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Foliar nutrition: A sustainable way for productivity enhancement in pulses

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Abstract
Pulses, recognized as climate-smart crops, are vital for global food and nutritional security, yet productivity remains constrained by biotic, abiotic, socio-economic, and physiological factors. One of the main reason for productivity decline is that they are grown as rainfed crops on marginal lands with minimum inputs. Fertilizer management is imperative in such soils where the soil application of nutrients alone cannot met the nutrient requirement. The foliar application of macro and micronutrients directly to leaf surfaces is a quick and effective way to significantly improve the growth, yield attributes, quality, nutrient uptake, and stress resilience in pulses, particularly under rainfed conditions where soil moisture is limiting. The integration of conventional water-soluble fertilizers, secondary nutrients, and novel nano-fertilizers not only accelerates nutrient availability and uptake but also enhances photosynthetic rates and dry matter accumulation Adoption of organic foliar sprays further supports fertilizer savings, profitability, and increases in quality indices and net returns. Nano-fertilizer-based foliar strategies, leveraging controlled-release kinetics and higher leaf penetration, represent an emerging avenue for nutrient use efficiency and resilience against climate variability. The foliar nutrition is a promising, cost-effective approach for addressing yield gaps and securing the future of pulse production within sustainable agri-food systems.

Keywords: Foliar nutrition, climate change, nano-fertilizers, productivity, sustainability

Introduction
Agriculture is considered as the backbone of Indian economy, with approximately 46 per cent of the population relying on it for their livelihood (Economic Survey, 2025) [1]. The covid -19 pandemic surged the need for self- sufficiency in food production. The rise in hunger due to pandemic is estimated to be 9.8 per cent in 2022 as against 8 per cent during pre-COVID times (FAO, 2023) [2]. The prevalence of stunting among children was greater than 30 per cent in 28 countries (FAO, 2023) [2]. Despite the global efforts to achieve food security and alleviate poverty, more than 670 million people (8 per cent of the world population) will still be undernourished by 2030 (WHO, 2024) [3]. Climate change further threatens global food security (FAO, 2022) [4]. In this context, pulse crops can be a good candidate for addressing the above issues offering potential benefits for nutrition, sustainable agriculture, and resilience against climate change.
Pulses are important dietary constituents for humans and animals. They contain high quality protein and substantial amount of slowly digestible starch and dietary fibers. The wider adaptability, longer shelf life without loss of nutritional value and lower price make them an affordable source of protein (Singh, 2018) [5]. The protein content of grain legumes is two and three times as that of wheat and rice respectively (Dixit *et al.*, 2024) [6]. They are a rich source of minerals like iron, potassium, magnesium and zinc and are also of vitamin B including folate, thiamin and niacin (FAO, 2016) [7].
Pulses are climate smart crops. They can adapt to climate change and mitigate its effect. Their ability to fix atmospheric nitrogen can reduce the dependence on synthetic fertilizers thus reducing green house gas emissions. The inclusion by products of pulses in livestock feed can improve feed conversion ratio while reducing greenhouse gas emissions (FAO, 2022) [4]. Pulses have dual role in cropping system due to soil health and nutritional security. The specific role of pulses in a cropping system includes high carbon sequestration capacity, low carbon and water

footprint, fixing atmospheric nitrogen in soil and soil health restoration thereby improving soil biodiversity (Adarsh *et al.*, 2019) [8]. They play an important role in mitigating factors associated with climate change and as an option for a sustainable diet (FAO, 2022) [4].

Constraints in pulse production

The constraints in pulse production can broadly be categorized as biotic, abiotic, socio-economic and physiological (Kumar *et al.*, 2022) [9]. Insect pests, disease causing organisms and weeds are the main biotic constraint in pulse production. Current studies suggest that the losses due to biotic stress account for 30 per cent. Pulses are particularly susceptible to various diseases caused by fungi (e.g., rust, anthracnose), bacteria (e.g., bacterial blight), viruses (e.g., bean common mosaic virus), and nematodes (e.g., root-knot nematodes). Insect pests such as aphids, pod borers and bruchids further exacerbate losses by damaging leaves, flowers, pods, and seeds, both in the field and during storage. Parasitic weeds like striga and cuscuta compete with pulses for nutrients and water, severely reducing productivity (Sunani *et al.*, 2024) [10]. The major abiotic constraints include extreme weather conditions, soil and land degradation and agronomic factors. Extreme weather and soil conditions such as drought, heat, waterlogging, soil acidity and salinity pose a threat to pulse production. About 87 per cent pulses cultivation is confined to rainfed areas (Dixit *et al.*, 2024) [6]. Drought stress during flowering is detrimental for yield of pulse crops (Baroowa *et al.*, 2012) [11]. The rapid increase in temperature causes forced maturity and attracts many biotic stresses (Ali *et al.*, 2012) [12].

There is a huge gap between the potential and realized yield in most of the pulses. One of the important reason for low productivity of pulses are they are grown on poor and marginal lands with minimum inputs. Indian soils are deficient in micronutrients such as boron (B), zinc (Zn) and other nutrients sulphur (S) and magnesium (Mg) (Pal *et al.*, 2018) [13].

The availability of good quality seeds, lack of proper infrastructure for post harvest processing and storage, inadequate credit and marketing facilities are major socio-economic constraints (Kumar *et al.*, 2022) [9].

Many farmers still resort to conventional agricultural practices. They lag behind in the adoption of recommended cultivation practises (Dixit *et al.*, 2024) [6]. The proper adoption of recommended practices of cultivation and newer technologies is essential for the rejuvenation of production. The low harvest index (15-20%), high rate of flower drop and prevalence of C3 mechanism are the major physiological limitation (Kumar *et al.*, 2022) [9]. Owing to the inadequate adoption of production technology that led to low productivity of pulses, various alternatives were considered over the conventional cultivation practices. Foliar nutrition with multi nutrients is an easy and economic method and also an alternative means used to increase the productivity and also to mitigate the abiotic stresses in the changing climate scenario.

Foliar nutrition

Foliar nutrition is defined as the application of mineral nutrients or plant growth promoting substances in liquid form directly to the leaf surface. The absorption of nutrients take place through the stomata and epidermis. The productivity decrease in pulses is mainly attributed to the decreased soil fertility especially micro and macro nutrients, imbalanced fertilizer application and physiological disorders. The factors such as inefficient partitioning of assimilates, poor pod setting, excessive flower abscission and lack of nutrients during critical stages lead to nutrient stress, poor productivity (Maheswari and Karthik, 2017) [14].

Foliar application may be useful to early maturing pulse crops under rainfed conditions where moisture is limiting factor. Foliar application of nutrients using water soluble fertilizer is one of the possible way to increase the nutrient use efficiency. In contrast with soil application, foliar application has been credited with quick and efficient utilization of nutrients, elimination of losses through leaching and fixation and regulation on the uptake of nutrient by plants (Manonmani and Srimathi, 2009) [15]. The efficient transport of nano fertilizer applied as foliar spray by plants contribute to increased photosynthetic rates and greater dry matter accumulation boosting stover output (Rajput *et al.*, 2022) [16].

Mechanism of foliar nutrition

1) **Penetration:** The nutrient gain entry into the leaf by penetrating through the outer cuticle and the wall of the underlying epidermal cell. Stomata also offers an alternate pathway for penetration of nutrients in foliar spray.
2) **Absorption:** Once penetration has been completed the nutrients are absorbed by the leaves through apoplastic and symplastic pathway.

Timing of foliar application

Meteorological conditions (Alshaal and El Ramady, 2017) [17]

Time of the day	Early morning: before 10:00 AM. Late evening: after 4:00 PM.
Temperature	Low temperature 18-19 ^{0}C (Ideal 21 ^{0}C)
Humidity	Greater than 70% relative humidity
Wind speed	Less than 5 mph
Rainfall	Minimum 24 hrs of rainfall free after foliar application

Role of foliar nutrition in productivity enhancement of pulses

1. Growth and physiology

Macronutrients

Das and Jana (2015) reported that application of 2% urea spray over basal dose of fertilizer application (control) during the pre-flowering stage in pulses produced a higher seed yield than the recommended dose fertilizer (RDF)-control) [18]. Maheswari and Karthik (2017) reported that foliar application of 2% DAP significantly increased the plant height number of branches per plant in black gram, green gram, cowpea and horse gram, respectively. This was statistically on par with spray of 1% KCl and 1% boron [14].

Girigoud *et al.* (2023) reported that nano DAP applied as foliar spray resulted in higher value of growth attributes such as plant height, number of branches, and total dry matter production compared to the control in pigeon pea [19].

Maheswari and Karthik (2017) reported that the leaf area index and dry matter production (81.57, 89.91, 101.50 and 92.83 g per plant) were increased with the foliar nutrition of 2% DAP for in black gram, green gram, cowpea and horse gram, respectively. This was comparable with foliar spray of 1% KCl and 1% boron at flowering and pod setting stage of pulse crop [14].

Sowmya *et al.* (2023) reported that foliar nutrition with KNO_3 0.5% in green gram at 15 and 30 DAS resulted in taller plants with more number of branches at flowering and at harvest stages [20].

Waghmare *et al.* (2019) reported that foliar spray of water soluble fertilizer (19:19:19) at 2.0% concentration along with

basal dose of fertilizer at flowering and pod development stages recorded significantly higher yield, higher nutrient uptake and higher protein content in chickpea [21].
Lakshmi *et al.* (2017) conducted a study to evaluate the effect of foliar application of secondary nutrients (1% $CaNO_3$, 1% $MgNO_3$ and 1% Sulphur) and zinc on growth and yield of green gram. The study revealed that RDF + Foliar application of 1% each of $CaNO_3$, $MgNO_3$ and Sulphur recorded the highest plant height (31.71cm), leaf area index (0.85) and dry matter production (2948 kg ha^{-1}) [22].

Micronutrients
Kavya *et al.* (2021) reported that combined application of RDF + Fe 0.5% + Zn 0.5% + Mn 0.5% at 30 DAS resulted in higher plant height (42.42 cm) which was 14.5% higher than the control (RDF + water spray). The foliar application Fe 0.5% resulted in maximum number of nodules which was significantly superior over rest of treatments [23]. Rathod *et al* (2020) reported that in chickpea along with RDF, foliar application of zinc as $ZnSO_4$ 0.5% + B as solubor (0.2%) resulted in higher number of branches (6.19), higher total biomass production (1944 kg ha^{-1}), number of nodules (30.22) and higher zinc and boron uptake by grain and straw (287.02 and 334.39 g ha^{-1} respectively) compared to control [24].
Vinutha (2019) reported that foliar application of B 3% + Mo 0.1% along with RDF recorded the highest plant height, the number of nodules per plant, the fresh weight of nodules per plant at 45 and 60 DAS, respectively. The N, P and K uptake was also significantly increased with the application of B and Mo showing the highest value for the application of B 3% + Mo 0.1% along with RDF [25].

2. Yield and Yield Attributes
Macronutrients
Das and Jana (2015) reported that irrespective of basal dose of fertilizer application, urea spray 2% was significantly better than all other treatments for better seed yield in green gram (1158 kg ha^{-1}), black gram, lathyrus (2155 kg ha^{-1}), lentil (2045 kg ha^{-1}) and chickpe a (2410 kg ha^{-1}) [18]. Maheswari and Karthik (2017) reported that foliar spray of 2% DAP recorded the highest values for yield attributing characters *viz.*, number of pods per plant, number of seeds per pod, pod length and test grain weight than other foliar spray treatments [14]. The increase in yield attributes might be due to the supplementation of nutrients at the critical stage without physiological stress. Foliar application of nutrients enhanced the number of floral buds, prevented the floral shedding by maintaining optimum bio-physiological conditions in plants. Adequate and continuous nutrient availability through soil and foliar nutrition promotes the supply of assimilates to sink or yield container, thus enlarging the size of the yield structure [14].
Sowmya *et al.* (2023) reported that foliar application of KNO_3 0.5% recorded higher number of pods, number of seeds per pod and grain yield (880.85 kg ha^{-1}) compared to other treatments. This was on par with DAP 2% + KNO3 0.5% [20].
Pooja *et al.* (2023) reported that foliar spray of 19:19:19 (1%) and naphtelene acetic acid (NAA) at 40 mg L^{-1} and Salicylic acid at 100 mg L^{-1} at 45 and 60 DAS resulted in higher seed yield, dry matter production and also higher net income and benefit cost ratio for Sumanjana and DBGV 5 varieties of black gram [26].
Fanish *et al*. (2022) reported that foliar application of 0.5% 19:19:19 spray along with RDF (25:50:25:20 kg NPKS ha^{-1}) recorded higher number of seeds per pod, 100 seed weight which was on par with foliar spray of 1% MAP in pigeon pea [27].

Micronutrients
Kavya *et al.* (2021) reported that yield attributing characters of green gram significantly influenced by combined foliar application of micronutrient. The maximum no. of pods/plant (58.40), maximum seed yield (1384 kg ha^{-1}) and maximum stover yield (2253.33 kg ha^{-1}) was obtained with RDF(20:40:20 kg NPK ha^{-1}) along with 0.5% Fe, Zn, Mn at 30 DAS (58.40) which was significantly superior over control by 19.64 per cent [23].
Rathod *et al.* (2020) reported that foliar application of micronutrient had a significant impact on yield attributes. The foliar application of as Zn SO_4 0.25%+ B as solubor 0.1% along with RDF (25:50:25 kg ha^{-1} NPK) resulted in higher seed yield (1262 kg ha^{-1}) was recorded than control (RDF alone) (765 kg ha^{-1}) [24].
Vinutha (2019) reported that RDF + foliar application of B 2% +Mo 0.1% recorded the maximum number of pods per plant whereas RDF+B 3%+Mo 0.1% recorded the maximum number of seeds pod^{-1}, green pod yield compared to RDF alone [25].

Foliar application of organic and bio fertilizer for productivity enhancement in pulses
Sridhara *et al.* (2022) reported that the foliar application of organics had significant impact on chickpea. The results showed that the foliar application of jeevamrutha 25% both at pre-flowering and at pod initiation stages recorded considerably more number of pods per plant (46.5), grain weight per plant (9.45 g), grain yield (2198 kg ha^{-1}), haulm yield (2954 kg ha^{-1}), higher net returns (Rs. 73619 ha^{-1}) and BC ratio (3.74) [27]. The foliar application of either jeevamrutha 25% or cow urine 10% both at pre-flowering and at pod initiation stages helped to increase growth and yield parameters, seed yield and maximum profit and benefit cost ratio in chickpea [28].
Prajapati *et al.* (2022) 75% RDF(20: 40: 00 kg NPK ha^{-1}) + panchgavya 4% at 30 and 45 DAS resulted in significantly higher growth attributes *viz.*, vine length, number of branches per plant, days to physiological maturity and 50 per cent flowering, number of root nodules per plant and fresh weight of nodules per plant as well as yield attributes *viz.*, pods per plant, seed weight per plant, seed index, seed 1957 kg ha^{-1}) and haulm yield (2515 kg ha^{-1}). A fertilizer saving of 25% was possible by adopting either foliar spray of panchgavya 4% or vermi wash 10% at 30 DAS along with 75% NPK application [29].
Ramesh *et al.* (2024) reported that foliar application of fermented fish waste extract (FFWE) 2.0% at flowering stage and 15 days after first spray in mung bean was found to improve the plant height, dry matter production (1770 kg ha^{-1}), leaf chlorophyll content, number of pods per plant, seeds per pod, grain yield and grain protein content [30].
Ajaykumar *et al.* (2022) reported that combination of 100% RDF (25:50: 25 kg ha^{-1} NPK) + PPFM 2% recorded higher growth characters *viz.*, plant height, number of branches per plant, leaf area index and yield attributes *viz.*, number of pods per plant, number of seeds per pod, pod weight, pod height, 100 seed weight and yield *viz.*, grain yield, straw yield and harvest index in black gram [31].

Nano fertilizers for foliar application
Nano fertilizers are synthesised by encapsulating plant nutrients inside nano materials or they are coated as a thin film on surface of these nutrients. Nano-fertilizers are smaller in size, with large

surface area leading to increase in absorption capacity and controlled-release kinetics to targeted sites. (Rameshaiah *et al*., 2015) [32]. Nano-fertilizer improves the ability of the plants to absorb nutrients. Nanopores and stomatal openings in plant leaves facilitate nanomaterial uptake and their penetration deep inside leaves leading to higher nutrient use efficiency (NUE) (Ali *et al*, 2021) [33]**.** Foliar application of 5ml L^{-1} each of Nano NPK L^{-1} of water as foliar application to french bean showed improvement in growth parameters like plant height; number of branches per plant, number of pods per plant, pod weight and pod yield per plot. It also performed best for quality parameters like TSS and ascorbic acid content (Maurya *et al*., 2024) [34]. Foliar application of nano-DAP@ 0.4 per cent at 20, 30 and 40 DAS along with 100 per cent recommended dose of nitrogen + S.T. of nano-DAP in black gram showed increase in growth attributes, number of nodules at flowering, leaf area index, straw and grain yield (Shete *et al*., 2024) [35]. Kandhare *et al.* (2024) conducted a research to study the effect of foliar application of nano fertilizers on the growth and yield of chickpea in rabi 2023-24. The results revealed that growth, yield, quality, nutrient content and uptake were significantly impacted due to foliar spray of nano urea, nano DAP and growth regulator along with 75% NPK. Among the various combination of treatments, treatment 75%RDF + 0:52:34 (0.5% spray) + nano Urea + nano DAP + GA 50 ppm 45 DAS contributed to the highest plant height (54.17 cm), number of branches (6.13), number of pods $plant^{-1}$ (35.61), maximum grain and straw yield (1538.89 and 3663.20 kg ha^{-1}) at harvest [36].

Conclusion

Pulses being important from the point of food and nutritional security has been facing a reduction in productivity over several years due to various reasons. Fertility management is imperative to ensure better crop production on exhausted soils. As it is majorly cultivated under rainfed condition with poor management practices, even soil application of fertilizers at right time and at right quantity may not be efficient due to lack of soil moisture. Availability of moisture becomes scarce, under these circumstances application of nutrients through seed and foliar nutrition may result in efficient absorption of assimilates from source to sink. Thus foliar nutrition is a promising tools for enhancing the productivity of pulses.

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