A Comprehensive Review on Role Of Micronutrients In Legumes

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Abstract
This review article delves into the pivotal role of micronutrients, including iron, zinc, and manganese, in legumes, elucidating their impact on plant growth, development, and overall nutritional quality. Micronutrient deficiencies in legumes can lead to detrimental consequences such as stunted growth, reduced yield, and compromised plant health. Moreover, the nutritional benefits of legumes for both human and animal consumption are underscored, emphasizing their significance in providing essential nutrients like proteins, carbohydrates, and dietary fibers. Furthermore, the review explores how legumes contribute to sustainable agriculture practices through nitrogen fixation, symbiotic relationships with bacteria, and soil health improvement. By understanding and managing the micronutrient requirements of legumes, we can enhance their symbiotic nitrogen fixation capacity, improve soil fertility, and reduce dependency on synthetic fertilizers. In conclusion, this review underscores the importance of addressing micronutrient deficiencies in legumes to optimize crop productivity, ensure food security, and promote sustainable agricultural practices. By integrating effective management strategies and biofortification techniques, we can harness the nutritional potential of legumes to support global health and well-being while fostering environmental sustainability.

Keywords: Micronutrient, Legumes, Nutritional quality, Biofortification

Introduction

Micronutrients, like iron, zinc, and manganese, are vital for plant growth, involved in enzyme activation and hormone synthesis. Their availability profoundly affects plant productivity and nutrient uptake. For instance, iron is necessary for chlorophyll production, while zinc aids in protein synthesis and carbohydrate metabolism (Marschner, 2012). Micronutrient deficiencies result in plant symptoms like chlorosis, stunted growth, and reduced yield, emphasizing the importance of managing and supplementing soils and fertilizers for optimal crop productivity. .Legumes, a varied plant group within the Fabaceae family, are crucial for agriculture and nutrition due to their high protein and nutrient levels, serving as vital food sources for both humans and animals (Herridge *et al*., 2008). Beyond their nutritional benefits, legumes contribute significantly to sustainable agriculture by fixing nitrogen in soil through symbiotic relationships with bacteria, reducing synthetic fertilizer requirements and improving soil health, thus integrating well into crop rotation practices. (Peoples *et al*., 2009).Moreover, legumes hold significant importance in traditional diets across various cultures, particularly in regions with limited access to animal protein, offering essential nutrients like iron, zinc, B-vitamins, and dietary fiber, which contribute to overall health and wellness.(Messina *et al*., 2017).The review paper aims to thoroughly investigate how micronutrients affect legumes, covering aspects like plant growth, development, and nutrition. It seeks to summarize research findings, examine deficiency impacts, explore uptake mechanisms, discuss biofortification, analyze rhizobia interactions, assess nutritional quality effects, consider environmental implications, and address challenges in managing micronutrients for sustainable legume production, while also outlining future directions.

Micronutrients in Legumes

Micronutrients, vital for the optimal growth and development of plants, are required in small amounts. These essential elements are pivotal in numerous metabolic functions and contribute significantly to the overall growth of leguminous plants. One such example is iron, which is indispensable for the synthesis of chlorophyll and the facilitation of energy transfer processes in legumes(Rout & Sahoo, 2015). Zinc is involved in enzyme activation and protein synthesis (Rudani *et al*., 2018), while manganese functions as a cofactor for various enzymes in legumes. Copper, on the other hand, is necessary for electron transfer reactions and also plays a role in lignin formation in legumes. Furthermore, a deficiency in any of these micronutrients can result in stunted growth, reduced yield, and poor quality of legume crops.

It is therefore important to ensure that the soil has adequate levels of these micronutrients and to consider supplementation if necessary to support optimal legume growth and development (Sharifi, 2013).
Micronutrients are vital for the growth and development of plants, playing a critical role in their physiological processes. These nutrients, needed in smaller quantities than macronutrients, are essential for various plant functions. For instance, iron is necessary for chlorophyll production, manganese aids in photosynthesis, zinc activates enzymes, and copper is pivotal for electron transportation during photosynthesis (Marschner, 2012). Furthermore, each micronutrient has a specific function in plant growth and development. For instance, boron (B) is necessary for cell wall formation and membrane function, while molybdenum is essential for nitrogen metabolism and the reduction of nitrate. Understanding the functions and impact of micronutrients on plant physiological processes is crucial for optimizing crop production and ensuring plant health (Baligar *et al*., 2007).

Micronutrient Deficiencies

Micronutrients are pivotal for the growth and development of leguminous plants, with their deficiencies resulting in a range of symptoms and outcomes. Common signs of micronutrient deficiencies in legumes encompass slowed growth, leaf discoloration (chlorosis), and diminished yields. Essential for the proper development of legumes like beans, lentils, and peas are micronutrients such as iron, zinc, and manganese (Cakmak, 2008; Impa *et al*., 2013). Deficiencies in these micronutrients can result in compromised plant health and ultimately reduce the quality and quantity of the harvest (Deshmukh *et al*., 2023). Consequences of micronutrient deficiencies in legumes also extend to human health. Legumes are an important source of nutrients for many people around the world, especially in developing countries. A lack of micronutrients in legumes can lead to poor nutritional quality of the crops, which can contribute to micronutrient deficiencies in human diets. This, in turn, can lead to various health issues such as anaemia, impaired immune function, and developmental delays, particularly in children (Messina *et al*., 2017).It's crucial to address and prevent micronutrient deficiencies in legumes to ensure both the health of the crops and the nutritional well-being of the people who rely on them as a primary source of nutrients. Legumes are key contributors to sustainable agriculture and food production because of their capacity to capture atmospheric nitrogen and enhance soil fertility. Deficiencies in micronutrients can profoundly affect the growth, productivity, and nutritional value of legumes. These critical elements, encompassing iron, zinc, copper, manganese, molybdenum, and boron, are essential for a range of physiological and biochemical functions within leguminous plants. For example, iron is integral to chlorophyll synthesis and photosynthesis, while zinc aids in activating enzymes and synthesizing proteins (Cakmak, 2009).Micronutrient deficiencies in legumes can hinder their overall growth and development, resulting in diminished yields and lower nutritional value of the crops. For instance, insufficient iron levels can cause chlorosis and decreased photosynthetic efficiency, ultimately affecting plant growth and productivity. Furthermore, these deficiencies can also influence the nutritional content of legumes by altering the levels of vital vitamins, minerals, and proteins in the harvested produce (Bækgaard *et al*., 2010). To delve deeper into the repercussions of micronutrient deficiencies in legumes, it's crucial to examine scientific investigations and scholarly articles that have explored the distinct impacts of each micronutrient on various legume varieties. Grasping the mechanisms through which these deficiencies influence plant growth, productivity, and nutritional value can offer valuable insights into possible remedies, such as implementing effective nutrient management techniques and utilizing fertilizers enriched with micronutrients (Rengel, 2015).

Micronutrient Uptake and Transport

Legumes are known for their ability to absorb and transport micronutrients, essential minerals that are required in small quantities for various physiological functions in plants. Legumes acquire micronutrients through diverse mechanisms, including ion uptake by root cells, active and passive transport mechanisms, and chelation. Ion uptake encompasses the absorption of micronutrients like iron, zinc, and copper from the soil solution by root cells. Active transport processes, facilitated by proton pumps and specific transport proteins, are particularly vital for the uptake of essential micronutrients (Romheld & Marschner, 2018). Moreover, legumes have the ability to uptake micronutrients through passive transport methods like diffusion. Following absorption, these micronutrients are conveyed within the plant via the xylem and phloem. The xylem carries water and mineral nutrients from the roots to the shoots and leaves, whereas the phloem distributes organic nutrients, inclusive of micronutrients, to different plant parts. These transportation processes guarantee the effective dispersal of micronutrients throughout the legume plant, thereby facilitating critical physiological processes and overall growth (White & Broadley, 2009). The presence of micronutrients in the soil significantly influences plant growth and development, particularly in legumes. Various factors such as soil pH, organic matter levels, soil texture, and microbial activity affect the availability of micronutrients in the soil. These factors interact with each other, influencing the solubility and movement of micronutrients in the soil, thereby affecting their uptake by legumes. For instance, acidic soil conditions often result in decreased availability of micronutrients like zinc and iron, while alkaline soils can limit the availability of manganese and copper. Additionally, the influence of micronutrient availability on legume uptake may also be impacted by the presence of specific soil amendments or fertilizers. For example, research has shown that using organic amendments can increase the availability of micronutrients in the soil, leading to improved yields and nutrient uptake in legumes. Moreover, there's growing recognition of the role soil microbes play in influencing micronutrient availability to legumes, with studies underscoring their role in solubilizing and mineralizing these nutrients for plant absorption. A thorough understanding of the intricate relationship between soil micronutrient availability and legume uptake is crucial for optimizing agricultural practices and ensuring sustainable crop production. Further exploration into soil-plant-microbe interactions and the development of targeted soil management approaches can greatly enhance micronutrient uptake by legumes and address nutritional deficiencies in agricultural settings (Roorkiwal et al., 2021).

Biofortification Strategies

Biofortification is a method aimed at boosting the micronutrient levels in food crops to combat nutrient deficiencies and enhance public health, especially in regions with limited access to varied and nutrient-dense diets, primarily in developing nations. Various biofortification techniques have been utilized to augment the micronutrient content in legumes like beans, lentils, and peas. These techniques encompass conventional breeding methods, transgenic approaches, and agronomic practices (Roorkiwal et al., 2021). In conventional breeding methods, legume varieties with naturally elevated levels of micronutrients like iron, zinc, and vitamin A are selected and crossbred. This method has proven effective in producing biofortified legume varieties with heightened micronutrient content while maintaining yield and other desirable agricultural characteristics. Transgenic approaches entail inserting genes responsible for synthesizing particular micronutrients into legume crops. For instance, scientists have enhanced the iron content in common beans by introducing ferritin genes, which are responsible for iron storage in plants (Connorton & Balk, 2019). Agricultural techniques, including soil nutrient management and foliar treatments, also hold importance in boosting the micronutrient levels in legumes. For example, modifying soil pH and using fertilizers rich in micronutrients can enhance the availability of vital nutrients for legume growth, resulting in heightened micronutrient accumulation in the harvested seeds. These biofortification methods present hopeful strategies to combat worldwide micronutrient deficiencies, backed by extensive research findings and studies supporting their potential impact on public health (Cakmak, 2008). Leguminous crops play a crucial role in global food security due to their high protein content and ability to fix atmospheric nitrogen (Mudryj *et al*., 2014). However, they are often deficient in essential micronutrients such as iron, zinc, and selenium, which can have detrimental effects on human health. To address the micronutrient deficiencies in leguminous crops, researchers have explored genetic and agronomic approaches to increase the bioavailability of these essential nutrients. Genetic methods encompass breeding or genetic manipulation to improve the absorption and storage of micronutrients in leguminous plants. For instance, scientists have pinpointed and studied genes linked to the uptake of iron and zinc in crops such as soybeans and common beans, aiming to create varieties with enhanced efficiency in acquiring and retaining these micronutrients. Additionally, genetic engineering can be employed to introduce genes that boost the availability of iron, zinc, and selenium in leguminous crops, thereby enriching their nutrient content. Agronomic methods centre on increasing the accessibility of micronutrients in the soil and enhancing nutrient absorption by crops. This goal is accomplished through soil management techniques like liming, adding organic matter, and applying fertilizers containing micronutrients. Furthermore, practices such as crop rotation and intercropping systems contribute to enhancing the soil's overall nutrient content and availability, thereby impacting the micronutrient composition of leguminous crops (Garg *et al*., 2018).

Interactions with Rhizobia

Legumes and nitrogen-fixing rhizobia share a mutually beneficial relationship: the legume supplies carbohydrates to the rhizobia, and in return, the rhizobia provide fixed nitrogen to the legume through nitrogen fixation. Leguminous plants like soybeans, peas, and alfalfa form symbiotic associations with nitrogen-fixing bacteria known as rhizobia. This symbiosis is vital for the availability of micronutrients, particularly nitrogen, in the soil. Nitrogen fixation refers to the process wherein rhizobia convert atmospheric nitrogen into a usable form for plants. This process is crucial for the growth and development of legumes, as they rely on fixed nitrogen for protein synthesis and overall plant productivity (Oldroyd, 2013). The symbiotic relationship between legumes and rhizobia involves intricate molecular signalling and recognition processes that result in the formation of specialized root structures known as nodules. Inside these nodules, rhizobia colonize plant cells and perform nitrogen fixation, supplying the host legume with a direct nitrogen source. Research indicates that the presence of nitrogen-fixing rhizobia can improve the overall nutrient status of legumes, including the availability of crucial micronutrients like phosphorus, potassium, and iron. Additionally, the interactions between legumes and rhizobia not only impact micronutrient availability for the host plant but also have broader implications for soil fertility and sustainable agricultural practices. With a deep understanding of this symbiotic partnership, researchers and agricultural experts can devise tactics to enhance nitrogen fixation, encourage nutrient cycling, and bolster the availability of micronutrients in agricultural ecosystems (Peoples *et al*., 2009). Micronutrients are essential for the nodulation and nitrogen fixation processes in legumes. The presence of micronutrients like molybdenum, iron, and zinc significantly influences these processes. Molybdenum, for instance, acts as a cofactor for the nitrogenase enzyme, which converts atmospheric nitrogen into ammonia during nitrogen fixation. Iron is crucial for the creation and operation of leghemoglobin, a protein that aids oxygen diffusion within root nodules, thus establishing an ideal environment for nitrogen-fixing bacteria (Fitzpatrick, 2008). Comprehending and addressing the micronutrient needs of legumes can greatly enhance their ability for symbiotic nitrogen fixation, leading to enhanced soil fertility and reduced reliance on synthetic nitrogen fertilizers (Udvardi & Poole, 2013). Moreover, zinc contributes to the production of indole-3-acetic acid, a plant hormone affecting nodule development and elongation of infection threads during nodulation. The complex interconnection between micronutrients and the processes of nodulation and nitrogen fixation in legumes highlights the necessity of ensuring sufficient availability of these micronutrients in agricultural soils (Cabot *et al*., 2019).

Impact on Nutritional Quality

Legume crops are known for their high nutritional value and play a crucial role in human and animal diets (Çakir *et al*., 2019). These crops are rich in essential macronutrients such as proteins, carbohydrates, and dietary fibres (Bolarinwa *et al*., 2019). However, the nutritional quality of legume crops is not solely determined by macronutrients. Micronutrients, including vitamins and minerals, are essential for enhancing the nutritional value of legume crops, benefiting both human and animal consumption. They enrich the overall nutritional composition by supplying vital vitamins, minerals, and other bioactive compounds that support health and vitality. Numerous studies have highlighted the substantial impact of micronutrients on the nutritional excellence of legume crops. For instance, research indicates that the inclusion of micronutrients like iron, zinc, and calcium in legume crops can elevate their nutritional content, enhancing their value for consumption by both humans and animals (Khor & Misra, 2012; Lopez *et al*., 2002). These micronutrients are crucial for a range of physiological functions, such as energy metabolism, immune response, and bone strength. Moreover, the accessibility of micronutrients in legume crops is pivotal for their efficient utilization in both human and animal diets. Elements like soil nutrient levels, plant genetics, and food processing techniques can impact the availability of micronutrients in legume crops (Hirschi, 2009). Grasping these elements is crucial for enhancing the nutritional excellence of legumes and guaranteeing that micronutrients are easily accessible for absorption and utilization by the body. Apart from vitamins and minerals, legume crops also harbor bioactive substances like flavonoids, phytoestrogens, and phytosterols, which are linked to diverse health advantages, including antioxidant and anti-inflammatory effects (Panigrahi *et al*., 2023; Panigrahi *et al*., 2023). These bioactive compounds also enhance the nutritional value of legume crops and their potential influence on human and animal health. Maintaining a diet abundant in micronutrients is essential for overall health and wellness. Legumes rich in micronutrients offer a plethora of health advantages due to their array of essential vitamins, minerals, and other vital nutrients. Varieties like lentils, chickpeas, and beans serve as excellent reservoirs of micronutrients like folate, iron, magnesium, and potassium. These nutrients are pivotal for numerous bodily functions, including energy generation, formation of red blood cells, and bone strength (Mudryj *et al*., 2014). Research has shown that incorporating legumes into a balanced diet may help reduce the risk of chronic diseases such as heart disease, diabetes, and certain types of cancer. For example, the high fibre content in legumes can contribute to improved digestive health and lower cholesterol levels, while their low glycaemic index makes them beneficial for managing blood sugar levels in individuals with diabetes (Bazzano *et al*., 2001).

Environmental Considerations

Legumes, as a crop, offer numerous environmental benefits due to their unique ability to fix atmospheric nitrogen and enhance soil fertility naturally. This ability to fix nitrogen reduces the need for synthetic nitrogen fertilizers, which are known for their negative environmental impacts such as groundwater pollution and greenhouse gas emissions (Vanlauwe *et al*., 2010). In addition, legumes play a vital role in crop rotation, which helps in pest and disease management and promotes overall soil health, thus reducing the reliance on chemical pesticides. Moreover, the use of micronutrients in legume cultivation can further enhance their environmental benefits. Micronutrients such as zinc, iron, manganese, and copper play crucial roles in plant growth and development, and their application can improve the efficiency of nitrogen fixation in legumes (Hafeez, 2013). Consequently, this can lead to higher yields and reduced environmental impacts as fewer resources are required to achieve the same outcomes (Peoples *et al*., 2009). Furthermore, the judicious use of micronutrients can also help in mitigating the environmental risks associated with their overuse, such as groundwater contamination and soil acidification. Proper soil testing and targeted application of micronutrients based on the specific needs of the legume crops can prevent wastage and minimize the environmental footprint of their use. Micronutrients play a critical role in the growth and development of legume crops, as they are essential for various metabolic processes. It is important to consider the ecological impact and sustainability of various micronutrient management practices related to legume crops. Sustainable micronutrient management practices aim to minimize environmental impact while maximizing crop yield and nutritional quality. One aspect of sustainable micronutrient management practices is the use of organic sources of micronutrients, such as compost or manure (Fageria *et al*., 2002). These materials can improve soil structure, enhance nutrient availability, and promote beneficial microbial activity, ultimately leading to improved micronutrient uptake by legume crops. Another sustainable practice is the use of micronutrient fertilizers applied at the right time and in the right amount to avoid overuse and potential environmental contamination (Cakmak, 2000). Additionally, precision agriculture techniques can be employed to target specific areas of the field where micronutrient deficiencies are identified, reducing overall environmental impact (Giller *et al*., 2009). Furthermore, crop rotation with non-leguminous species can help maintain soil fertility and balance nutrient levels, reducing the need for excessive micronutrient inputs while supporting sustainable agricultural practices (Fageria & Baligar, 2005). By incorporating these sustainable micronutrient management practices, farmers can effectively support the ecological balance of their agricultural systems while promoting the long-term sustainability of legume crop production (Fageria *et al*., 2002).

Challenges and Future Directions

Micronutrients play a crucial role in the growth and development of legumes, which are important crops for both food security and sustainable agriculture (Çakır *et al*., 2019). Several challenges hinder a comprehensive understanding of micronutrient dynamics in legume crops. Firstly, there is limited research on the specific micronutrient requirements of various legume crops, reflecting a gap in our understanding of their nutritional needs (Bolarinwa et al., 2019). The interaction between soil pH and micronutrient availability in legumes remains ambiguous, posing a challenge in effectively managing micronutrient deficiencies, as different pH conditions may impact the availability of specific micronutrients (unexplored). Furthermore, the intricate nutrient interactions within legumes, involving both micronutrients and other essential elements, present a complex puzzle that demands deciphering for tailored nutrient management (White & Broadley, 2009). The genetic variability among diverse legume varieties adds another layer of complexity, requiring in-depth studies to unravel the genetic mechanisms governing micronutrient accumulation, essential for targeted breeding efforts (Cakmak, 2008). Additionally, the bioavailability and absorption of micronutrients in legumes remain inadequately understood, highlighting a knowledge gap that needs addressing (Fageria et al., 2002). Research on the synergistic or antagonistic effects of micronutrients in legumes is still limited, impeding precision in nutrient management strategies. Influential factors such as soil properties, root morphology, and microbial interactions play a role in micronutrient bioavailability and uptake, yet standardized methods for evaluating this are lacking, making it challenging to compare studies and draw conclusive results. Altogether, these limitations underscore the need for extensive research efforts to unravel the intricacies of micronutrient dynamics in legume crops.

Potential areas for future research and innovations

Micronutrient management for leguminous crops is an important area of research due to their high nutritional value and role in sustainable agriculture. Future research and innovations in the realm of legume crop nutrition could strategically focus on several key areas to propel agricultural sustainability and address nutritional challenges. Firstly, there's immense potential in the development of leguminous crop varieties with heightened micronutrient content, achieved through advanced breeding or genetic engineering – a promising avenue to counteract micronutrient deficiencies in human diets while concurrently enhancing crop productivity and resilience (Cakmak, 2008). Embracing precision agriculture techniques is another frontier, aiming to optimize micronutrient application by leveraging soil and plant tissue testing. This method promises efficient micronutrient utilization and a reduced environmental footprint. Delving deeper into the intricacies of micronutrient interactions in leguminous crops is essential, unraveling their effects on growth, yield, and nutrient content. This understanding forms the bedrock for crafting effective and balanced micronutrient management strategies. Further innovation lies in the exploration of nano-fertilizers, where nanotechnology is harnessed for targeted delivery of micronutrients to leguminous crops, potentially enhancing uptake efficiency and minimizing losses (Marchiol, 2018). Finally, the development of innovative micronutrient delivery systems, such as micronutrient-coated seeds or foliar sprays, stands out as a transformative approach to augmenting micronutrient uptake in leguminous crops. These inventive solutions not only promise improved nutrient use efficiency but also hold the potential to reduce application costs (Farooq et al., 2012). Collectively, these research directions hold the key to ushering in a new era of sustainable and nutrient-rich legume agriculture.

Conclusions

In conclusion, this review highlights the critical role of micronutrients in legumes, emphasizing their significance in plant growth, productivity, and overall nutrient uptake. Micronutrients such as iron, zinc, and manganese play essential roles in enzyme activation, hormone synthesis, and various metabolic processes within legume plants. The availability of these micronutrients profoundly impacts the health and yield of legume crops, with deficiencies leading to symptoms like chlorosis and stunted growth. Furthermore, legumes not only serve as a valuable source of nutrition for humans and animals but also contribute significantly to sustainable agricultural practices. Through nitrogen fixation and soil health improvement, legumes play a crucial role in enhancing soil fertility, reducing the need for synthetic fertilizers, and promoting ecosystem sustainability. Overall, understanding the importance of micronutrients in legumes is essential for optimizing crop productivity, ensuring food security, and promoting sustainable agricultural practices. By addressing micronutrient deficiencies and implementing effective management strategies, we can harness the full potential of legumes to meet the nutritional needs of populations worldwide while fostering environmental stewardship and agricultural resilience.

ACKNOWLEDGEMENT

This research is supported Division of Research & Innovation Uttaranchal University, Dehradun, India.

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