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Impact of foliar micronutrients on growth and yield of Blackgram: A review

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Abstract
Black gram is an important pulse crop extensively cultivated in South Asia providing an essential source of protein to millions of people. Several constraints responsible for the lower productivity of black gram. Its productivity is often limited by inadequate and unbalanced nutrition, especially deficiencies in essential micronutrients such as boron, molybdenum, zinc, and iron. These micronutrients are vital for various physiological processes, including photosynthesis, enzyme activation, and nutrient translocation, which directly impact crop growth, yield, and quality. Foliar application of the micronutrients has emerged as an effective strategy to enhance black gram productivity by providing direct and rapid nutrient uptake, particularly during critical growth stages. This review highlights the impact of micronutrient foliar feeding on black gram, demonstrating significant improvements in plant height, pod formation, seed yield, and overall crop performance compared to soil application methods. Despite its advantages, further research is needed to optimize application techniques, develop region-specific guidelines, and explore novel formulations to maximize the benefits of foliar feeding. The adoption of such practices is essential for enhancing black gram productivity, ensuring food security, and promoting sustainable agricultural practices.

Keywords: Blackgram, micronutrients, foliar application, growth, yield

Introduction

In India, pulses are the major source of dietary protein in the vegetarian diet. Besides, being a rich source of protein, also they have the unique ability of biological nitrogen fixation which helps to maintain soil fertility. Black gram (*Vigna mungo* L), also called urad bean, is a significant pulse crop grown in many parts of Asia, especially in India. India is said to be its origin and its existence has been referred to in Vedic literature such as Kautilya's "Arthasasthra" and the "CharakSamhita" which provides credence to the theory that it originated in India (Darade *et al.*, 2019) [10]. Black gram (*Vigna mungo* L) is the fourth important pulse crop grown throughout the country. Being a highly proteinaceous crop, black gram supplements a major share of protein food in the vegetarian diet. It contains nearly 26% protein, 1.2% fat and 56.6% carbohydrate, 0.8% fiber, 3.5% minerals, 75 mg calcium, 405 mg phosphorus, and 8.5 mg iron (Wakudkar *et al.*, 2018) [64]. It also has a considerable amount of folic acid, magnesium, potassium and vitamin B which is necessary for human health. Black gram has numerous medicinal properties. It contains both soluble and insoluble fiber which aids good digestion and it helps in reducing cholesterol which enhances cardiovascular health. The high amount of magnesium and folate compounds present in it improves blood circulation. It can be considered as a mini-fertilizer factory since it has the unique ability to sustain and restore soil fertility by fixing atmospheric nitrogen in a symbiotic association with rhizobium bacteria found in the root nodules. In India, it is grown under both irrigated and rainfed conditions. According to reports, black gram supplements fifty-nine thousand tons of urea annually by producing 22.10 kg N $ha^{-1} yr^{-1}$ (Tejaswini *et al.*, 2023) [60].

In general, pulses produce numerous flowers but very few of those retains and matured into pods. Flower drop and fruit drop are the primary physiological constraints limiting blackgram production, aside from its genetic makeup.

Study was conducted on all outpatients and inpatients who presented with a breast lump, from all units of the Department of General Surgery in Annasaheb Chudaman Patil Medical College and Hospital (A.C.P.M.M.C.H), Sakri road, Dhule.

A healthy pulse crop stand always has a great demand for the right proportions of macro as well as micronutrients *i.e.*, balanced nutrition to facilitate bacterial functions in the root nodules, particularly in case of growing on a nutrient deficit soil. The proper utilization of macronutrients in conjunction with micronutrients is necessary for the coordination of a wide range of physiological processes in plants, which in turn improves the quality and production of plants (Sharmila *et al.*, 2020) [54]. Soil application of macro and micronutrients is a common method but the entire applied nutrient may not be utilized by the plants due to various soil physico-chemical properties. Most of micronutrients and macronutrients are primarily fixed on the soil complex as insoluble forms, which results in their relatively low availability to plants in soil solution. In addition, excessive use of fertilizers in the soil increases the cultivation cost and affects the alive soil system.

One of the most recent advances in agriculture is the foliar application of growth-regulating agents at the critical stages of the crop to enhance crop performance (Singh *et al.*, 2013) [56]. Foliar fertilization assumed greater importance because the nutrient is brought into the immediate vicinity of the metabolizing area *viz.*, foliage without the process of being first mineralized in the soil, adsorbed through the roots and then transported to the leaf for assimilation. The need for foliar feeding becomes more and it is effective by providing a quick and earlier absorption by the plants and it is required in lesser quantity which is independent of different soil conditions. Basant *et al.* (2020) [3] reported that foliar feeding can supply the nutrients which is necessary for the growth and development of crops when the plant is unable to obtain the nutrients from the soil. Foliar feeding hastens the uptake of nutrients from the soil through the roots. It is evident that nutrients pass through the cuticle to reach the leaf cells, where they are then transferred by plasmodesmata to other areas (Pooja and Ameena, 2021) [47]. Therefore, applying small amounts of micronutrient through foliar application enhances the quality by directly reaching the site of metabolic activity and maintaining the yield with minimum impact on the environment (Raushan *et al.*, 2020) (Fig. 1) [51].

In black gram, combined application of micronutrients as foliar spray results in increased plant growth and formation of nodules as well (Kiruthika *et al.*, 2021) [24]. The foliar application of nutrients positively influences the crops growth, physiology activities directly impact on increased yield of black gram (Jeyakumar *et al*., 2008) [19]. Dry matter accumulation is one of the important factors that have a direct impact on the yield of legumes (Fig. 2). Foliar application of nutrients seems to increase the total dry matter production by influencing the growth indices like Absolute Growth Rate (AGR), Crop Growth Rate (CGR) and Leaf Area Duration (LAD) which significantly increased the yield of black gram (Thakur *et al.*, 2017) [61]. This review aims to explore the various aspects of the foliar application of micronutrients in black gram, including its benefits, methodologies, and potential challenges.

Effect of micronutrients on growth and yield of black gram

In plants usually, micronutrients are needed in small quantities yet they play a key role in crop growth and productivity and they function as a cofactor in different enzymatic activities and are involved in many redox reactions. Thus, a balanced supply of micronutrients is important for optimizing the overall development of pulse crops. Micronutrient deficits in crops have become more common in recent years due to a variety of factors, including greater use of chemical fertilizers, decreased use of manures, leaching, liming of acid soils, intense cropping, increased soil erosion and the use of marginal lands for crop production (Rathor *et al.*, 2023) [50]. Mostly black gram grown under rainfed conditions which gives lower yield potential due to poor agronomic management practices indirectly affects certain physiological and biochemical processes that slow down crop growth.

Many researchers are experimenting with foliar application of biological formulations, growth regulators and nutritional formulations in pulses. Studies have shown that foliar application of micronutrients, such as zinc, iron and molybdenum, can significantly improve the yield and quality of black gram. Enhanced nutrient availability can lead to better pod formation, seed development and overall plant health (Mahla *et al.*, 2001; Divyashree *et al.*, 2020; Pandey *et al.*, 2024) [34, 13, 43]. In addition, the amount of crude protein, amino acids, total lipids, energy value and other nutrients are enhanced by the application of micronutrients. The application of micronutrients augments the better growth and establishment of black gram.

Impact and significance of foliar application of Boron (B)

Among various micronutrients, B is the most commonly deficient one in soils. In more than 80 countries, over 132 crops have been shown to be deficient in boron. Approximately one-third of the soils in India, especially the alluvial soils are deficient in B over a large area (Kumar *et al.*, 2018) [29]. B deficiency in soil is primarily caused by leaching along with some factors like raised soil pH level, texture especially sandy nature, low organic matter and poor soil moisture. A lack of B for reproductive development can also be caused by inadequate translocation of B from leaves and other mature tissues to the floral parts since it is a phloem immobile element.

Boron is essential for the flowering and fertilization processes. Thus, Boron deficiency in plants causes a significant reduction in reproductive yield than biomass yield (Basant *et al.*, 2020) [3]. Boron has a key role in pollen germination and pollen tube elongation. It stabilizes the cell wall pectic network followed by regulation of cell wall pore size. It aids in the translocation of sugars and nutrients from leaves to reproductive organs, increases pollination, seed formation and seed development (Devi *et al.*, 2012; Naznin *et al.*, 2020) [12, 38]. B maintains the structure of the plasma membrane by forming cis-diol complex molecules with glycoproteins and glycolipids contributing to the membrane metabolism and function, which means that it is engaged in enzyme processes and the movement of ions, metabolites and hormones (Raj and Raj 2019) [49]. Insufficient boron supply in plants causes DNA synthesis to be inhibited, which leads to pyrimidine base deficiencies and the termination of root growth. As the shoot-to-root ratio rises, plants become increasingly vulnerable to nutrient imbalances and drought. Lack of B impairs male fertility by means of reduction of microsporogenesis, germination and elongation of the pollen tube. Boron plays a major role in plant metabolism by activating certain enzymes and cell division, increasing the uptake of some nutrients like calcium and potassium, it is also involved in the synthesis of protein (Janaki *et al.*, 2018) [36]. The role of B in phenol metabolism was provided by Brown *et al.* (2002) [8] who further added that accumulation of phenol under boron deficiency leads to the damage of membrane structure and function. Hence, the application of B is necessary to improve the productivity and quality of blackgram.

The adsorption and uptake of Boron by plants are affected by different factors such as soil pH, moisture availability, organic matter and plant species. Boron uptake is higher through the foliar application (Kumar *et al.,* 2020) [30]. In black gram, seed yield and seed quality in terms of storage seed proteins (albumin, globulin, glutenin and prolamin) and carbohydrates (sugars and starch) could be increased by means of applying B as a foliar application. Pandey and Gupta (2013) [41] showed that foliar spray of different concentrations of B (i.e. 0.05 to 0.2%) at different stages of black gram (prior to flowering, before and after the formation of bud) significantly increased the reducing, non-reducing and total sugars especially 0.2% of B lead to threefold higher seed yield than control. Black gram plants with B deficiency produced less number of pods which were found to be shrunken and smaller. The spray given after the formation of bud potentially improved the seed yield both quantitatively and qualitatively as it increases the pollen-producing capacity, pollen tube elongation and anther size. Foliar feeding of B at 100 ppm concentration under rainfed conditions substantially increased root length, root surface area, nodule length and leaf nitrogen content (Pegu *et al.,* 2013) [46]. Furthermore, the foliar application of B enhanced the photosynthetic parameters, such as internal CO_2 content (ppm), stomatal conductance (mole CO_2 /m^2 /s) and photosynthetic rate (μmole CO_2 /m^2 /s). Soil application of boron @ 1.5 kg ha^{-1} and foliar application of borax @ 0.25% at 20 and 40 DAS along with N, P_2O_5 and K_2O offered a maximum yield of about 1050 kg ha^{-1} (Sharmila *et al.,* 2020) [54]. Similar result (898 kg ha^{-1}) was registered with foliar application of B at the rate of 2 kg ha^{-1} along with zinc application in black gram (Mishra *et al.,* 2018) Application of 2% NPK (19: 19: 19) + 0.2% Borax + 0.5% $ZnSO_4$ spray prior to anthesis produced highest possible seed yield of about 804 kg ha^{-1} and stover yield of 1648 kg ha^{-1} (Debata *et al.,* 2022) [11]. Foliar application of B at critical stages enhanced the growth, seed yield and seed quality of black gram. Therefore, providing B through foliar treatment to plants offers a higher yield under all conditions.

Impact and significance of foliar application of Molybdenum (Mo)

Regarding nutritional aspects, Mo is a flourisher to the growth and yield of pulses. It enhances the bioavailability of some other nutrients. Approximately 11% of Indian soils are deficient in available Mo, making it one of the major nutritional factors affecting crop development in pulse growing areas (Raju *et al.,* 2019) [49]. In leguminous crops, molybdenum is necessary for the synthesis and activity of molybdoenzymes such as nitrate reductase and nitrogenase, which initiate rhizobial activity and control root nodulation and symbiotic N fixation. Furthermore, Mo is essential to the uptake and transport of iron (Fe) in plants. Mo actively participates in the synthesis of ascorbic acid, which is responsible for converting unavailable Fe into its available forms (Banerjee *et al.,* 2021) [2]. Mo has the ability to increase plants' photosynthetic rate and regulate physiological functions. It also prevents the flower drop in pulse crops. In particular, molybdenum helps in redox processes by acting as an enzyme cofactor, assisting in the conversion of nitrates to ammonia before plant cells can produce proteins and amino acids (Sastry and Dawson, 2023) [53]. Thus, the deficiency of molybdenum will directly affect the nitrogen fixation and finally result in the reduction of growth and yield in legumes.

Molybdenum is involved in carbohydrate metabolism. It activates several enzymes in the plant system and is found to be the specific inhibitor for acid phosphatase. The plants with Mo deficiency have reduced concentrations of sugars. Though the requirement of Mo in plants is small, it plays a specific role in plant metabolism. Many studies have reported that Mo has a positive impact on black gram productivity and growth by modifying every trait that contributes to yield and growth. Mo positively influenced the nodule activity and seed yield in black gram. (Mahilane *et al.,* 2018) [33]. Mo-applied plants had an abundance of flowers which resulted in an increased number of pods per plant and also higher dry matter production than untreated plots. This might be due to the doubling of Leaf Area Index which significantly increased the number of branches per plant. Anwarulla and Shivashankar (1987) [1] confirmed the beneficial effect of Mo on the black gram growth and yield. And also the early dropping of leaves was also delayed with the application of Molybdenum as a foliar treatment. Jongruaysup *et al.,* (1994) [20, 21] studied the relationship of molybdenum concentration in leaves and nodules of black gram with different levels. There was a significant decrease in shoot dry matter and shoot N content in severely Mo-deficient plants. Foliar spray of 0.05% ammonium molybdate solution at 25 and 40 days after sowing recorded the highest seed yield (1269.50 kg ha^{-1}) over water spray (1164.50 kg ha^{-1}). The seed yield was 9.02% higher than the control which might be due to the positive influence of Mo on nodulation, total dry matter accumulation and yield attributes (Biswas *et al.,* 2009) [6]. Molybdenum increases nodulation in black gram which in turn indirectly increases the oxygen content thus enhancing the availability of oxygen for root growth (Kathyayani *et al.,* 2021) [23]. Foliar application of Molybdenum (800 ppm/ha) along with boron offered maximum plant height (48.47 cm), higher dry weight/plant (9.43 g), number of pods/plant (29.80), number of branches/plant (32.07), number of nodules/plant (6.80), crop growth rate (2.68 g/m^2/day), number of seeds/pod (7.73), Test weight (40.20 g), Seed yield (1.39 t/ha) and Stover yield (2.99 t/ha) (Pandey and Dawson, 2023) [53].

Impact and significance of foliar application of Zinc (Zn)

Zn is one of the prevalent micronutrients which is deficient in most of the Indian soil. The low availability of soil Zn is the widest ranging abiotic stress. About thirty percent of the world's cultivable soils have low amounts of zinc that are available to plants, as estimated by the Food and Agriculture Organization (FAO). Intense cultivation of food crops, mostly cereals and legumes, is the cause of zinc deficiency. Zinc is the most common trace element, involved in many physiological processes, although at high concentrations it becomes toxic to plants (Munirah *et al.,* 2015) [37]. Zinc is a cofactor of more than 300 proteins and enzymes that are involved in protein synthesis, nucleic acid processing and cell division. It is necessary for maintaining the structural orientation of ion transport systems and macromolecules (Hafeez *et al.,* 2013) [16], as well as maintaining the integrity of cellular membranes by interacting with phospholipids and the sulphydryl groups of membrane proteins. Zinc is necessary for the synthesis of tryptophan, a precursor to IAA and also actively participates in the synthesis of auxin, an important growth hormone. Zinc application significantly alleviates the impact of drought stress on plant growth by decreasing the production of reactive oxygen species, inhibiting photooxidative damage, raising the activities of SOD, POD and CAT involved in detoxifying ROS and regulating the activity of membrane-bound NADPH oxidase (Toor *et al.,*2020) [62]. Zinc plays a crucial role in the development of the reproductive system and is a component of several Zn finger proteins, which form a structural motif of the DNA binding region of regulatory proteins (Pathak and Pandey, 2010) [44]. Zn-deficient plants exhibit symptoms including suppression of vegetative growth, reduction of internodes, branching and leaf size. The leaves showed marginal chlorosis and the number of flowers produced decreased. Lower zinc levels lead to increased activity of hydrolytic enzymes such as acid phosphatase and peroxidase, which impacts pollen tube development and ultimately results in poor fertilization and seed set in black gram. Farmers prefer soil application of Zn. But most of the released zinc (about 80%) is fixed in the soil in a non-exchangeable state which makes it unavailable to crops (Shukla, 2013) [55]. Zn application through the soil increases crop grain production, but foliar spray increases Zn concentration in grains. Thus, foliar application is an excellent choice to overcome zinc shortage as it rapidly mitigates the resulting shortfall.

Zinc deficiency is linked to low seed yield because zinc is important for pollen function and pollen-pistil interaction, which is necessary for seed formation and fertilization. Plants that are zinc deficient have reduced membrane integrity, increased heat stress susceptibility and lower production of auxin, cytochromes, carbohydrates, nucleotides and chlorophyll. Foliar application of Zinc (0.1% $ZnSO_4$) in blackgram before bud initiation offered more flowers, higher pod setting percentage and ultimately higher seed yield. Foliar treatment also raises the Zn concentration in seeds, which is good for human consumption (Pandey *et al.*, 2013) [41]. Foliar treatment of Zinc (0.2%) together with secondary nutrients like calcium, magnesium and sulphur at 1% each exhibited a synergistic effect on the black gram. Significant increases were observed in the dry matter production, seed yield and haulm yield of blackgram. (Lakshmi *et al.*, 2018) [32]. Foliar application of 0.5% Zn EDTA along with phosphorous had a positive effect on blackgram growth and yield reported by Chama *et al.*, (2023) [9]. Zinc plays a significant role in blackgram seed development and yield. The highest seed yield of 804 kg/ha was achieved with foliar application of STBFR + 2% NPK (19: 19: 19) + 0.5% $ZnSO_4$ + 0.2% Borax in blackgram. This could be the result of providing the crop with balanced nutrition through foliar application of NPK, Zn and B (Debata *et al.*, 2022) [11]. Blackgram performed better under foliar feeding of 0.5% $ZnSO_4$ along with the recommended dose of NPK fertilizer + silixol @ 0.5 percent twice at pre flowering and flowering stage (Elayaraja and Jawahar, 2020) [14]. The root length, number of lateral roots, root dry weight, shoot dry weight, leaf dry weight and leaf area per plant were all considerably increased by applying zinc via foliage (Haider *et al.*, 2018) [17].

Impact and significance of foliar application of Iron (Fe)

Iron, the fourth most abundant element in the lithosphere, is typically found in large amounts in soils; yet, its bioavailability is limited in aerobic and neutral pH environments. Iron is mostly found in Fe^{+3} forms as a component of very poorly soluble oxyhydroxide polymers which meagerly meets the demand of the crop (Kobayashi *et al.*, 2019) [25]. The plants are unable to uptake iron under higher soil pH *i.e.* alkaline soils. In higher plants, interveinal chlorosis of young leaves and reduced root growth are the typical symptoms of Fe deficiency. Iron is an essential part of chloroplasts since it plays a role in the porphyrin structure of chlorophyll. On average, photosynthetic cells contain about 80% of the iron that is needed for the electron transport system and the synthesis of heme molecules like chlorophyll, cytochromes and Fe-S clusters (Rout and Sahoo, 2015) [52]. Iron also interacts with non-heme proteins as an iron-sulfur protein (e.g., ferredoxin, superoxide dismutase). It functions as a cofactor in redox processes that are essential for the synthesis and utilization of oxygen due to its physicochemical characteristics, particularly its affinity for active metalloprotein sites. Thus, Fe is a key element in plant redox systems. As an iron-sulfur protein, iron also interacts with non-heme proteins like superoxide dismutase and ferredoxin.

The difficulties with applying iron to soil are typically avoided by using the foliar technique. In blackgram, 1% ferrous glycinate at 25 and 45 DAS, recorded higher growth and yield parameters, including increased chlorophyll content which ensures that Fe has a major role in chlorophyll synthesis (Jawahar *et al.*, 2021) [18]. Similarly, application of $FeSO_4 \cdot 6H_2O$ (0.5%) at 30 DAS along with $ZnSo_4$ performed better in obtaining higher nutrient concentration and uptake, maximum yield and nutrient status in soil. (Bhargavi *et al.*, 2018) [5]. At the stage of flower and pod initiation, 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ was shown to have a considerably higher number of seeds/pod than 0.5% $ZnSO_4$ alone. This demonstrates that applying zinc and iron at all doses and application stages improved the plant's metabolic process, leading to improved yield qualities (Soni and Kushwaha, 2020) [59]. The grain yield of mung beans was raised by 65.38% and 31.53%, respectively, by a single spray of 0.5% $FeSO_4$ at 25 DAS (716.67 kg/ha) and 45 DAS (570 kg/ha) (Saini, 2017). The combined application of 12.5 kg S ha^{-1} as $ZnSO_4$ + 12.5 kg S ha^{-1} as SSP + 1.0% $FeSO_4$ at 25 DAS had a significant effect on root nodules $plant^{-1}$ and the average maximum number of root nodules $plant^{-1}$ (30.05, 58.04, and 73.82) at all subsequent stages of crop growth (30, 45, and 60 DAS). Rathor *et al.* (2023) [50] reported that application of 75% RDF + Rhizobium 600 g ha^{-1}+ PSB @ 600 g ha^{-1} + foliar spray of 0.1% $FeSO_4$ + 0.5% $ZnSO_4$ at pre-lowering and pod formation stage resulted in significantly greater protein content in urdbean seed (24.19%) and protein yield (308.5 kg ha^{-1}).

Impact and significance of foliar application of Copper (Cu)

Copper is one of the essential micronutrients required for normal plant growth but too much of it can be harmful to their development, metabolism, and physiological functions. In general, the amount of copper present in the soil is not readily available to crops as it binds to the soil colloids. It is a cofactor of several cytochromes which mediate the energy transduction in the bacteroid infection in the root nodules. Hence, the application of copper as foliar spray could be effective for better utilization by crops. Weisany *et al.*, (2013) [65] confirmed that copper plays a vital role in protein formation that is required for fixing nitrogen in rhizobium. Thus, copper nutrition positively influenced nitrogen fixation. With the increased application of copper, the nitrogen content and protein level in the plant also got increased (González-Guerrero *et al.*, 2014) [15]. Bhakuni *et al.*, (2009) [4] studied the effect of copper stress on the growth, metabolism and yield of chickpea. They pointed out that the copper deficiency in chickpea suppressed the crop growth and it resulted in the chlorosis and stunting of primary and secondary branches. Further, the flowering and its maturity were also severely affected by Cu deficiency. As a consequence of this, the biomass yield was reduced and led to lesser productivity. Patel (2016) [45] stated that copper fertilization was found to be effective in increasing the total biomass accumulation of soybean. The leaf chlorophyll value of the leaves was increased significantly, which was attributed to the better growth and yield. Similarly, reported that the pod yield of soybean, faba bean and yellow lupin was significantly increased with the application of copper.

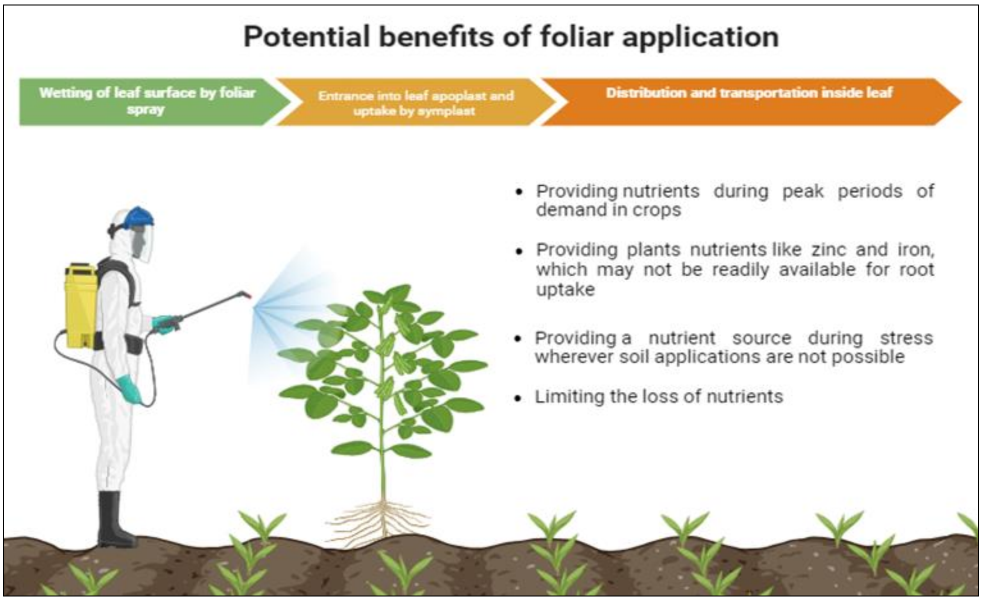

Fig 1: Potential benefits of applying foliar application of micronutrient

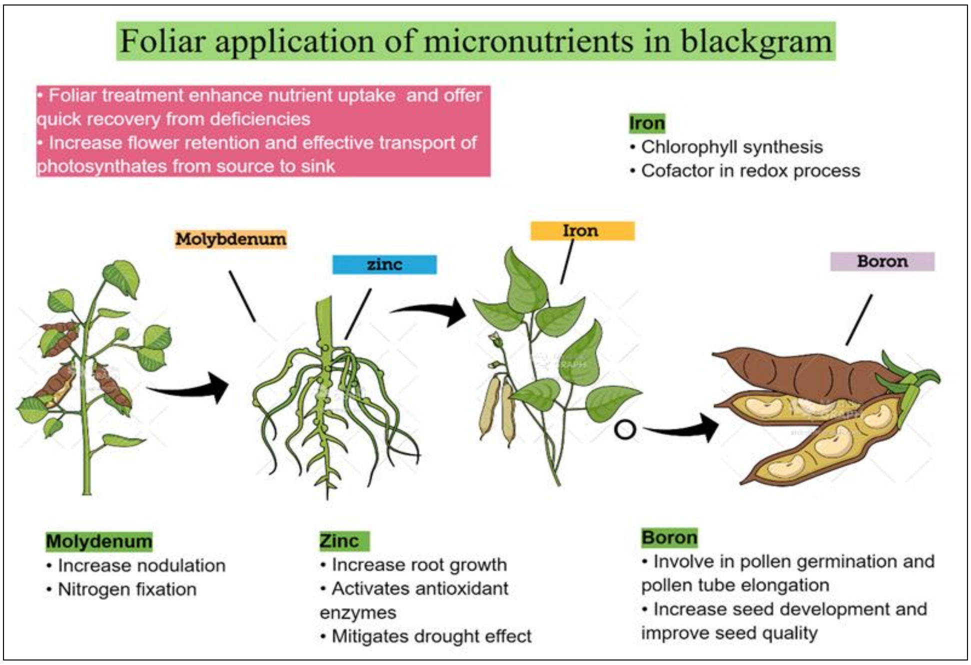

Fig 2: Role of foliar application of micronutrients in blackgram

Conclusion

The foliar application of micronutrients plays a pivotal role in enhancing the growth, yield, and overall productivity of black gram. It increases yield by 15 to 25%, making it a promising practice for improving blackgram productivity and ensuring food security. The combined application of micronutrients through foliar feeding has been proven more effective than soil application, offering direct nutrient absorption with minimal environmental impact. This approach not only corrects micronutrient deficiencies rapidly but also mitigates limitations associated with soil-based fertilization, such as nutrient fixation, antagonism, and varying soil conditions.

Despite the evident benefits, challenges remain in optimizing the timing, concentration, and combination of micronutrient applications to maximize the benefits in diverse environmental conditions and cropping systems. Future research should focus on developing region-specific recommendations and integrated nutrient management strategies that incorporate foliar micronutrient applications. Advanced research is also needed to explore novel micronutrient formulations, including nano-fertilizers and bio-enhancers, which could further improve nutrient uptake efficiency and crop resilience. Additionally, there is a need for more in-depth studies on the long-term impact of repeated foliar applications on soil health and crop sustainability. Investigations into the interactions between micronutrients and other agronomic practices, such as irrigation and pest management, will help fine-tune recommendations. Emphasizing technology transfer and farmer education on the benefits of foliar micronutrient applications will be crucial to ensure widespread adoption, thereby improving black gram productivity, food security, and overall agricultural sustainability.

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