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Riya Thakur
PG Student, School of
Agriculture, Uttaranchal
University, Dehradun,
Uttarakhand, India

Diksha Nautiyal
Assistant Professor, School of
Agriculture, Uttaranchal
University, Dehradun,
Uttarakhand, India

Sharad Pandey
Professor, School of
Agriculture, Uttaranchal
University, Dehradun,
Uttarakhand, India

Corresponding Author:
Riya Thakur
PG Student, School of
Agriculture, Uttaranchal
University, Dehradun,
Uttarakhand, India

Biofertilizers, a boon for Lentil (*Lens culinaris* Medik L.) production: A Review

Riya Thakur, Diksha Nautiyal and Sharad Pandey

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Abstract

Lentil (*Lens culinaris* Medik L.) is one of the important cool season legume crops worldwide which is rich in protein, dietary fibre and micronutrients. Poor soil fertility, low nutrient availability and excessive use of costly chemical fertilizers are among the major constraints in lentil production. Formulations containing living beneficial microorganisms, known as biofertilizers have proven to be economical and environmentally friendly and have become an alternative solution to increase the growth, nodulation and yield of lentils. The main types of biofertilizers that can be used for lentil are: Rhizobium inoculants, phosphate-solubilizing bacteria (PSB), arbuscular mycorrhizal fungi (AMF), and plant growth-promoting rhizobacteria (PGPR). This review aims to bring together the latest research (2020-2026) on the different types of biofertilizers, their mode of action, effects on plant growth parameters and productivity of lentil, impact on soil health, and the challenges and potential of their broader application. The potential of biofertilizers - especially as a combination - to significantly increase lentil productivity and to lower the environmental burden of lentil production is well supported.

Keywords: Biofertilizers, lentil, rhizobium, nitrogen fixation, PGPR, phosphate solubilization, arbuscular mycorrhizal fungi, sustainable agriculture

Introduction

Lentil (*Lens culinaris* Medik L.), a member of the Fabaceae Family, is one of the most ancient cultivated legume crops. A food security crop that is eaten throughout South Asia, West Asia, the Mediterranean and Sub-Saharan Africa. Lentil has a higher amount of protein, (24-32%) compared with many other legumes, it is relatively low fat and also pretty loaded with dietary fiber. In addition, it brings micronutrients in meaningful levels like iron zinc, and folate, even. The protein is said to keep a good equilibrium of essential amino acids (Thavarajah *et al.*, 2022) [22]. Canada, India, Australia, Turkey and Nepal are the leading lentil-producing countries. Although lentils are important crops in terms of agronomic and nutritional value, many smallholder farming systems have low yields. In South Asia average yields mostly sit around 700-1,000 kg/ha, which is well under what can be achieved if management is better, roughly 2,500-3,500 kg/ha (FAO, 2023) [5]. This difference is usually blamed on low soil fertility, irregular rainfall and also high rates of chemical fertilizer use that people simply can't afford, plus crop management that is not so good. Though chemical fertilizers improve short-term productivity, they also aggravate soil degradation, soil acidification, loss of biodiversity and greenhouse gas emissions which pose serious sustainability issues (Kumar *et al.*, 2021) [11]. Biofertilizers, which contain living microorganisms that are able to fix atmospheric nitrogen, solubilize mineral phosphorus and/or stimulate plant growth by producing hormones and enzymes, are a promising alternative. They are affordable, eco-friendly, environmentally friendly, and do not pose any issues for organic farming practices, and can significantly enrich the plant's nutrient uptake without having environmental impact as compared to the synthetic inputs (Nosheen *et al.*, 2021) [15]. New developments in microbial biotechnology have also increased biofertilizer products to lentil farmers. It is a review of the current knowledge (2020-2026) about the use of biofertilizers for lentil production covering their mechanism, effectiveness under field conditions, soil health effects, coinoculation and challenges for wider use.

Lentil: Crop Profile and Nutritional Significance

Lentil is pretty much a self-pollinating herbaceous annual plant that can grow up to about 20-75 cm tall. It has small, pinnately compound leaves, and then lens shaped seeds sitting in short, flattened pods. This crop tends to do better in cooler, semi-arid surroundings, and it also fits dryland farming systems pretty well too. It likes well drained soils, preferably neutral to just slightly alkaline, Erskine *et al.*, 2011, as cited in Tiwari *et al.*, 2022)^[23].

Lentil seeds are a good source of protein (24-32%), complex carbohydrates (50-60%) and iron (6-9 mg/100g), are one of the best plant sources of zinc (3-5 mg/100g), source of folate and polyphenols (Didinger & Thompson, 2021)^[3]. Lentil is especially useful in vegetarian, low-income foods which lack animal protein. It also plays an important role in food system sustainability, as it is less water and fertilizer intensive than cereals.

Lentil has been seen to add fertility to the soils in cropping systems, resulting from the symbiotic relationship between Rhizobium bacteria and lentil that leaves behind residual N in the soil for the next crop of cereal (Iqbal *et al.*, 2020)^[8]. This is a contribution of nitrogen that is a major reason lentil is a key component in many sustainable rotation systems around the world.

Biofertilizers Definition, Classification, Mode of Action

Biofertilizers are the substances containing living or latent microorganisms which, when applied to the rhizosphere or plant interior via external surfaces of seeds, plant or soil, helps the growth process by increasing the supply or availability of primary nutrients (Nosheen *et al.*, 2021)^[15]. Biofertilizers have the advantage of not providing nutrients directly to plants as do chemical fertilizers, but rather improving the capacity of the plant to utilize the nutrients present in the natural environment.

Lentil production can be supplemented with biofertilizers, which can be divided into 4 major groups according to the microorganism type and the nutrient that is targeted:

- **N₂ fixation biofertilizers:** These are the symbiotic bacteria which fix air borne N₂ in the root nodule like Rhizobium leguminosarum bv viciae and free living bacteria like Azotobacter and Azospirillum fix nitrogen in the rhizosphere (Sindhu *et al.*, 2020)^[19].
- **Phosphate-solubilizing biofertilizers:** The bacteria and fungi like Bacillus, Pseudomonas and Aspergillus spp. which transform the insoluble inorganic phosphates into soluble and available inorganic phosphates by producing organic acids and phosphatases (Khan *et al.*, 2021)^[10].
- **Arbuscular Mycorrhizal Fungi (AMF):** These are fungi that form symbiotic association with roots of lentils and increase the absorbing area of roots for phosphorous, zinc and water by a great factor (Garg & Bhandari, 2021)^[6].
- **Plant Growth-Promoting Rhizobacteria (PGPR):** These are free-living bacteria which are able to promote plant growth by various direct or indirect mechanisms such as production of phytohormones, synthesis of siderophores and induced systemic resistance (ISR) (Etesami & Maheshwari, 2021)^[4].

The use of rhizobium inoculants and biological N₂ fixation in lentil: Biological nitrogen fixation (BNF) is basically the enzymatic reduction of dinitrogen (N₂) into

ammonia (NH₃) carried out by the nitrogenase enzyme complex, and most of it happens in root nodules of lentil, those nodules formed through symbiosis with Rhizobium leguminosarum bv. viciae. This process is pretty important for the N economy of lentil cropping systems (Iqbal *et al.*, 2020)^[8].

Using effective Rhizobium strains to inoculate lentil seed just before planting is a simple, low cost approach, it should help ensure solid nodulation, especially when Rhizobium populations are small in the soil, or when the local indigenous strains are not very effective. Jaiswal *et al.* 2021^[9] reported that Rhizobium inoculation gave a higher nodule number (35 to 50% more than the uninoculated control) and a higher nodule dry weight (about 40% above the uninoculated control). These nodulation gains also came with about a 22% jump in grain yield, plus a clear improvement in seed protein content.

A multi location field trial was also carried out, in which inoculated lentil was grown with effective Rhizobium isolates taken from lentil growing areas of Bangladesh, Alam *et al.* (2020)^[1] did this work and they found that seeding inoculation with locally sourced, effective Rhizobium strains could spare roughly 20-30 kg N/ha of synthetic nitrogen fertilizer, and still the grain yield stayed similar to chemically fertilized plots. Overall, this confirms the financial value and environmental friendliness of Rhizobium inoculants for lentil production.

The success of Rhizobium inoculants will mostly hinge on how well the strain, matches the host, plus the optimum soil pH (6.0-7.5), soil temperature, and also the lack of certain agrochemicals that can act as inhibitory compounds (Sindhu *et al.*, 2020)^[19]. In fact, the inoculant performance is much reduced in acidic as well as very saline soils so there is that practical need for stress tolerant Rhizobium strains when the soil conditions feel rough.

Sharma *et al.* (2023)^[18] recently put forward that acid tolerant Rhizobium strains, picked through screening, were able to nodulate lentil even when soil pH dropped to around 5.5, and this sort of result creates new chances for lentil cultivation in areas that had been regarded as unsuitable earlier.

Phosphate-Solubilizing Biofertilizers in Lentil.

Phosphorus (P) is the second macronutrient, after nitrogen, that is most likely to limit production of lentils. Many of the phosphorus contained in soil is in forms that are chemically bonded to calcium, iron or aluminum and is unavailable to plants; many believe that 60-80% of soil phosphorus is unavailable in this manner. Phosphate-solubilizing bacteria (PSB) release these locked phosphates through the production of low-molecular-weight organic acids such as gluconic acid, citric acid, oxalic acid and tartaric acid and phosphatases and phytases which make the phosphorus more plant available in the rhizosphere (Khan *et al.*, 2021)^[10].

In a controlled greenhouse study, Meena *et al.* (2020)^[13] showed that the available soil phosphorus level was higher by 38% and the shoot dry biomass rose by 29% for lentil plants, when you compare them to the uninoculated plants. The work also noticed that the enzyme activities (acid and alkaline) were clearly higher in the rhizosphere soil than in bulk soil, so there seems to be more biochemical action right there near the roots..

In field experiments, Pande *et al.* (2022) ^[16] worked in the lentil belt of Madhya Pradesh, India and reported that the grain yield with PSB (*Bacillus subtilis*) + 50% of the recommended dose of phosphate fertilizer was statistically on par with the full recommended dose of chemical fertilizer. From that outcome, it can be said that PSB use may cut down the phosphate fertilizer input by as much as 50% in lentil cultivation, and this can help smallholder farmers save phosphate cost, basically easing their expense burden.

The secondary benefits of the organic acids produced by PSB is their ability to chelate micronutrients like the chelation of zinc and iron and render the micronutrients more available to lentil plants in micronutrient deficient soils (Nosheen *et al.*, 2021) ^[15].

Lentil (*Lens culinaris* Medik L.) cultivation with plant growth-promoting rhizobacteria (PGPR)

PGPR are a wide range of soil bacteria which grow around the rhizosphere and have a promoting effect on the growth of the plant through both direct and indirect effects. Direct mechanisms include:

Production of Auxin (indole-3-acetic acid, IAA): PGPR make auxin (IAA), and this seems to help in encouraging root hair proliferation. It also supports lateral root formation plus root elongation, so the plants end up with a more extensive root setup, basically allowing them to explore soil better and tap nutrients and water (Etesami & Maheshwari, 2021) ^[14].

Gibberellin and cytokinin production: These plant growth regulators are linked with shoot elongation and cell division, in a sort of complementary way, and therefore they boost the vegetative vigor of lentil plants (Backer *et al.*, 2020) ^[12].

ACC deaminase activity: PGPR additionally produces 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase, which reduces plant ethylene levels. Less ethylene means stress responses are countered, and root growth can keep going even when drought, salinity or heavy metal conditions show up (Glick, 2020) ^[17].

Siderophore production: Another trait is siderophore output, meaning iron-chelating molecules. By grabbing iron in the rhizosphere, PGPR can improve iron nutrition in lentil and also slow down soil borne fungal pathogens, because the microbes end up competing for that same iron (Singh *et al.*, 2022) ^[20].

Indirect effects of PGPR involves the induction of systemic resistance (ISR). They can also produce volatile organic compounds (VOC) that repel insect pests, and biofilm formation that helps stabilize the rhizosphere communities, so it becomes more settled and less chaotic (Backer *et al.*, 2020) ^[12].

Kumar *et al.* (2022) ^[12] tested 16 PGPR strains on lentil that were grown in a field setting in Uttar Pradesh, India, and they found that the *Bacillus velezensis* strain BV-11 had the top IAA concentration (38 µg/mL), plus it was also the most compatible with *Rhizobium*. Because of that, there were reported gains of about 28% for grain yield and 24% for straw yield, when compared to the uninoculated control. They even noted an improvement in lentil wilt, which is caused by *Fusarium oxysporum*, by 34%, so overall it points toward both growth promoting and biocontrol type effects.

Then Nosheen *et al.* (2021) ^[15] did a meta-analysis covering 45 field trials across South Asia and saw that when PGPR were inoculated into lentil and other food legumes, grain

yield jumped roughly 16-22% on average. The strongest results showed up mainly in nutrient poor places or during drought, so the advantage wasn't random, it was more like stressed conditions favored the response.

Response of Lentil to Arbuscular Mycorrhizal Fungi (AMF):

About 80% of terrestrial plants, such as lentil, can form obligate mutualistic association with arbuscular mycorrhizal fungi (AMF). Fungal hyphae reach several centimetres beyond the rhizosphere to give the plant access to soil volumes and nutrient pools which are greater than the root hairs alone. The plant, in turn, receives a 10-20% of the photosynthetically fixed carbon from the plant (Garg & Bhandari, 2021) ^[16].

In lentil the main benefit of AMF is better phosphorus uptake. AMF have extremely fine hyphae which can penetrate narrow pores in soil which the roots cannot reach, and the AMF enzyme, alkaline phosphatase, which is produced by the AMF hyphae, can break down organic phosphate and make it more available for the plant. The inoculation of *Rhizophagus irregularis* on lentil resulted in an increase in phosphorus uptake by 55% and grain phosphorus concentration by 40% in phosphorus-limited soils (Salloum *et al.*, 2022) ^[17]. In addition to phosphorus, AMF increase level of uptake of zinc, copper, and water in lentil and greatly increase plant tolerance to drought and soil salinity. However, Garg & Bhandari 2021 have shown that AMF-colonized plants had significantly higher relative water content, Chl content and antioxidant enzyme activity compared to AMF-free plants under 60% FC (water stress), highlighting the protective effect of AMF in drought conditions ^[16].

AMF also increase the nodulation and nitrogen fixation ability of lentil as they have a beneficial effect on improving the overall phosphorus and zinc status of the plant which are necessary co-factors of the nitrogenase enzyme complex (Tauqeer *et al.*, 2022) ^[21]. This results in a strong three-way symbiosis (lentil + *Rhizobium* + AMF) which optimizes both the uptake of nitrogen and phosphorus.

Combined (synergistic) use of Biofertilizers (Co-inoculation):

The simultaneous application of two or more compatible beneficial microorganisms in biofertilizer is referred to as co-inoculation, and this development has been one of the most impactful in the field of biofertilizer research. The co-inoculation effect is the result of specific synergistic mechanisms that result in effects that are generally larger than the sum of the individual applications. Some of the most commonly investigated co-inoculation mixtures for lentil are:

***Rhizobium* + PSB:** Both nutrients (N₂ and P) that are most limiting for the production of lentils are supplied at the same time: *Rhizobium* is used to fix atmospheric nitrogen, and PSB is used to make soil available for lentil crop uptake.

***Rhizobium* + PGPR:** PGPR increase nitrogen fixation ability of *Rhizobium*, increase root architecture, improve nodulation and help to protect against pathogens.

***Rhizobium* + AMF**

AMF enhances the availability of P and Zn, which can improve plant water relations and function of the nodules and N fixation.

Triple inoculation (Rhizobium + PSB + PGPR): Triple inoculation that targets nitrogen fixation, phosphate solubilization and growth promotion.

A 2-year field trial in Varanasi, India, with co-inoculation using *Rhizobium leguminosarum* and *Bacillus megaterium* (PSB) on lentil kinda showed that grain yield was 34% higher, and biological nitrogen fixation 29% higher, compared with using single *Rhizobium* inoculation only (Mishra *et al.* 2020)^[14]. The soil assessment pointed toward a higher level of available phosphorus 18 kg/ha and also higher microbial biomass carbon, relative to the uninoculated soil, so yeah.

Zahir *et al.* (2021)^[25] did triple co-inoculation of lentil using *Rhizobium*, PGPR (*Pseudomonas fluorescens*) and AMF (*Glomus mosseae*) across three soil types in Pakistan. For this triple inoculation, it was consistently more effective than any of the single, or even dual inoculation combinations, and that “better-than” pattern held during the whole study. Overall, grain production rose by 41-48%, seed protein increased by 4.2%, and the requirement for NPK fertilizers dropped by about 40%, all without reducing productivity, or lowering the output.

A recent systematic review (Yadav *et al.*, 2023)^[24] that provided a meta-analysis of 78 published studies on legume biofertilizer co-inoculation concluded that the average crop yield by multi-strain inoculation was 30-45% higher than the uninoculated control, and that the most consistently observed treatment was the three strain inoculation (*Rhizobium* + PSB + AMF) under different soil and climate conditions.

Issues on Biofertilizers

Biofertilizers not only boost the growth of the plants throughout the cropping season but have a long-term beneficial effect on soil biological health that can be carried over from one season to the next. These benefits include:

Enhanced soil microbial biomass and diversity: When biofertilizers are added, they tend to raise the carbon stored in microbial biomass (MBC), shift the fungal to bacterial proportion, and even increase soil bacterial diversity. This has been shown using high throughput sequencing of the 16S RNA gene, (Tauqeer *et al.*, 2022)^[21]. In other words, a more diverse and quite energetic soil microbiome can handle organic matter breakdown better, recycle nutrients, keep harmful organisms in check, and also tolerate small disturbances in the field.

Increased soil enzyme activity: Enzymes in soil, like dehydrogenase, urease, phosphatase, and beta-glucosidase are widely used as signals for soil biological condition. In biofertilizer amended lentil soils, these activities are usually higher. Singh *et al.* (2022)^[20] reported that in *Rhizobium* + PSB co-inoculated soils, dehydrogenase activity jumped by about 25-40% compared with uninoculated soils, and phosphatase activity was roughly 30-45% greater in the co-inoculated treatment.

Biofertilizer treated crops also release more root derived inputs. Root exudates, sloughed root cells, and the mycorrhizal hyphal network all work together, and they can enlarge soil organic carbon pools in a pretty noticeable way. Over seasons, this often supports improved soil aggregate stability, better water holding capacity, and stronger Cation Exchange capacity in the soil (Kumar *et al.*, 2021)^[11].

Less nutrient leaching into water: Biofertilizers keep nutrients either bound up in the plant-microbial biomass or

as unattached ions in soil solution and this helps to control nutrient leaching into groundwater, which plays a key role in minimizing eutrophication of water bodies (Nosheen *et al.*, 2021)^[15].

Biofertilizers: an emerging solution to alleviate abiotic stress in lentil:

Climate change is making abiotic stresses (such as drought, heat and salinity) more prevalent in lentil production. Recently, it has been revealed that biofertilizers play an important role in helping the lentil plant withstand these stresses. AMF colonization under drought stress conditions has a significant effect on the water relations of plants, enhancing the surface area of the root system and the presence of glomalin-related soil proteins that enhance water retention and soil aggregate stability. In a situation of moderate drought (about 50% FC) Salloum *et al.* (2022)^[17] reported something like AMF-inoculated lentil plants staying with a photosynthetic performance, keeping their relative water content, and also retaining shoot fresh weight by roughly 25-35% compared to non-mycorrhizal stressed plants.

In lentil, it has been reported that PGPR with ACC deaminase activity can reduce stress ethylene production, so the plants can keep growing their roots and shoots more or less normally even under NaCl concentrations up to 100 mM (Glick, 2020)^[7]. The findings by Zahir *et al.* (2021)^[25] also indicate that PGPR inoculation eased the negative impacts of moderate salinity on germination rate, seedling vigor and early stage establishment in lentil, so the early phase looks steadier.

Meanwhile, *Rhizobium* strains that were isolated from the roots of tolerant legumes, have been described as capable of nodulating legumes well in warm soil, and they are being refined into new inoculant formulations to support lentil yields in warmer regions (Sharma *et al.*, 2023)^[18]. This matters quite a lot for South Asian conditions, because soil temperatures tend to be a limiting factor during the lentil pod filling period in spring, and that timing is not very forgiving.

Challenges and constraints in adoption of biofertilizers

Although the evidence of their effectiveness is high, biofertilizers have several challenges to overcome for their large scale use among the lentil farmers especially in the developing countries.

Poor shelf life and viability problems: Most biofertilizers consist of living microorganisms, whose viability is affected in the process of storage, transportation and usage in the field. Peat-based carriers are suitable for storage for 6-12 months while liquid formulations may become unsuitable when stored under too warm conditions in tropics (Yadav *et al.*, 2023)^[24].

- **Strain-host specificity:** *Rhizobium* inoculants tend to be, very picky about how well they work, meaning the real effectiveness depends on the fit between the bacterial strain and the specific lentil cultivar. So the inoculant that works well for one lentil type may not really work at all for another type, and this kinda narrows how useful the recommendations are for farmers that grow different lentil varieties (Sindhu *et al.*, 2020)^[19].

- **Biofertilizer sensitivity to soil environment constraints:** The soil pH, temperature, moisture, plus heavy metal and pesticide burdens are key drivers for

how biofertilizers perform. These inoculants can become unusually fragile, especially when soils are strongly acidic, waterlogged, or fumigated, also when soils get heavy pesticide treatment (Meena *et al.*, 2020)^[13].

- **Competition from native microorganisms:** If the soils already have a high population of native Rhizobium, or even other rival bacteria, the introduced Rhizobium strains may not manage to colonize the rhizosphere properly, so you end up with poor nodulation (Iqbal *et al.*, 2020)^[8].
- **Lack of quality control and regulation:** In several markets across South Asia and Africa, commercial biofertilizer products are often under par, with inadequate counts of living cells or cultures, and sometimes they also end up contaminated. That situation then causes inconsistent results in the field and, well it makes farmers lose trust pretty quickly (Kumar *et al.*, 2021)^[11].
- **Lack of awareness and extension gaps among farmers:** Many smallholder lentil farmers basically do not know about biofertilizers, the right way to apply them, or what the benefits actually look like in practice. Also, restricted access to agricultural extension services and even credit makes adoption slower, or delayed (Pande *et al.*, 2022)^[16].

Directions for future research and prospects

The field of biofertilizer research is a very dynamic one as new technologies such as microbial metagenomics, nanotechnology, and precision agriculture emerge. There are several avenues of research that are emerging in lentil that show tremendous promise for enhancing the performance of biofertilizers:

Whole genome sequencing and comparative genomics are helping to identify the genes affecting the nitrogen fixation efficiency, stress tolerance and host compatibility of Rhizobium and PGPR strains in order to guide strain improvement. This knowledge is being applied to create improved strains of inoculants via targeted mutagenesis or directed evolution (Sharma *et al.*, 2023)^[18].

Nano-biofertilizers: The idea with nano-carriers like chitosan nanoparticles, halloysite clay nanotubes, and silica nanoparticles is that they can shield microbial cells or the metabolites from those tough environmental conditions. They also tend to extend shelf life, and then, you can get a slower, more controlled release right in the rhizosphere, kind of like a steady drip rather than a quick burst. Early work suggests that formulations containing nano-encapsulated Rhizobium along with PGPR, are more usable in real field situations than the usual peat based products (Yadav *et al.*, 2023)^[24].

Microbiome engineering for lentil: The work on metagenomic studies, on how microorganisms actually live in the rhizosphere of high yielding lentil plants is starting to reveal the kind of variety these friendly microbes have. More and more researchers are pushing toward customized, designer microbial consortia that are matched to lentil genotype and also the soil situation, and honestly this feels like a fresh lane inside biofertilizer science (Tauqeer *et al.*, 2022)^[21].

Precision and digital agriculture integration: There are also trials now for smart delivery systems that lean on real-time soil sensor information plus satellite imagery, and they

deliver biofertilizers with very exact rates, exact spots, and the right time windows in field crops including legumes. In principle these systems can improve the use efficiency of biofertilizer inputs, so not much is wasted (Backer *et al.*, 2020)^[2].

Variety development for lentil: Considering the nodulation efficiency and mycorrhizal responsiveness as selection criteria in lentil variety development has gained importance and lentil is being bred for optimum nodulation and/or mycorrhizal responsiveness to the available biofertilizer inoculants (Singh *et al.*, 2022)^[20].

Conclusion

Biofertilizers are among the most promising technologies to promote a sustainable improvement in lentil production. The evidence reviewed here clearly indicates that Rhizobium inoculants and phosphate-solubilizing bacteria, plant growth-promoting rhizobacteria and arbuscular mycorrhizal fungi can have a positive effect on the nodulation, growth and yield of lentil, and on the biological health of soils, when used individually or collectively. Often, inoculants of two or three groups of microbes can be combined into a co-inoculant treatment and seen to perform better than inoculation with a single microbial group, and yield improvements of 30-48% may be achieved when compared to uninoculated control. In addition to providing yield benefits, over time, biofertilizers can show benefits of reducing reliance on expensive and environmentally damaging synthetic fertilizers, and increase the resilience of the lentil crop to drought, heat and salinity stress, all of which are likely to be increased as a result of climate change. Achieving the maximum benefits of biofertilizers in lentil production, however, needs coordinated action on various fronts such as formulation technology, quality, stress-tolerant and host-compatible strains, improved access of farmers to biofertilizers through extension services and credit availability, and investments in the research and development of new generation - nano-biofertilizers and microbiomes engineering. Overall, biofertilizers are a positive addition to lentil production and play a pivotal role in establishing sustainable, nutritious, and climate-smart agriculture systems for lentil around the globe.

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