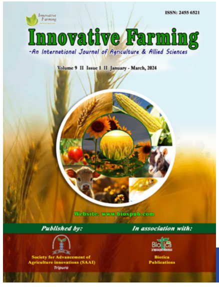

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Review Article

Impact of Foliar Nutrition of Iron and Zinc on Groundnut

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Abstract

Groundnut (*Arachis hypogaea* L.) functions as a crucial food grain legume and an oilseed crop due to its higher oil production while serving the edible oil industry. The cultivation techniques and mineral nutrition affect the productivity of groundnuts, despite their rain-dependent nature. Zinc (Zn) and iron (Fe) deficiencies still remain as primary constraints that restrict yield potential while diminishing nutritional quality. Lack of these micronutrients in the soil slows down plant growth and development. This can lead to Zn and Fe deficiencies in humans, which need effective nutrient management. The technique of applying fertilizers directly onto leaves functions as an effective solution that enables plants to absorb nutrients more effectively since it bypasses soil-related challenges, such as nutrient fixation and leaching, which leads to enhanced enzyme activation and chlorophyll production and metabolic processes. Research on crop nutrition shows extensive development, yet few studies present specific findings on applying Zn and Fe through foliage applications in groundnuts. Recent advancements in foliar application techniques have demonstrated significant improvements in pod yield, kernel quality and micronutrient density, offering a promising approach to addressing both agricultural and nutritional challenges. This review consolidates existing research on the role of foliar-applied Zn and Fe in groundnut cultivation, emphasizing its agronomic benefits, physiological impacts and potential contributions to sustainable agriculture and human nutrition.

Keywords: Foliar nutrition, Groundnut, Iron, Micronutrient, Sustainable agriculture, Zinc

Introduction

Groundnut (*Arachis hypogaea* L.) is a self-pollinating and vital edible oilseed crop globally, being originated from South America. It is a significant vegetable oil crop worldwide, ranking 13th among the primary economic crops in the world (Singh *et al.*, 2004). It is essential for sustainable agriculture due to its nitrogen-fixing capability. This crop is highly exhausting compared to other leguminous crops, as minimal residue remains in the soil post-harvest. In India, the groundnut is cultivated within an area of 4.73 million ha, which accounts for 6.72 million tonnes of production with a productivity of 1,422 kg ha^{-1} (India Stat, 2021). In Telangana, it occupies an area of 0.126 million ha, which accounts for 0.313 million tonnes of production with the productivity of 2,491 kg ha^{-1}.

Groundnut is an erratic, high-consumption legume planted globally across nearly all soil types. Groundnuts, which are nutritionally dense, consist of approximately 50% oil, 25-30% protein, 20% carbohydrates and 5% fibre and ash content. Its cultivation serves as an essential cash crop, benefiting millions of small-scale farmers globally due to its considerable economic and nutritional significance. Groundnut oil is particularly valued for its high content of monounsaturated oleic acid (omega-9), which enhances thermal stability and making it ideal for deep frying, while its polyunsaturated linoleic acid contributes to cardiovascular health. Additionally, groundnuts are an excellent source of high-quality protein (26%), higher than meat and containing 2.5 times more protein than eggs. They are also abundant in essential minerals including calcium, phosphorus, iron,

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zinc and boron, along with vital vitamins, including vitamin A, B-complex and vitamin E. These attributes underscore groundnut's significance as a highly nutritious and economically valuable crop.

The modern production systems have an adverse effect on the nutrient balance and soil fertility (Karthik *et al.*, 2021). The recommended application of NPK fertilizer does not lead to the expected yield output. A significant limitation for low groundnut production is the shortage of micronutrients. The intensification of agriculture, application of synthetic fertilisers and escalating crop demands due to enhanced productivity have amplified the demand for micronutrients in soil fertility management, hence posing significant limits to agricultural production.

Zinc may occasionally exist in the soil yet remain inaccessible to plants. A high soil pH, or calcareous soil, indicates less zinc availability. Crops in certain soil conditions may experience zinc insufficiency. Zinc is a crucial element in numerous dehydrogenases, proteinases and peptidases. All these enzymes show sensitivity to Zn deficiency. So that metabolism can be strongly and specifically affected. Following N and P, Zn is presently classified as the 3rd most restrictive dietary factor in agricultural yield. It participates in auxin synthesis, carbohydrate transformation and sugar control in plants. Zinc deficiency in plants occurs because of the presence of calcareous and light-textured soils and low soil organic matter along with higher soil phosphorus, low soil temperature and deficient zinc content in soils. Applying a foliar spray containing Zn (0.2%) marginally enhanced the yield and quality of peanuts (Ali and Mowafy, 2003). Foliar application of zinc on the leaves of plants during flowering or seed-filling stages improves their yield attributes and pod yield (El-Habbasha *et al.*, 2013). However, in India, the per capita demand for groundnuts is insufficient due to its low productivity. Increasing the Zn density in groundnuts has emerged as a possible strategy to achieve adequate Zn intake, according to Lal and Singh (2007). This approach requires increased elevated Zn concentrations in seeds *via* foliar nutrition and the selection of genotypes with high Zn density.

The human body and all other organisms require iron as an important mineral. The physiological mechanisms within plants require Fe to synthesize chlorophyll and perform respiration and redox-based processes. Fe deficiency restricts plant growth and development and may also contribute to anaemia in humans and animals. Soils with low iron availability in alkaline regions frequently cause Iron deficiency chlorosis among plant crops. This condition exists in different parts of the world where crops grow on calcareous and alkaline soils which also contain erosion and low organic matter and cold temperatures. The most obvious role of iron in plant metabolism is the maintenance of chlorophyll in plants. Hence, its deficiency leads to chlorosis. The prevalence of iron insufficiency in India is second, only after zinc and appears to be 1/4th as widespread as zinc deficiency. It is a crucial component in numerous redox processes involved in photosynthesis, respiration and the reduction of sulphates and nitrates. The important factors contributing to the iron chlorosis in plants are low iron content in soils, free calcium carbonate, moisture extremes, high soil phosphorus, poor aeration and heavy manuring. Because iron chlorosis affects heavy-textured calcareous soils so extensively the necessity to apply iron to plants has become unavoidable because it addresses chlorosis symptoms and creates better growing environments leading to increased crop productivity. According to the WHO report, among the 20 most significant risk elements worldwide, Zn and Fe deficiencies rank 11th and 12th; while they stand as 5th and 6th amongst the 10 most crucial risk elements affecting developing countries (WHO, 2002).

Plants require vital micronutrients like zinc (Zn) and iron (Fe) to support their growth processes and development as well as improve survival during stressful situations. Zinc works as an enzyme activator and participates in chlorophyll formation along with gene regulation and plant defence mechanisms, which enhance photosynthetic efficiency, improve nutrient absorption and increase resilience tolerance to abiotic and biotic stresses (Muhammad *et al.*, 2022; Bastakoti, 2023). Similarly, iron is a vital component of metabolic processes, including photosynthesis, respiration and DNA synthesis, but its bioavailability is generally hindered in alkaline soils due to its inclination to form insoluble compounds (Berger *et al.*, 2023). Plants have developed sophisticated mechanisms, including specialised transport proteins and regulatory signalling pathways, to sustain iron homeostasis and alle*via*te toxicity (Vélez-Bermúdez and Schmidt, 2023; Ning *et al.*, 2023). However, excessive iron accumulation can induce oxidative stress and can negatively impact the plant metabolism and the yield (Harish *et al.*, 2023). Due to prevalent deficiencies of Zn and Fe in agricultural soils, innovative approaches like nano-fertilizers and foliar nutrition have arisen as effective methods to enhance micronutrient bioavailability, improve crop quality and mitigate nutritional deficiencies in both plants and humans (Saleem *et al.*, 2022; Shakoor *et al.*, 2023). Integrating these advanced nutrient management approaches is essential for sustainable groundnut cultivation to ensure growth, yield and nutritional quality.

Nutrient supply is a critical management strategy that significantly influences crop development and overall productivity. The ongoing application of substantial quantities of high-analysis fertilisers, coupled with a significant reduction in the application of organic manures and minimal recycling of crop residues, reduces organic matter in the topsoil. These influence the physico-chemical characteristics of soil, resulting in micronutrient deficiency in crop production. The requirement for the micronutrient has been fully satisfied by its indigenous soil reserves, thereby reducing crop production. Followed by iron, the prevalence of zinc deficiency has become prevalent and ranks after nitrogen, phosphorus and potassium.

Role of Micronutrients (Zn and Fe) in Plants

Role of Zinc

Zinc is a vital element of a variety of dehydrogenases, proteinases, peptidases. All these enzymes show sensitivity to Zn deficiency so that metabolism can be strongly and specifically affected. Zinc stands as the 3rd most restricting nutritional factor for crop agriculture after N and P. The auxin production process and carbohydrate transformation along with sugar regulation in plants operate through this mechanism. The development of plant zinc deficiency stems from two main factors including calcareous and light-textured soils along with lower soil organic matter contents and higher soil phosphorus levels and soil temperatures below 20 °C and low zinc content in the soil.

Now-a-days, research has progressively demonstrated that zinc (Zn) functions as a vital factor for plant development and growth processes. Zinc functions as an essential micronutrient because it participates in enzyme activation processes and chlorophyll synthesis and gene regulatory functions which boost photosynthetic efficiency and agricultural yield production (Muhammad *et al.*, 2022). Plants use Zn as a crucial element to strengthen defence mechanisms through the regulation of signalling pathways which along with antioxidant systems suppress disease severity and stop pathogen attacks (Bastakoti, 2023). Application of Zn reduces heavy metal toxicity and improves membrane stability as well as it enhances nutrient uptake in unfavorable environments (Hassan *et al.*, 2022). Moreover, the application of zinc protects cell homeostasis while it reduces abiotic stress effects through Chlorophyll preservation and reduced oxidative damage (Ganguly *et al.*, 2022). Biotechnological innovations that enhance zinc availability and uptake need immediate development mainly because Zn deficiency significantly affects alkaline soil regions thus posing threats to sustainable agricultural production and food security (Saleem *et al.*, 2022; Muhammad *et al.*, 2022). The importance of designing innovative biotechnological solutions to improve Zn access and root absorption becomes urgent need because Zn deficiencies widespread across many areas including alkaline soils (Saleem *et al.*, 2022; Muhammad *et al.*, 2022).

Role of Iron

The most obvious role of iron in plant metabolism is the maintenance of chlorophyll in plants. Hence, its deficiency leads to chlorosis. In India, iron deficiency is more common than zinc deficiency and it seems to be about a quarter as common as zinc deficiency (Malewar and Ismail, 1995). It is an essential component of many redox reactions that include photosynthesis, respiration along with sulphate and nitrate reduction. The important factors contributing to the iron chlorosis in plants are low iron content in soils, free calcium carbonate, moisture extremes, high soil phosphorus, poor aeration and heavy manuring. It has become inevitable to supply iron to plants because iron chlorosis frequently appears on heavily textured calcareous soils. This practice helps correct chlorosis and enhances plant growing conditions and yields.

Recent studies promote the important function of zinc for plant development as well as the fundamental nature of iron (Fe) as an essential micronutrient that supports crucial metabolic processes of photosynthesis and respiration and DNA synthesis (Shakoor *et al.*, 2023; Ning *et al.*, 2023). Soils with neutral to alkaline conditions pose restrictions for Fe bioavailability because the element tends to form insoluble metal oxides and hydroxides (Berger *et al.*, 2023). The plant adaptation to Fe deficiency has led to complex molecular mechanisms, such as specific transport proteins and signalling pathways, which stabilize Fe homeostasis to avoid toxic effects (Vélez-Bermúdez and Schmidt, 2023; Harish *et al.*, 2023; Ning *et al.*, 2023). However, excessive Fe accumulation can lead to oxidative stress, negatively impacting cellular structures and overall plant productivity (Harish *et al.*, 2023). Recent advancements in nano-fertilizer technology have demonstrated potential in improving Fe availability and enhancing crop quality, offering a promising approach to mitigating Fe deficiency in both plants and human nutrition (Shakoor *et al.*, 2023). Thus, ensuring optimal Fe levels through effective nutrient management strategies remains essential for sustaining plant health and improving agricultural productivity.

Impact of Iron and Zinc on Physiological Traits in Groundnut

Akhtar *et al.* (2019) noticed that $FeSO_4$ spray improved the photosynthetic rate and transpiration rate by 53% and 35% as compared to control and spraying of iron along with citric acid, it improved the photosynthetic rate by 23% SPAD value up to 12% over control. Gowthami and Ananda (2018) performed an experiment to examine the impacts of zinc and iron fortification on the yield and iron absorption of groundnut plants. The adoption of 25 kg ha^{-1} of soil and a 0.5% $ZnSO_4$ foliar treatment had the highest leaf area index (2.10), kernel yield (2,051 kg ha^{-1}) and shelling percentage (73.21%). It has also improved the absorption of iron in the kernel, haulm production and the overall iron uptake in the plants. Gowthami and Ananda (2017) noticed that combined application (soil and foliar) of $FeSO_4$ improved the dry matter significantly from 3.01 to 5.75 g $plant^{-1}$ and 20.70 to 39.55 g $plant^{-1}$ at 60 DAS and at harvesting, respectively. Hagari and Pattar (2017) reported that spraying of iron @ 0.5% ha^{-1} and cured zinc @ 0.5% ha^{-1} has boosted the plant height, dry matter and chlorophyll content by 10.9%, 59.2% and 20.7%, respectively, in comparison to the control.

Kumar *et al.* (2015) found that the highest dry matter accumulation and the largest no. of effective pods m^{-2} were obtained with 3 foliar absorptions of 2% iron sulphate, succeeded by 3 foliar absorptions of 0.5% iron chelate in groundnut. Rahevar *et al.* (2015) have studied the impact of FYM, iron and zinc on growth and productivity of summer groundnut and found that 0.5% $FeSO_4$ application substantially enhanced the plant population, plant height and dry matter production. Sale and Nazirkar (2013) noticed that plant height, chlorophyll content, no. of branches and no. of pods $plant^{-1}$ were substantially augmented with the mix use of 0.5% $ZnSO_4$ and 0.5% $FeSO_4$, in comparison with the control and sole absorption of zinc and iron. El-Haggan and Abdel-Latif (2014) concluded that foliar use of Fe+Zn+Mn+B in groundnut has resulted in highest plant height, no. of branches $plant^{-1}$, no. of pods $plant^{-1}$, 100 kernel weight, seed yield plant^{-1}, kernel yield when compared to control.

Gill and Walia (2014) concluded that foliar absorption of iron and zinc has enhanced the plant height, dry matter, leaf area index and effective tillers m^{-2} significantly, in comparison to the control. Galavi *et al.* (2012) indicated that the absorption of 1.0% iron enhanced plant photosynthesis and root development, resulting in increased net photosynthesis and biological yield, in comparison with the control and the mix use of any two micronutrients in safflower. Ebrahimian and Bybordi (2011) studied the effect of iron sprays in drought conditions and found that sunflower growth and yield was decreased significantly under drought conditions but iron sulphate sprays @ 0.4% significantly increases the dry matter production, seed and oil yield. Sonawane *et al.* (2010) noticed that foliar absorption of 1% iron sulphate including a recommended dose of fertilizer improved chlorophyll content, dry matter accumulation and other growth parameters in groundnut.

Bharti *et al.* (2010) analysed the impact of micronutrients on growth parameters and productivity of groundnut and concluded that the use of micronutrients (Zn, Fe and B) along with recommended doses of fertilizer increased the growth parameters and chlorophyll content. Application of 20 kg $ZnSO_4$ and 5 kg borax ha^{-1} as soil absorption along with 3 foliar sprays of 1% iron sulphate has obtained the highest pod yield (up to 49.94%). Ravi *et al.* (2008) found that combined foliar application of iron @ 0.5% + zinc @ 0.5% at 30 and 65 DAS on safflower observed prominently higher growth factors *i.e.,* plant height (97.5 cm), no. of leaves (81.5 plant^{-1}), primary branches (10.8 plant^{-1}), secondary branches (17.3 plant^{-1}) and dry matter production (2,440.7 kg ha^{-1}) over to control (80.4 cm, 65.4 plant^{-1}, 7.6 plant^{-1}, 13.7 plant^{-1} and 2,029.6 kg ha^{-1}, respectively).

Impact of Iron and Zinc on Yield and Yield Attributes of Groundnut

Nakum *et al.* (2019) analysed the effect of iron and zinc fertilization on productivity of groundnut and concluded that higher pod yield (2,527 kg ha^{-1}) and haulm yield (5,342 kg ha^{-1}) with the mix use of RDF + 1% $ZnSO_4$ and 1% $FeSO_4$ foliar application at 30 and 45 DAS and these results are statistically at par with the individual use of iron and zinc and lowest pod and haulm yield were documented in control. Rajitha *et al.* (2018) noticed that foliar application of 1% of $CaCO_3$, $MgNO_3$ and Sulphur + 0.2% micronutrient mixture has resulted in highest pod yield (2,654 kg ha^{-1}) and it has also improved other yield components *i.e.,* no. of pods plant^{-1} (60%), 100 kernel weight (48.2%), shelling percentage (29.4%) and haulm yield (74.05%) over control. Poonia *et al.* (2018) studied the impact of iron fertilization on iron, nitrogen composition and uptake and concluded that nitrogen and iron uptake in plant as well as kernel improved with the adoption of $FeSO_4$ @ 25 kg ha^{-1} as basal dose + foliar spray of $FeSO_4$ @ 0.5% at 45 and 75 DAS + citric acid @ 0.1% at 45 and 75 DAS + 5 t FYM ha^{-1}, in comparison to the control and alternative approaches.

Rahevar *et al.* (2015) studied the impact of FYM, iron and zinc on growth and productivity of groundnut and reported that foliar application of 4 kg ha^{-1} iron improved the pod number (16.4%), pod weight (25%), 100-kernel weight (13.3%), kernel yield (18.2%) and haulm yield (12.4%), in comparison with the control. Sinta *et al.* (2015) carried out an investigation to know the role of micronutrient on growth, seed yield and quality of groundnut using iron (Fe), zinc (Zn) and noticed that foliar spray of 0.5% $FeSO_4$ has lead to higher growth rates with reference to net assimilation rate and crop growth rate. Bahrani (2015) reported that foliar application of micronutrient (iron and zinc) substantially improved the yield attributes as well as yield in rapeseed.

Ali *et al.* (2014) indicated that a foliar absorption of $FeSO_4$ (1.5%) during both the branching and flowering stages led to a rise in the no. of pods plant^{-1} (44.64%), no. of seeds pod^{-1} (45.31%), 1000 kernel weight (18.97%) and crop production (38.66%) in groundnut relative to the control group. EL-Kader and Mona (2013) discovered that the use of sulphur, in conjunction with foliar sprays of zinc and boron, enhanced all quantitative yield parameters. The foliar absorption of zinc and boron combined with sulphur resulted in the highest production characteristics and overall yield, whereas the foliar absorption of micronutrients enhanced the concentrations of both macro and micronutrients in peanut seeds. Debroy *et al.* (2013) investigated the enhancement of groundnut genotypes with Fe by ferti-fortification and found that both soil and foliar applications of 5.5 kg Zn ha^{-1} combined with a 0.1% Zn spray using $ZnSO_4{\cdot}7H_2O$ led to an increase in 57% rise in kernel yield and a 56.4% increase in straw yield.

Elayaraja and Singaravel (2012) discovered that the foliar application of 0.5% and 150% NPK combined with $ZnSO_4$ at 30 kg ha^{-1} and borax at 15 kg ha^{-1}, alongside the application of composted coir pith, resulted in a substantially higher pod yield of 2,466 kg ha^{-1} and haulm yield of 3,354 kg ha^{-1}, representing increases of 31.31% and 25.95% in pod and haulm yield, respectively, compared to 100% NPK uses in groundnut. Pareek and Poonia (2011) reported that foliar spray of iron combining with citric acid effectively rectified the chlorotic diseases and significantly enhanced the yield parameters of groundnut and pod yield. Pendashteh *et al.* (2011) determined that foliar spray of zinc has a favourable impact on kernel yield and yield attributes in groundnut and increased levels of zinc spraying from 0 to 1 g l^{-1} improved the plant height, pod yield, seed yield and 100 kernel weights in groundnut.

Moosavi and Ranaghi (2011) reported that foliar application is the appropriate method because foliar application of 1% $FeSO_4$ improved the yield, number of mature pods and iron content in soybean in comparison to the control. Thakur *et al.* (2010) indicated that the use of iron and zinc, along with the prescribed fertiliser dosage of 25:50 kg N and P ha^{-1}, culminated in a significantly increased pod yield (1,992 kg ha^{-1}) and kernel yield (1,418 kg ha^{-1}) relative to the control in groundnut. Gohari and Niyaki (2010) noticed that the use of Fe+Zn improves the no. of pods plant^{-1} and also the no.

of mature pods, shelling percentage, 100 kernel weight and pod yield. Guruprasad *et al.* (2009) found that the use of 0.5% $FeSO_4·7H_2O$ significantly enhanced pod yield, shelling percentage and dry pod yield compared to the control in groundnut and foliar spray is a better method over soil application to correct chlorosis and to get a higher yield. Direct absorption of the Fe by foliage due to foliar application resulted in the higher bio-mass and kernel yield.

Masih *et al.* (2008) found that groundnut crop suffers from iron chlorosis at 35 days after emergence when iron in soil was below pivotal limit (4.5 mg kg^{-1}). They gave treatments of iron, citric acid and H_2SO_4. Results indicated that the application of 0.5% $FeSO_4$ combined with 0.1% citric acid effectively treated iron chlorosis and considerably increase the haulm and pod yield. Kuligod *et al.* (2007) found that the administration of higher fertiliser dosages (1.5 times the recommended dosage) contributed to increased yields (22.5 q ha^{-1}) in comparison with the conventional practice of manures and fertiliser use by the farmers (17.7 q ha^{-1}). The pod yield was increased to 23.9 q ha^{-1} because of the incorporation of 0.5% ha^{-1} each of $ZnSO_4$ and $FeSO_4$, including the appropriate fertiliser dosage for groundnut. Patel *et al.* (2008) indicated that a foliar treatment of 0.5% and a soil application of $FeSO_4$ and $ZnSO_4$ at 25 kg ha^{-1} each led to considerably increased pod and haulm yields compared to the control in groundnut.

Impact of Iron and Zinc on Nutrient Composition in Groundnut

Mann *et al.* (2015) found that the use of active iron improved the iron content by 5.6% in LGN-2 and 163.18% in CSMG-84-1. Ali *et al.* (2014) found that the use of a 1.5% foliar spray of $FeSO_4$ at the branching and the flowering stages enhanced the grain properties by escalating protein content by 6.60% and Fe content by 46.39%, in comparison with the control in groundnut. Debroy *et al.* (2013) reported that the soil and the foliar application of 5.5 kg Zn ha^{-1} + 0.1% Zn spray through $ZnSO_4·7H_2O$ has lead to high Zn concentrations in kernel as well as straw of groundnut over the control. Additionally, they concluded that the optimal approach to enhance Zn concentration is the simultaneous uses of soil and foliar Zn, resulting in a 5.5-fold rise in Zn levels. Guruprasad *et al.* (2009) noticed that foliar spray of $FeSO_4$ enhanced the Zn, Cu and Mn uptake by the crop because of better nutrition which ultimately results in higher dry matter production. Patel *et al.* (2008) undertaken an investigation to know the influence of foliar nutrition on the yield and absorption of micro-nutrients by groundnut and noticed that soil deficit in available Fe and Zn significantly respond to foliar application and obtained a higher pod yield and absorption of micronutrients (Zn, Mn, Fe, Cu) by spraying 4% seaweed fertilizer at 15, 30 and 45 DAS.

Conclusion

Iron and zinc are the major yield limiting micronutrients in groundnut growing regions and vital for many physiological processes in plants. Inadequate supply of Fe and Zn leads to failure of physiological processes which results in low productivity groundnut. Hence, foliar application of iron and zinc at different phases will boost the groundnut growth and its yield. Individual spaying of iron and zinc sulphate results in poor yield because of less nutrient uptake. So combined application of iron and zinc sulphate during flowering and peg formation stages is recommended for the farmers of groundnut.

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