microflora, and macro- and micronutrients, which help improve the nutrient status and physico-chemical and biological properties of soil (Ingelmo et al., 2012). Recent studies on maize-based systems further support the value of combining organic and mineral nutrient sources for sustaining yield and improving soil fertility indicators (Wang et al., 2025; Abdul-Aziz et al., 2026).

The essentiality of zinc in plants was first established by Mazé (1915) in maize and subsequently in barley and sunflower (Sommer and Lipman, 1926). The critical limit of available zinc in soil suitable for growth is 0.6 mg kg-1. Available zinc extracted with DTPA in Indian soils is less than 1 per cent of the total zinc content (Takkar and Mann, 1975). Analysis of DTPA-extractable Zn in soils has shown that 40 per cent of soil samples were potentially zinc deficient (Shukla et al., 2014). It has been postulated that zinc deficiency is likely to increase from 49 to 63 per cent by 2025, as most marginal soils brought under cultivation show symptoms of zinc deficiency (Arunachalam et al., 2013). Zinc is an essential micronutrient and plays an important role in various enzymatic and physiological activities of plants. Most soils of Rajasthan have been found deficient in zinc, with low zinc availability associated with coarse-textured soils having medium organic carbon content (Singh and Singh, 1981). Therefore, when soil zinc supply is inadequate, crop yields may be adversely affected, making zinc application and utilisation important. Comparative evaluation of mineral fertiliser, organic fertiliser and rhizobacteria in maize has also shown that crop performance can differ according to the nutrient-management approach and field stress conditions (Nassif et al., 2025). However, limited information is available on the combined effect of nutrient-enriched compost and zinc application on maize seed quality, nutrient uptake by seed and stover, and profitability under the sub-humid Southern Plain and Aravalli Hill region of Rajasthan.

Objective: The present investigation was undertaken to evaluate the response of maize to different levels of nutrient-enriched compost and zinc application in terms of seed quality, nutrient uptake by seed and stover, net return and benefit-cost ratio.

2. Materials and Methods

Experimental Site and Soil: The field experiment was conducted during kharif 2020 at the Instructional Farm (Agronomy), Rajasthan College of Agriculture, Udaipur, situated at an altitude of 579.5 m above mean sea level and at 24°34' latitude and 73°42' longitude. This region falls under agro-climatic zone IVa (Sub-humid Southern Plain and Aravalli Hills) of Rajasthan. The experimental soil was alkaline (pH 8.26+0.16), non-saline (electrical conductivity 0.631+0.01 dS m-1) and clay loam in texture; medium in organic carbon (0.63+0.01%); low in available N (272+5 kg ha-1) and available P (17.97+0.32 kg ha-1); high in available K (352+7 kg ha-1); and low in available zinc (0.59+0.01 mg kg-1).

Experimental Design and Treatments: The experiment was laid out in a factorial randomised block design with three replications in plots of 4.0 m x 3.0 m (12 m2). The treatments comprised four levels of nutrient-enriched compost (NEC), namely control (NEC0), 2.0 t NEC ha-1 (NEC1), 4.0 t NEC ha-1 (NEC2) and 6.0 t NEC ha-1 (NEC3), and four levels of zinc (Zn) application, namely control (Zn0), 10 kg ZnSO4 ha-1 as basal + 0.5% ZnSO4 foliar spray (Zn1), 15 kg ZnSO4 ha-1 as basal + 0.5% ZnSO4 foliar spray (Zn2) and 20 kg ZnSO4 ha-1 as basal + 0.5% ZnSO4 foliar spray (Zn3). Maize variety PM-9 was sown in rows spaced 60 cm apart. According to the treatments, the full quantity of NEC was broadcast at the time of sowing. Nitrogen at 120 kg ha-1 was applied in two equal splits; half was applied as basal and the remaining half was top-dressed at the time of first irrigation. The basal N dose was applied through urea after adjusting the quantity supplied through diammonium phosphate. The full quantities of phosphorus (60 kg P2O5 ha-1) through diammonium phosphate and potassium (30 kg K2O ha-1) through muriate of potash were applied basally. Basal zinc (10, 15 or 20 kg ZnSO4) was applied through zinc sulphate heptahydrate at the time of sowing. A foliar spray of 0.5% zinc sulphate heptahydrate was applied at 35 days after sowing.

Preparation of Nutrient-enriched Compost (NEC): For the preparation of NEC, 15 kg of air-dried maize stover chopped into 5-6 cm pieces was soaked in water for 24 hours. After soaking, it was mixed thoroughly with the required quantities of rock phosphate (RP) and waste mica. To reduce the C:N ratio of maize stover, urea solution @ 0.25 kg N per 100 kg of maize stover and fresh cow dung @ 10 kg per 100 kg of maize stover were added as natural inoculants. Phosphate-solubilising microorganism @ 50 g per 100 kg was also added to the maize stover. The whole composting mass was then mixed thoroughly, placed in cemented pits and covered with jute bag sheets to maintain moisture. To provide adequate aeration, turning was performed after 15, 30 and 60 days of composting, and moisture was maintained at 60% of water-holding capacity throughout the experiment. Composting continued for 120 days. The chemical composition of the nutrient-enriched compost used in the field experiment was N 0.847±0.016%, P 1.217±0.025%, K 1.157±0.024% and Zn 114.2+1.31 ppm.

Nutrient Uptake: The nutrient contents were analysed using standard methods, and the concentrations of N, P and K were expressed as percentages, whereas the concentration of Zn was expressed as ppm. Nutrient uptake by seed and stover was calculated by multiplying nutrient concentration (%) in grain and stover by their respective yields.

Protein Content: Protein content in seed was obtained by multiplying the nitrogen (N) percentage by 6.25 (Association of Official Agricultural Chemists, 1955).

Economics: Net return (₹ ha-1): Net monetary returns (₹ ha-1) were calculated by subtracting the cost of treatment and cost of cultivation from the gross income obtained. The cost of cultivation and net profit were calculated on the basis of the prevailing prices of produce and inputs.

Benefit-cost ratio: The benefit-cost ratio was calculated using the following formula:

$$\text{BC ratio} = \frac{\text{Net return (Rs ha}-1)}{\text{Total cost (cost of cultivation + cost of treatment) (Rs ha}-1)}$$

Statistical Analysis: The data recorded for different parameters were analysed using the analysis of variance (ANOVA) technique, as outlined by Panse and Sukhatme (1985), for a factorial randomised block design. The results are presented at the 5% level of significance (P=0.05).

3. Results and Discussion

3.1 Nutrient Content and Uptake

3.1.1 Effect of Nutrient Enriched Compost (NEC)

The application of increasing levels of NEC significantly increased nutrient content and uptake by maize seed and stover over the control (Table 1 and Table 2). The highest numerical values of N, P, K and Zn content in seed and stover (1.590 and 0.705%, 0.439 and 0.272%, 0.490 and 1.382%, and 27.45 and 20.37 mg kg-1, respectively) and uptake (68.27 and 48.84 kg ha-1, 18.69 and 18.58 kg ha-1, 21.17 and 95.96 kg ha-1, and 118.64 and 141.23 g ha-1, respectively) were obtained with the application of NEC @ 6 t ha-1, whereas the minimum values were recorded under the control (NEC0). However, the values recorded under NEC3 @ 6 t ha-1 were statistically at par with NEC2 (4 t ha-1). The increased content and uptake of N, P, K and Zn with nutrient-enriched compost might be due to increased nutrient availability in the root zone, coupled with enhanced metabolic activity at the cellular level, which may have promoted nutrient accumulation in different plant parts (Biswas, 2011). The addition of nutrient-enriched compost led to a significant increase in soil microbial population and soil enzymatic properties (Doodhawal et al., 2021a). This indicates enhanced soil metabolic activity and provides important information on nutrient cycling in soil (Dsouza et al., 2018). When NEC is added to soil, complex N compounds slowly decompose and sustain a steady nutrient supply throughout crop growth. A similar pattern was also observed for P and K uptake, which might be attributed to greater solubilisation of native P and K from soil through the action of organic acids released during the decomposition of organic materials (Chavan et al., 1997). Humic acid released from decomposing organic manure can influence nutrient uptake by affecting the synthesis and activity of membrane proteins, particularly proton pumps that increase the electrochemical proton gradient across the plasma membrane (PM) (Morsomme and Boutry, 2000). By stimulating plasma membrane H+-ATPase activity, Zandonadi et al. (2010) showed that humic compounds derived from organic compost could promote lateral root growth in maize plants. Therefore, a healthier root system stimulates shoot growth and increases nutrient absorption and uptake. NEC application may have improved the availability of native micronutrient cations, which may have contributed to the increase in Zn content by converting solid-phase forms into soluble metal complexes. The findings of the current investigation are close to those of Sharma et al. (2020) and Doodhawal et al. (2021b). Similar responses to organic amendments in nutrient uptake have also been reported in another field crop (Verma et al., 2014).

3.1.2 Effect of Zinc Application

The maximum nutrient content in seed and stover (N 1.586 and 0.709%, K 0.499 and 1.383%, and Zn 28.16 and 20.99 mg kg-1, respectively) and uptake (N 67.11 and 48.88 kg ha-1, K 21.25 and 95.59 kg ha-1, and Zn 120.78 and 145.01 g ha-1, respectively) were recorded under the treatment receiving 20 kg ZnSO4 ha-1 + foliar spray of 0.5% Zn (Zn3) over the control (Table 1 and Table 2). However, the differences between Zn2 and Zn3 treatments for N and K content and uptake in seed and stover were statistically at par. Zinc application appeared to have a synergistic effect on N, K and Zn content. The higher nitrogen content in grain and stover could be due to the role of zinc in the synthesis of DNA and RNA and in metabolic processes that result in the formation of lipids, carbohydrates and proteins. Zinc also significantly influences chlorophyll synthesis, which ultimately leads to greater biomass yield and nitrogen uptake (Hussain et al., 2020). Potassium and zinc work synergistically; applied zinc aids enzyme synthesis, translocation and plant metabolic processes, which might ultimately facilitate potassium uptake (Shivay et al., 2015). Improved Zn content in maize could be attributed to its increased absorption due to greater availability in the rhizosphere and enhanced translocation resulting from increased plant metabolic activity under Zn fertilisation. This may be because soil application of Zn in a highly deficient soil increased its availability (Verma et al., 2023). Higher uptake of Zn resulted from higher Zn concentration and greater dry matter production. The results obtained in the present investigation are in close conformity with those of Mali et al. (2017) and Jat et al. (2018).

The maximum P content in seed (0.441%) and stover (0.277%) was found under the control, whereas the highest uptake by seed (16.78 kg ha-1) and stover (16.88 kg ha-1) was recorded with the application of 15 kg ZnSO4 ha-1 + foliar spray of 0.5% Zn (Zn2) (Table 1 and Table 2). Phosphorus content in maize seed and stover decreased with increasing zinc level. This might be due to the antagonistic effect of zinc on phosphorus absorption, which could be attributed to impeded P translocation caused by increased Zn availability that interfered with the absorption and/or translocation of phosphorus absorbed by roots (Dewal and Pareek, 2004).

Table 1. Effect of nutrient enriched compost and zinc application on nitrogen, phosphorus, potassium and zinc content in seed and stover of maize

Treatments	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Zinc (mg kg^{-1})	
	Seed	Stover	Seed	Stover	Seed	Stover	Seed	Stover
Nutrient enriched compost levels (t ha^{-1})								
Control (NEC$_0$)	1.406	0.619	0.371	0.238	0.430	1.199	23.41	17.92
2(NEC$_1$)	1.513	0.666	0.404	0.250	0.461	1.256	24.74	19.11
4(NEC$_2$)	1.573	0.703	0.429	0.270	0.488	1.372	26.91	20.34
6 (NEC$_3$)	1.590	0.705	0.439	0.272	0.490	1.382	27.45	20.37
S.Em±	0.010	0.006	0.004	0.003	0.004	0.006	0.273	0.174
CD (P=0.05)	0.030	0.017	0.010	0.009	0.012	0.019	0.789	0.503
Zinc application (kg ha^{-1})								
Control (Zn$_0$)	1.410	0.615	0.441	0.277	0.426	1.196	23.25	17.80
10 kg $ZnSO_4$ + foliar spray of Zn 0.5% ha^{-1} (Zn$_1$)	1.515	0.667	0.430	0.265	0.463	1.260	24.60	18.76
15 kg $ZnSO_4$ + foliar spray of Zn 0.5% ha^{-1} (Zn$_2$)	1.572	0.702	0.406	0.250	0.482	1.370	26.50	20.19
20 kg $ZnSO_4$ + foliar spray of Zn 0.5% ha^{-1} (Zn$_3$)	1.586	0.709	0.365	0.238	0.499	1.383	28.16	20.99
S.Em±	0.010	0.006	0.004	0.003	0.004	0.006	0.273	0.174
CD (P=0.05)	0.030	0.017	0.010	0.009	0.012	0.019	0.789	0.503

Table 2. Effect of nutrient enriched compost and zinc application on nitrogen, phosphorus, potassium and zinc uptake by seed and stover of maize

Treatments	Nitrogen (kg ha^{-1})		Phosphorus (kg ha^{-1})		Potassium (kg ha^{-1})		Zinc (g ha^{-1})	
	Seed	Stover	Seed	Stover	Seed	Stover	Seed	Stover
Nutrient Enriched compost levels (t ha^{-1})								
Control (NEC$_0$)	45.56	32.35	11.51	11.98	13.86	64.12	75.30	93.51
2(NEC$_1$)	54.72	38.64	14.54	14.50	16.63	72.14	89.71	111.48
4(NEC$_2$)	64.87	47.08	17.65	17.96	20.22	91.77	112.09	136.36
6 (NEC$_3$)	68.27	48.84	18.69	18.58	21.17	95.96	118.64	141.23
S.Em±	1.21	0.75	0.34	0.33	0.41	1.54	1.99	2.19
CD (P=0.05)	3.51	2.17	0.99	0.96	1.18	4.46	5.75	6.33
Zinc application (kg ha^{-1})								
Contro l(Zn$_0$)	46.06	31.85	14.31	14.23	13.82	62.61	76.17	92.72
10 kg $ZnSO_4$ + foliar spray of Zn 0.5% ha^{-1} (Zn$_1$)	55.92	38.93	15.74	15.77	16.99	73.72	90.01	109.03
15 kg $ZnSO_4$ + foliar spray of Zn 0.5% ha^{-1} (Zn$_2$)	64.33	47.25	16.78	16.88	19.80	92.07	108.77	135.82
20 kg $ZnSO_4$ + foliar spray of Zn 0.5% ha^{-1} (Zn$_3$)	67.11	48.88	15.55	16.13	21.25	95.59	120.78	145.01
S.Em±	1.21	0.75	0.34	0.33	0.41	1.54	1.99	2.19
CD (P=0.05)	3.51	2.17	0.99	0.96	1.18	4.46	5.75	6.33

However, the increase in P uptake by maize seed and stover may be due to higher seed and stover yields, which partially balanced the decline in P content. The results are supported by the findings of Jat et al. (2021), Todawat et al. (2017), and Ranpariya and Polara (2018).

3.2 Protein Content

3.2.1 Effect of Nutrient Enriched Compost (NEC)

Increasing levels of nutrient-enriched compost significantly increased the protein content of maize seed over the control (Table 3). The maximum protein content of seed (9.93%) was observed with the application of nutrient-enriched compost @ 6 t ha-1 (NEC3), whereas the minimum (8.79%) was recorded under the control (NEC0). However, the difference between NEC2 and NEC3 treatments was statistically at par. The increase in protein content was 7.62, 11.83 and 12.96% with the application of nutrient-enriched compost @ 2, 4 and 6 t ha-1 over the control, respectively. Nitrogen is a basic constituent of protein, and increased N availability through nutrient-enriched compost application resulted in enhanced protein content in maize seed (Yadav et al., 2019). Similar results were also reported by Abhishek et al. (2022).

Table 3. Effect of nutrient enriched compost and zinc application on protein content, net return and BC ratio of maize

Treatments	Protein content (%)	Net return(₹ ha^{-1})	B :C
Nutrient enriched compost levels (t ha^{-1})			
Control (NEC_0)	8.79	53027	2.29
2(NEC_1)	9.46	60648	2.67
4(NEC_2)	9.83	70980	2.88
6 (NEC_3)	9.93	72585	2.72
S.Em±	0.07	1269	0.05
CD (P=0.05)	0.19	3665	0.14
Zinc application (kg ha^{-1})			
Control (Zn_0)	8.81	51469	2.20
10 kg $ZnSO_4$ + foliar spray of Zn 0.5% ha^{-1} (Zn_1)	9.47	60330	2.56
15 kg $ZnSO_4$ + foliar spray of Zn 0.5% ha^{-1} (Zn_2)	9.82	71182	2.85
20 kg $ZnSO_4$ + foliar spray of Zn 0.5% ha^{-1} (Zn_3)	9.91	74259	2.95
S.Em±	0.07	1269	0.05
CD (P=0.05)	0.19	3665	0.14

3.2.2 Effect of Zinc Application

The data presented in Table 3 indicate that zinc application significantly increased seed protein content compared with the control (Zn0). The maximum seed protein content (9.91%) was observed with the application of 20 kg ZnSO4 ha-1 + foliar spray of 0.5% Zn (Zn3), whereas the minimum (8.81%) was recorded under the control (Zn0). However, the difference between Zn2 and Zn3 treatments was statistically at par. The increase in protein content was 7.49, 11.46 and 12.49% with the application of Zn1, Zn2 and Zn3 over the control, respectively. This may be because of increased nitrogen content in seed, which could be due to the increased availability of nitrogen to plants under zinc application. Another possible reason for higher nitrogen content may be increased nitrate reductase enzyme activity due to zinc application (Alloway, 2004). This result was supported by Meena et al. (2021).

3.3 Profitability

3.3.1 Effect of Nutrient Enriched Compost (NEC)

Increasing levels of NEC application significantly increased the net return and BC ratio of maize over the control (Table 3). The highest net return (₹ 72585 ha-1) was recorded with the application of NEC @ 6 t ha-1 (NEC3), whereas the highest BC ratio (2.88) was found under NEC @ 4 t ha-1 (NEC2). However, the differences between NEC2 and NEC3 treatments were statistically at par for net return and BC ratio. The net return and BC ratio increased significantly as a consequence of increased seed and stover yield (Abhishek et al., 2022).

3.3.2 Effect of Zinc Application

Zinc application significantly increased net returns compared with the control (Zn0). The maximum net return (₹ 74259 ha-1) and BC ratio (2.95) were obtained with the application of 20 kg ZnSO4 ha-1 + foliar spray of 0.5% Zn (Zn3), whereas the minimum values were recorded under the control (Zn0) (Table 3). However, the increase was significant up to Zn2, which was statistically at par with Zn3. The increase in net return and BC ratio might be due to increased seed and stover yield, which ultimately resulted in higher net return and B:C ratio. The increase in net return and BC ratio due to zinc application was also reported by Meena et al. (2021).

4. Conclusion

The present investigation showed that nutrient-enriched compost and zinc application improved maize seed quality, nutrient uptake and profitability under the tested conditions of South-West Rajasthan. Protein content and uptake of nitrogen, phosphorus, potassium and zinc by seed and stover increased with rising levels of nutrient-enriched compost and zinc application. The highest numerical values were generally recorded with 6.0 t NEC ha-1 and 20 kg ZnSO4 ha-1 with 0.5% ZnSO4 foliar spray; however, these treatments were statistically at par with 4.0 t NEC ha-1 and 15 kg ZnSO4 ha-1 with 0.5% ZnSO4 foliar spray for several key parameters. Economic analysis also indicated favourable net returns and benefit-cost ratio with these treatments. Therefore, the application of 4.0 t nutrient-enriched compost ha-1 along with 15 kg ZnSO4 ha-1 and a 0.5% ZnSO4 foliar spray may be considered an agronomically efficient and economically viable option for improving maize quality, nutrient uptake and profitability in the sub-humid Southern Plain and Aravalli Hill region of Rajasthan.

5. Limitation

The experiment was conducted during a single kharif season at one location in Udaipur, Rajasthan; therefore, the results may vary under different soil types, rainfall conditions, maize cultivars and management practices. The study focused on nutrient-enriched compost and zinc application, while long-term effects on soil fertility, nutrient balance and residual benefits were not assessed. The findings are based on the tested treatment combinations and local input-output prices. Multi-season and multi-location trials are required before wider recommendation across maize-growing regions.

Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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