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MICRONUTRIENT MANAGEMENT FOR HIGHER PRODUCTIVITY AND PROFITABILITY OF GROUNDNUT (*ARACHIS HYPOGAEA L.*): A REVIEW

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ABSTRACT:
Groundnut (Arachis hypogaea L.) is an important oilseed and food legume, but its productivity remains low where fertiliser use is unbalanced and soils are deficient in micronutrients, most commonly zinc, boron and iron. This review draws together published field studies and reviews on the physiological roles of zinc, boron, iron, manganese, copper and molybdenum in groundnut, their deficiency symptoms and critical limits, and the relative merits of soil, seed and foliar application, including their economic returns. In a calcareous soil, leaving out any one micronutrient from a complete fertiliser package lowered pod yield by 8.4–26.0%, with the greatest loss from boron omission. On acidic soils of Odisha, soil-applied zinc, boron and molybdenum increased pod yield by 31% over NPK alone, while on a calcareous soil a combined soil dose of iron, zinc and boron with recommended fertiliser and farmyard manure gave 3654 kg ha−1. A 0.5% boron spray with the full fertiliser dose produced 2618 kg ha−1 and the highest benefit–cost ratio (3.55), and a multi-micronutrient mixture was most effective when sprayed twice, at the vegetative stage and at flowering. Because the range between deficiency and toxicity is narrow, particularly for boron and molybdenum, application should be guided by soil and plant testing. Integrating micronutrients with secondary nutrients, organic manures and biofertilisers offers a profitable and resource-efficient means of narrowing the groundnut yield gap.

KEYWORDS: Boron, Foliar nutrition, Groundnut, Micronutrients, Profitability, Zinc

1.INTRODUCTION

Groundnut (Arachis hypogaea L.) is a leading oilseed legume of tropical and subtropical regions, valued for its edible oil, protein-rich kernels and fodder, and for the biological nitrogen fixation through which it enriches soil fertility (Datta et al., 2014; Suresh et al., 2026). India is among the major groundnut-producing countries of the world (Singh, 2004; Potdar et al., 2025); nevertheless, the national average yield in 2021–22 was only 1863 kg ha−1, well below the attainable potential (Potdar et al., 2025), and domestic oilseed output continues to lag behind demand (Jegadeeswari et al., 2025).

Unbalanced nutrition is one of the main causes of this yield gap. Groundnut removes large quantities of nutrients from the soil, yet it is grown largely under rainfed conditions on impoverished soils that receive little fertiliser,

and nutritional disorders can reduce yield by 30–70% depending on soil type (Singh, 2004; Veeramani and Subrahmaniyan, 2011). Intensive cropping, reliance on straight fertilisers and nutrient mining by high-yielding cultivars have depleted soil reserves of secondary nutrients and micronutrients, which are now regarded as a major limitation to productivity (Meena et al., 2007; Rajitha et al., 2018). Deficiencies of zinc, boron and iron are the most widespread in Indian soils, particularly under alkaline conditions, and micronutrient deficiency alone may reduce pod yield by up to 60% (Jegadeeswari et al., 2025).

Although needed in small amounts, micronutrients regulate enzyme activity, photosynthesis, pollination and pod filling, and in legumes they also control nodulation and symbiotic nitrogen fixation (Singh, 2004; Suresh et al., 2026). Correcting deficiencies through the soil is often inefficient, with recovery reported to be below 3%, and the crop responds poorly once visible symptoms have developed (Jegadeeswari et al., 2025). These limitations have encouraged the use of foliar feeding, pre-mixed multi-nutrient formulations and integrated nutrient management.

This review examines the published evidence on micronutrient management in groundnut. It outlines the functions and deficiency symptoms of the key micronutrients, compares soil, seed and foliar methods of supply, evaluates their effects on yield, nutrient uptake, kernel quality and profitability, and identifies priorities for future research. The review is based on field experiments, surveys and review articles on groundnut nutrition published in India, with quantitative results compiled in tables and figures.

2. ROLES OF MICRONUTRIENTS AND CONSEQUENCES OF DEFICIENCY

Micronutrients act mainly as enzyme constituents and regulators. Zinc controls the activity of enzymes such as carbonic anhydrase; iron is required for chlorophyll formation and nitrate reduction; manganese takes part in photosynthesis; and copper is involved in protein synthesis and nitrogen fixation (Singh, 2004). Boron is essential for pollen germination, sugar translocation and calcium utilisation, while molybdenum forms part of the nitrogenase and nitrate reductase enzymes and is therefore indispensable for symbiotic nitrogen fixation (Suresh et al., 2026). A crop producing 2.0–2.5 t ha−1 of pods takes up about 3–4 kg of iron, 300–400 g of manganese, 150–200 g of zinc, 140–180 g of boron, 30–40 g of copper and 8–10 g of molybdenum per hectare (Singh, 2004). The characteristic deficiency symptoms, critical concentrations and recommended corrective measures are summarised in Table 1.

Table 1: Deficiency symptoms, critical levels and corrective measures for micronutrients in groundnut

Micronutrient	Deficiency symptoms and critical level	Corrective measure
Zinc (Zn)	Mottled, ivory-yellow chlorosis of upper leaves; leaf Zn < 20 ppm	ZnSO4 at 2–4 kg ha−1 to soil, or 0.2% foliar spray
Boron (B)	Death of stem apex; hollow heart in kernels; soil B < 0.2 ppm	Borax (0.5–1.0 kg B ha−1) to soil, or 0.05–0.1% boric acid spray
Iron (Fe)	Chlorosis of young leaves that become papery white; leaf Fe < 30 ppm	0.5% FeSO4 + 0.02% citric acid, three sprays at 30, 50 and 70 DAS
Manganese (Mn)	Interveinal chlorosis with dark green veins; leaf Mn < 20 ppm	1–4 kg Mn ha−1 to soil, or 0.2% MnSO4 spray
Copper (Cu)	Curling and cupping of young leaves; leaf Cu < 5 ppm	CuSO4 at 2–6 kg ha−1 once in 3–4 years, or 0.1% spray
Molybdenum (Mo)	Yellowing resembling N deficiency; poor nodulation; leaf Mo < 0.2 ppm	Molybdate at 0.5–1.0 kg ha−1 (soil or seed), or 0.01% spray

DAS, days after sowing. Source: Singh (2004).

Micronutrient deficiencies are widespread in Indian groundnut soils. Surveys have recorded zinc deficiency in up to 83% of soil samples in Karnataka, iron deficiency in 33–39% of samples in Haryana and Karnataka, boron deficiency in 47% in Bihar, copper deficiency in 38% in Tamil Nadu and molybdenum deficiency in 18% in Madhya Pradesh (Singh, 1999). In calcareous and alkaline soils, high bicarbonate concentrations restrict iron uptake and induce chlorosis (Meena et al., 2007), whereas molybdenum deficiency occurs mainly in acid soils (Singh, 2004). The importance of a balanced supply is evident from omission trials on a calcareous soil, in which leaving out any one micronutrient from a complete fertiliser package reduced pod yield by 8.4–26.0% over three seasons; the largest reduction followed the omission of boron (Fig. 1; Singh, 2004).

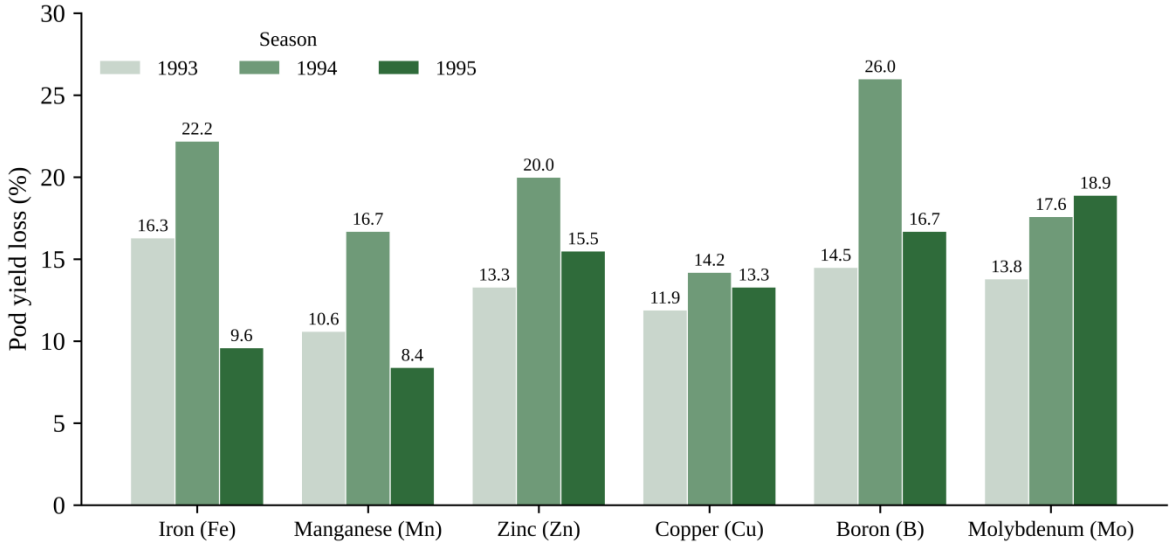


Fig. 1. Reduction in pod yield of groundnut when one micronutrient was omitted from a complete macro- and micronutrient package on a calcareous soil over three seasons. Source: Singh (2004).

3. METHODS OF MICRONUTRIENT APPLICATION

3.1 Soil and seed application

In farmers' fields on acidic soils of Odisha receiving 20:40:40 kg N:P2O5:K2O ha−1, the joint soil application of zinc (5 kg ha−1), boron (1 kg ha−1) and molybdenum (0.5 kg ha−1) increased mean pod yield from 1.17 to 1.53 t ha−1 (31%), whereas zinc alone raised yield by only 11% (Fig. 2). The combination of zinc and boron with sulphur (40 kg ha−1) recorded the highest shelling percentage (72%) and kernel oil content (38.4%) (Nayak et al., 2009). Seed treatment with zinc oxide, borax and sodium molybdate increased yield by 13.8%, less than half the gain from soil application of the same three nutrients (30.8%).

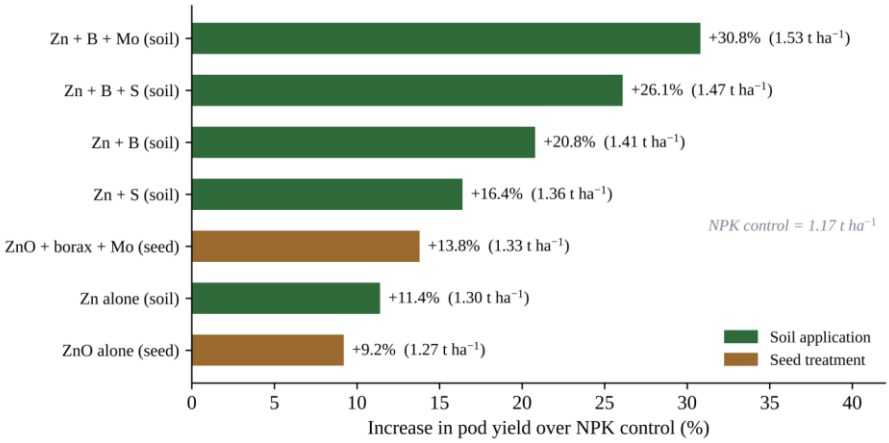


Fig. 2. Increase in pod yield over the NPK control (1.17 t ha−1) with soil or seed application of zinc, boron, sulphur and molybdenum on acidic soils of Odisha. Soil doses (kg ha−1): Zn 5, B 1, S 40, Mo 0.5; seed treatment: ZnO 0.3%, borax 0.5%, sodium molybdate 0.05%. Source: Nayak et al. (2009).

On a calcareous soil, the addition of 20 kg FeSO4, 15 kg ZnSO4 and 5 kg borax ha−1 to the recommended fertiliser dose and farmyard manure produced the highest dry pod yield (3654 kg ha−1), compared with 2307 kg ha−1 in the absolute control. Individual micronutrients gave 3203–3259 kg ha−1, indicating a synergistic effect when the three were applied together (Potdar et al., 2025). Application rates must, however, be kept within a narrow safe range: boron at more than 3 kg ha−1 caused a sharp fall in pod yield (Meena et al., 2007), and soil concentrations above 5 ppm boron or 1 ppm molybdenum are toxic to the crop (Singh, 2004).

3.2 Foliar application and timing of sprays

Foliar application avoids the fixation and leaching losses that reduce the efficiency of soil-applied micronutrients (Rajitha et al., 2018). On a loamy soil, a 0.5% boron spray combined with the full nitrogen dose produced the largest number of nodules (88 plant−1) and the highest pod yield (2618 kg ha−1), compared with 2306 kg ha−1 from soil-applied boron and 1921 kg ha−1 in the control; a 0.3% molybdenum spray was the next best treatment

(2472 kg ha−1). Even with nitrogen reduced by 25%, the boron spray (2229 kg ha−1) out-yielded the control that received the full nitrogen dose (Suresh et al., 2026). On a calcareous soil, 0.5% sprays of iron, zinc and boron salts applied at peg and pod development were statistically on par with soil application (Fig. 3; Potdar et al., 2025). In iron-chlorotic conditions, foliar ferrous sulphate with citric acid increased pod yield by 29% and reduced the incidence of chlorosis from 38% to 7% (Singh, 1999).

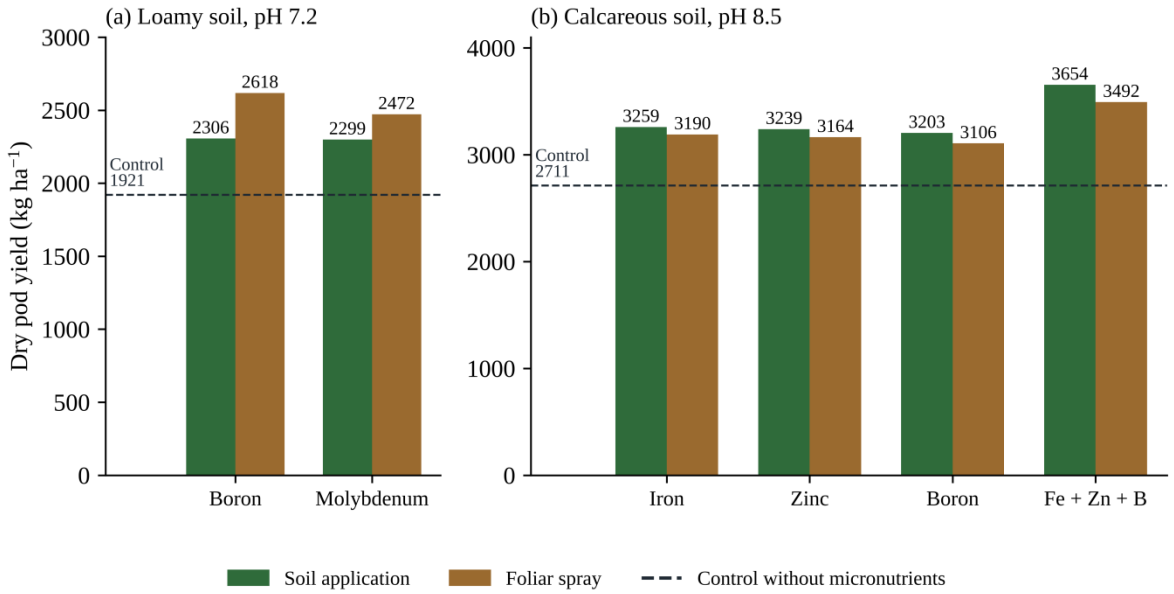


Fig. 3. Pod yield of groundnut with soil and foliar application of micronutrients on (a) a loamy soil with 100% N (soil: 5 kg ha−1 B or Mo; foliar: 0.5% B or 0.3% Mo) and (b) a calcareous soil with recommended fertiliser and farmyard manure (soil: 20 kg FeSO4, 15 kg ZnSO4 and 5 kg borax ha−1; foliar: 0.5% of each at peg and pod formation). Sources: Suresh et al. (2026); Potdar et al. (2025).

The number and timing of sprays also determine the response. Among four grades of the Tamil Nadu Agricultural University groundnut micronutrient mixture containing Zn, Fe, Mn, Cu and B, Grade IV was the most effective. Two sprays, one at the vegetative stage and one at flowering, increased pod yield by 12–13% and kernel yield by 37–43% over the water spray, whereas a third spray at pod formation gave lower yields than two sprays (Fig. 4; Jegadeeswari et al., 2025). In another study, a 0.2% mixture of B, Cu, Fe, Mn, Mo and Zn together with 1% each of calcium nitrate, magnesium nitrate and sulphur, sprayed at 22 days after sowing, increased pod yield by 77% over the recommended fertiliser alone (Rajitha et al., 2018).

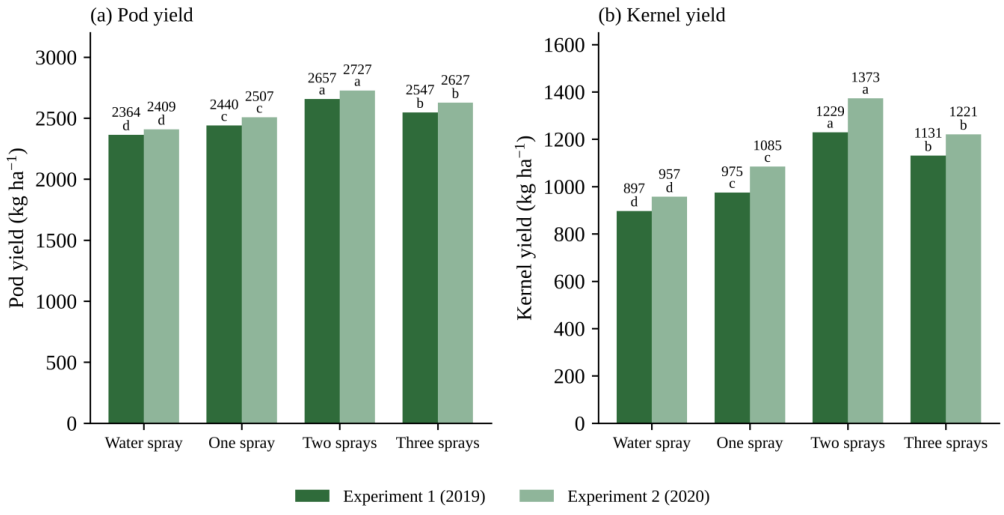


Fig. 4. Effect of the number of foliar sprays of a multi-micronutrient mixture (Zn, Fe, Mn, Cu, B) on (a) pod yield and (b) kernel yield of groundnut in two experiments. One spray at the vegetative stage; two sprays at the vegetative and flowering stages; three sprays additionally at pod formation. Values are means of four mixture grades; bars with the same letter do not differ significantly ($p \leq 0.05$). Source: Jegadeeswari et al. (2025).

4. NUTRIENT UPTAKE, KERNEL QUALITY AND ECONOMICS

Micronutrient application also improves the uptake of major nutrients. Soil application of Fe, Zn and B raised the uptake of nitrogen, phosphorus and potassium to 189, 29 and 97 kg ha−1, against 96, 14 and 53 kg ha−1 in the control, and produced kernels with the highest oil (48.9%) and protein (27.7%) contents; combined foliar sprays were statistically comparable (Potdar et al., 2025). Foliar application of secondary nutrients and micronutrients similarly maximised nutrient uptake (Rajitha et al., 2018), although improvements in kernel quality from boron or molybdenum sprays were not significant (Suresh et al., 2026).

Economic returns closely followed yield. The 0.5% boron spray with the full fertiliser dose gave a net return of ₹185,275 ha−1 and a benefit–cost ratio of 3.55, compared with ₹121,254 ha−1 and 2.76 in the control, at an additional cost of only ₹3,650 ha−1 (Suresh et al., 2026). Integrated nutrient management further strengthens these gains: combinations of NPK with farmyard manure, Rhizobium, gypsum and micronutrient mixtures have generally outperformed NPK alone (Veeramani and Subrahmaniyan, 2011). In Tripura, Rhizobium inoculation with 50 kg ha−1 each of P2O5 and K2O produced 1.96 t ha−1 of pods and the highest net return (Datta et al., 2014). The principal yield, quality and economic responses reported in the reviewed studies are compared in Table 2.

Table 2: Yield, quality and economic responses of groundnut to micronutrient management in selected studies

Soil / location	Treatment	Pod yield (treated vs control)	Increase	Other responses	Source
Acidic soils, Odisha (farmers' fields)	Zn 5 + B 1 + Mo 0.5 kg ha−1 to soil, with NPK 20:40:40	1.53 vs 1.17 t ha−1	31%	Zn + B + S gave highest shelling (72%) and oil (38.4%)	Nayak et al. (2009)
Calcareous soil, pH 8.5	FeSO4 20 + ZnSO4 15 + borax 5 kg ha−1 with RDF + FYM	3654 vs 2307 kg ha−1 (absolute control)	58%	N, P, K uptake 189, 29, 97 vs 96, 14, 53 kg ha−1; oil 48.9%, protein 27.7%	Potdar et al. (2025)
Loamy soil, pH 7.2	0.5% boron spray + 100% N	2618 vs 1921 kg ha−1	36%	88 nodules plant−1; net return ₹185,275 ha−1; B:C ratio 3.55 vs 2.76	Suresh et al. (2026)
Loamy soil, pH 7.2	0.5% boron spray + 75% N	2229 vs 1921 kg ha−1	16%	Exceeded control receiving 100% N	Suresh et al. (2026)
Two experiments (2019, 2020)	TNAU micronutrient mixture (Grade IV), two sprays	2657–2727 vs 2364–2409 kg ha−1	12–13%	Kernel yield +37–43%; third spray reduced yield	Jegadeeswari et al. (2025)
Not specified	0.2% B, Cu, Fe, Mn, Mo, Zn + 1% Ca(NO3)2, Mg(NO3)2 and S at 22 DAS	–	77%	Highest N, P and K uptake	Rajitha et al. (2018)
Iron-chlorosis-affected fields	Foliar FeSO4 + citric acid	–	29%	Chlorosis reduced from 38% to 7%	Singh (1999)
Tripura, subtropical humid	Rhizobium + 50 kg ha−1 each P2O5 and K2O	1.96 t ha−1	–	Highest net return	Datta et al. (2014)

Increase over the respective control, calculated from the reported yields where not stated by the authors. DAS, days after sowing; FYM, farmyard manure; RDF, recommended dose of fertiliser; TNAU, Tamil Nadu Agricultural University.

5. FUTURE PROSPECTS

Future research should progress from single-nutrient trials towards integrated, site-specific nutrient management. Combinations of soil and foliar application need to be evaluated so that soil deficiencies are corrected while the crop's peak demand is met through sprays (Jegadeeswari et al., 2025). Wider adoption could be promoted through pre-mixed multi-micronutrient formulations, customised fertiliser blends, digital advisory services and region-specific economic analyses (Jegadeeswari et al., 2025; Suresh et al., 2026). Critical limits in soil and plant tissue

should be re-examined for modern high-yielding cultivars, supported by systematic soil and plant analysis, standardised rates, timings and sources, and the screening of nutrient-efficient and iron-chlorosis-tolerant genotypes (Singh, 2004). Other priorities include defining safe application limits for boron and molybdenum, understanding how nutrition influences kernel quality and aflatoxin contamination, and assessing the energy budget of different nutrient packages (Datta et al., 2014; Singh, 2004).

6. CONCLUSION

Micronutrient management is an important but under-exploited means of closing the groundnut yield gap. Zinc, boron, iron, molybdenum, manganese and copper govern flowering, pod development, nodulation and nitrogen metabolism, and the omission of any one of them can reduce pod yield by 8–26%. Soil application of zinc, boron and molybdenum on acidic soils, and of iron, zinc and boron on calcareous soils, increased yields substantially, and foliar application was equally or more effective. A 0.5% boron spray with the full fertiliser dose gave the highest pod yield (2618 kg ha−1) and benefit–cost ratio (3.55), and a multi-micronutrient mixture performed best when sprayed twice, at the vegetative and flowering stages. Since the margin between deficiency and toxicity is narrow, application rates must be chosen carefully. Soil testing, split foliar application and integration with organic manures, biofertilisers and secondary nutrients, backed by site-specific research on soils, cultivars and application methods, should form the basis of profitable and resource-efficient groundnut production.

ACKNOWLEDGEMENT

The authors sincerely acknowledge the support extended by Odisha University of Agriculture and Technology (OUAT), Bhubaneswar, through the provision of essential institutional facilities and an encouraging academic environment. The authors are also deeply appreciative of the university's continued assistance, which contributed significantly to the successful development and completion of this review article.

AUTHOR'S CONTRIBUTIONS

Ashish Toppo: Conceptualization, literature acquisition, and initial manuscript preparation. Suchismita Tripathy: Literature synthesis, scientific compilation, manuscript review, and editorial refinement. Akshaya Kumar Sethy: Critical evaluation of published literature and manuscript editing. Asim Chandra Dash: Scientific guidance, conceptual inputs, and manuscript revision. Anita Mahapatra: Literature assessment and scientific contributions. Jyoti Rekha Patnaik: Supervision, conceptual guidance, critical manuscript revision, and final approval. Sarika Jena: Literature assessment and manuscript refinement. S. K. Sahoo: Scientific inputs, critical assessment, and editorial revision. Dharani Dhar Pradhan: Literature compilation, scientific synthesis, and manuscript drafting. Anisha Dalai: Manuscript evaluation and critical revision. Krishna Kumar: Literature identification, compilation, and manuscript improvement. Pradyumn Mahato: Scientific literature collection and manuscript review. Nikhil Munda: Information synthesis and manuscript revision. Sangeeta Beck: Critical assessment and editorial refinement.

All authors contributed to the preparation and scholarly evaluation of the review article and approved the final manuscript for submission.

COMPLIANCE WITH ETHICAL STANDARDS

The research was carried out in compliance with relevant institutional requirements and ethical standards. The study involved field-based experiments on Groundnut, with all experimental activities conducted in accordance with established agronomic protocols and applicable institutional guidelines.

CONFLICT OF INTEREST

The authors declare that no financial, professional, or personal relationships exist that could be perceived as influencing the research reported in this manuscript. The datasets generated and/or analysed during the study are available from the corresponding author upon reasonable request. During the preparation of the manuscript, generative artificial intelligence (AI) applications, specifically ChatGPT (OpenAI) and Claude AI (Anthropic), were employed solely to assist with manuscript preparation and data analysis. All AI-generated or AI-assisted outputs were critically examined, verified, and appropriately revised by the authors. The authors take full responsibility for the accuracy, originality, scientific validity, and integrity of the final manuscript.

ETHICAL ISSUES

Field staff were engaged in carrying out routine agronomic activities, such as crop establishment, irrigation, herbicide application, weed control, and experimental data recording. Nevertheless, the research did not involve the recruitment of human subjects, nor did it entail the collection of any personal, medical, or biological data from individuals.

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