MICROBIAL TECHNOLOGIES for GRAIN LEGUMES

ICAR

ICAR-Indian Institute of Pulses Research

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Preface

Grain legumes are integral to Indian agriculture owing to their vital role in ensuring nutritional security, improving soil fertility through biological nitrogen fixation, and enhancing the sustainability of diverse cropping systems. Pulses such as chickpea, pigeonpea, mungbean, urdbean, lentil, field pea, and other grain legumes contribute significantly to protein intake, particularly among resource-poor populations. Despite their importance, productivity of legume crops remains constrained by biotic stresses such as diseases and insect pests, soil health degradation, and the increasing impacts of climate variability. Addressing these challenges through environmentally benign and resource-efficient approaches has become a national priority.

Microbial technologies have emerged as powerful and sustainable alternatives to conventional chemical-based crop protection and nutrient management practices. Beneficial microorganisms including fungal, bacterial, and viral agents play a multifunctional role in legume production systems by suppressing pathogens and insect pests, promoting plant growth, improving nutrient availability, inducing systemic resistance, and enhancing tolerance to abiotic stresses. Recognizing this potential, the Indian Council of Agricultural Research (ICAR), through its network of national institutes, coordinated research projects, and All India Coordinated Research Programmes, has made significant contributions to the development, validation, and dissemination of microbial technologies specifically tailored for pulse crops.

This book, *Microbial Technologies for Grain Legumes*, has been conceived to compile and present, in a systematic manner, the microbial products and technologies developed by ICAR institutes, with special emphasis on the contributions of the ICAR–Indian Institute of Pulses Research (ICAR-IIPR), Kanpur, and other collaborating ICAR institutions. The contents encompass the biopesticide scenario at global and national levels, the status of microbial technologies in pulses, and detailed accounts of microbial products for disease management, plant growth promotion, and insect pest management. The book further addresses critical aspects such as bio-efficacy evaluation, field application, shelf-life enhancement, storage, quality assurance, regulatory and policy frameworks, biosecurity concerns, and process and methodology involved in microbial product development.

In addition, the publication highlights success stories, impact assessments, intellectual property management, and strategies for partnerships and scaling-up to facilitate effective translation of research outputs into farmer fields and commercial ventures. The inclusion of microbial repository and resource management underscores the importance of conservation, characterization, and judicious utilization of indigenous microbial resources.

The editors gratefully acknowledge the pioneering and sustained efforts of ICAR and its constituent institutes, particularly ICAR-IIPR and collaborating national research centres and State Agricultural Universities, for developing and promoting microbial products for pulse crops. It is hoped that this book will serve as a valuable reference for researchers, extension professionals, industry stakeholders, policymakers, and students, and will contribute meaningfully to the wider adoption of microbial technologies for enhancing productivity, profitability, and sustainability of grain legume production systems in the country.

(Authors)

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Introduction

Agriculture today is confronting unprecedented challenges arising from climate change, declining soil fertility, loss of biodiversity, increasing pest and disease pressure, and the over-dependence on synthetic agrochemicals. These issues collectively threaten global food security and the sustainability of agri-food systems. In this context, microbial technologies—rooted in the manipulation, application, and management of beneficial microorganisms—represent one of the most promising, eco-friendly, and scientifically validated approaches for ensuring long-term soil and crop health. The resurgence of interest in microbial-based solutions reflects a paradigm shift towards biological intensification, where soil biology and natural ecological processes become central to crop production.

Soil is a living system that harbors billions of microorganisms per gram, including bacteria, fungi, actinomycetes, protozoa, and algae. These microorganisms drive essential soil processes: decomposition, nutrient mineralization, carbon cycling, soil aggregation, disease suppression, and plant–microbe interactions. However, intensive farming practices—characterized by excessive tillage, blanket chemical fertilization, pesticide overuse, monocropping, and poor organic matter management—have severely disrupted soil microbial balance. This has resulted in reduced nutrient use efficiency, weakened soil structure, accelerated pathogen build-up, and lower crop resilience. Microbial technologies aim to restore and enhance this soil biological system by harnessing the functional capabilities of beneficial microbial strains.

Over the past two decades, substantial advancements in microbial isolation, characterization, fermentation, genomics, and formulation science have transformed microbial products from rudimentary biofertilizers into highly sophisticated biotechnological interventions. Today, microbial products for soil and crop health management include a diverse range of agents such as nitrogen-fixing bacteria (*Rhizobium, Azotobacter, Azospirillum*), phosphate- and potassium-solubilizing microbes, plant growth–promoting rhizobacteria (PGPR), mycorrhizal fungi, biocontrol fungi such as *Trichoderma* spp., biocontrol bacteria like *Bacillus* and *Pseudomonas*, *entomopathogens* (*Beauveria, Metarhizium*), and novel microbial consortia containing metabolite-producing or stress-tolerant microbes. These organisms perform multiple direct and indirect functions—enhancing nutrient availability, producing growth hormones, combating pathogens, degrading toxins, improving soil organic matter, and strengthening plant defense mechanisms.

One of the most significant applications of microbial technologies is in soil health restoration. Healthy soils are characterized by high microbial biomass, functional diversity, stable soil aggregates, balanced pH, high organic carbon, and efficient nutrient cycling. Microbial inoculants contribute to these attributes by solubilizing bound nutrients, fixing atmospheric nitrogen, decomposing crop residues, improving soil porosity, and activating dormant biological processes. For example, strains of *Bacillus*, *Trichoderma*, and *Pseudomonas* produce extracellular enzymes such as cellulases, proteases, chitinases, and glucanases that degrade organic matter and suppress pathogenic fungi. Similarly, mycorrhizal fungi enhance root architecture and nutrient uptake, especially phosphorus, zinc, and micronutrients.

Microbial technologies also play a transformative role in crop health management, particularly in managing soil-borne and root diseases that have become major constraints to crop production. Soil-borne pathogens such as *Fusarium spp.*, *Rhizoctonia solani*, *Sclerotium rolfsii*, *Macrophomina phaseolina*, and *Phytophthora spp.* are persistent and difficult to control with chemicals. Microbial biocontrol agents suppress these pathogens through diverse mechanisms:

- Mycoparasitism (direct attack on pathogen hyphae),
- Antibiosis (production of antibiotics, VOCs, and metabolites),

- Competition for nutrients and space,
- Iron chelation through siderophore production,
- Induction of systemic resistance (ISR) in the host plant, and
- Production of defense-related enzymes.

In legumes, especially chickpea, pigeonpea, lentil, mungbean, mothbean, cowpea, horsegram, soyabean and uradbean, microbial technologies have become indispensable for managing diseases such as *Fusarium wilt*, *dry root rot*, *collar rot*, *stem canker*, and *Phytophthora blight*. Native strains of *Trichoderma harzianum*, *T. asperellum*, *T. harzianum*, *T. viride*, *Bacillus subtilis*, and *Pseudomonas fluorescens* have shown remarkable efficacy in suppressing these diseases while enhancing plant vigour, root health, and yield. Indigenous microbial strains are often better suited to local agro-climatic conditions, making them more effective and sustainable than generic or exotic strains.

Advancements in formulation technology have further expanded the utility of microbial products. Traditional talc-based powders, while widely used, are gradually giving way to more stable and high-performance formulations such as liquid fermentation-based inoculants, oil-based EC formulations, water-dispersible granules (WDG), alginate encapsulated beads, and bio-priming formulations. These new-generation products offer longer shelf-life, higher CFU, reduced contamination risk, faster field action, and greater convenience for farmers. Additionally, multi-strain and multi-functional microbial consortia are increasingly being developed to provide synergistic effects—for example, combinations of *Trichoderma* with *Bacillus*, or PGPR with Rhizobium—in enhancing plant growth and disease suppression.

On a policy level, microbial technologies are being mainstreamed into national agricultural programs. The Government of India, through initiatives such as Paramparagat Krishi Vikas Yojana (PKVY), National Mission on Sustainable Agriculture (NMSA), National Food Security Mission (NFSM), and Bharatiya Prakritik Krishi Paddhati (BPKP), actively promotes the use of microbial-based inputs. At the same time, strict regulatory oversight under CIBRC ensures quality, biosafety, and strain-level authentication. The widespread use of microbial products aligns with the global push for climate-resilient agriculture, reduced chemical footprints, improved soil fertility, and safer food systems.

As agriculture transitions toward sustainability and resilience, microbial technologies are expected to become foundational components of integrated crop management. Their role extends beyond disease suppression and nutrient enhancement—they contribute to carbon sequestration, soil biodiversity conservation, and mitigation of climate-induced stresses such as drought, salinity, and heat. For pulse-based cropping systems, microbial products offer unique advantages by improving root health, biological nitrogen fixation, and pathogen suppression under rainfed conditions.

This chapter provides a comprehensive overview of microbial technologies and product profiles relevant to soil and crop health management. It discusses their functional mechanisms, categories, formulation types, application strategies, regulatory requirements, and their emerging role in building resilient and sustainable agricultural ecosystems. By understanding and integrating these microbial solutions, farmers, researchers, and policymakers can collectively contribute to restoring soil vitality and achieving long-term productivity in pulse crops and other agricultural systems.

Biopesticide Scenario

1. Global

Currently, the USD 56 billion worldwide pesticide market is anticipated to have a biopesticide market between USD 3 and 4 billion. With compound annual growth rates of 14.1%, it is estimated that the development of biopesticides will outpace that of chemical pesticides. The US biopesticides market is now estimated at roughly USD 205 million, with a predicted increase to nearly USD 300 million by the end of the decade. North America consumes approximately 40% of the world's biopesticide production. The market for European biopesticides was predicted to be worth over USD 135 million in 2005 and reached approximately USD 270 million by 2010, with Oceanic and European countries accounting for 20% of global sales, respectively, as depicted in. Sales of chemical pesticides are anticipated to decrease, whereas sales of biopesticides are predicted to expand moderately in South and Latin America, which, together, account for 10% of the global biopesticide market. As the mega-economies of China and India increase their usage of biopesticides, the Asian market—while still relatively small—presents a significant opportunity for biopesticides. According to India's agricultural ministry, biopesticides currently account for only 2.89% of the 100,000 metric tons of pesticides sold worldwide, but are expected to grow by an estimated 2.3% annually. Bacterial products, particularly those from Bt, are increasingly commonly employed. The biopesticide sector has traditionally placed a high priority on the production of Bt, which is currently the primary bacterium used to control agricultural pests. Its strong position in the biopesticide sector is demonstrated by the fact that, according to the Centre for Agriculture and Bioscience International (CABI 2010), 200 Bt-based products occupy more than 53% of the global biopesticide market, with the USA and Canada consuming approximately 50% of this total . *Bacillus thuringiensis*, which accounts for over 70% of all bacterial biopesticide use, is followed by *B. subtilis* and *B. fluorescens*. In addition to bacterial insecticides, fungi are now being employed as pesticides. Approximately 60% of the market for fungal biopesticides is made up of *Beauveria* species, and 60% of the market for viral biopesticides is made up of nucleopolyhedrosis virus. In general, smaller farms are more likely to use predator and virus biopesticides. Nematodes hold the largest market share (approximately 60%) among the “other” class of biopesticides.

By 2023, biopesticides were estimated to expand at an average annual rate of 8.64% and make up more than 7% (USD 4.5 billion) of the global crop protection industry. In terms of market size, biopesticides are anticipated to catch up to synthetics between the late 2040s and the early 2050s, but there are significant uncertainties surrounding the uptake rates, particularly in regions such as Africa and Southeast Asia, which account for a large portion of the projections' flexibility.

Although the usage of biopesticides is rising by approximately 10% annually on a global basis, it appears that the industry will need to expand even more in the future if these pesticides are to play a significant part in replacing chemical pesticides and eliminating the existing over-reliance on them. Future market growth for biopesticides is closely correlated with biological control agent research. In order to improve the cooperation of businesses and research institutes on this problem, several scientists from various research institutes have conducted some studies. The agriculture industry can and should profit from the coexistence of biopesticides and chemical pesticides as it appears that biopesticides cannot yet totally replace chemical pesticides. In this context, it is envisioned that large-scale industrial development will be facilitated by speeding up the practical application of research findings.

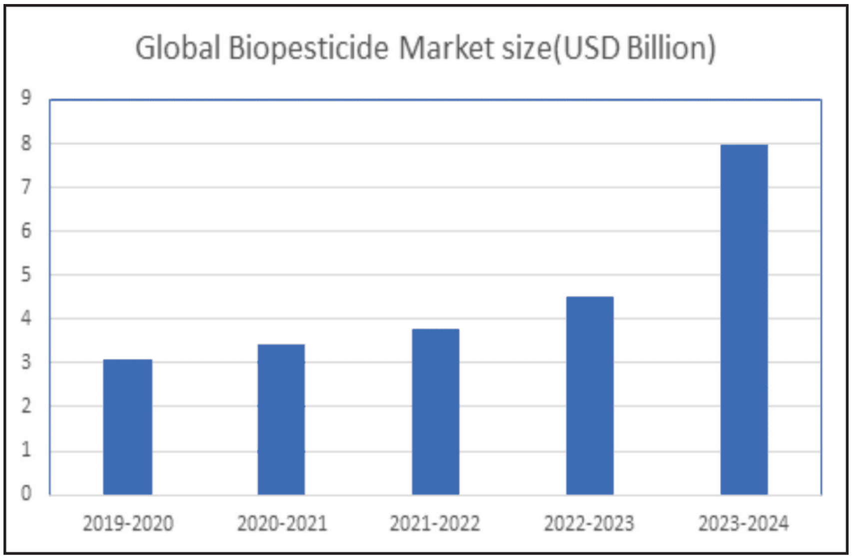


Fig. : Global biopesticide market size (Fortune Business)

Major Companies in the Global Market

- Bayer BioScience
- Syngenta Biologicals
- Corteva Agriscience
- BASF BioSolutions
- Certis USA
- Marrone Bio Innovations (now part of Bioceres)
- Valent BioSciences
- Koppert Biological Systems
- Novozymes
- AgBiome
- Andermatt Biocontrol

These companies invest heavily in R&D, genomics, and formulation technologies.

Regulatory Environment (Global Overview)

United States (EPA)

- Simplified data requirements for microbial biopesticides.
- Rapid approval (3 years on average) compared to chemical pesticides.

European Union (EFSA)

- Stringent regulations but increasing emphasis on low-risk biologicals.
- EU aims to reduce chemical pesticide use by 50% by 2030.

Codex and FAO

- Guidelines for safety evaluation of microbial and botanical pesticides.
- Encourages harmonization to support international trade.

Latin America

- Brazil and Argentina have become hotspots for biopesticide innovation.
- Fast-track regulatory frameworks encourage commercialization.

Global Trends and Innovations

Microbial Consortia

Combining *Trichoderma*, *Bacillus*, *Pseudomonas*, and entomopathogens for broad-spectrum activity.

RNAi-based Biopesticides

Highly specific and environmentally safe gene-silencing pesticides.

CRISPR-Engineered Microbial Strains

Improved metabolite production, stress tolerance, and shelf-life.

Encapsulation and Nano-formulation

Allows:

- Slow-release
- Protection from UV and temperature stress
- Higher stability

Microbiome Engineering

Manipulation of plant-associated microbiome for pest and disease suppression.

Drone-based Application

Quick, uniform application of microbial and botanical solutions.

AI-based Prediction Tools

Pest forecasting models for timely biopesticide intervention.

Global Adoption Scenario

High-Adoption Regions

- USA
- European Union
- Brazil

- China
- Australia
- Israel

Moderate Adoption Regions

- India
- Southeast Asia
- Latin America (outside Brazil)

Low Adoption Regions

- Africa (except Kenya, South Africa)
- Middle East

Factors Influencing Adoption

- Government policies
- Organic farming expansion
- Export-oriented agriculture
- Farmer awareness and training
- Climatic suitability for microbial survival

Challenges in Global Biopesticide Sector

1. Short shelf-life and sensitivity to environmental conditions
2. Variability in field performance
3. High production costs of some formulations
4. Regulatory complexity in many countries
5. Limited farmer awareness in developing regions
6. Interaction with native microbiome not fully understood
7. Intellectual property issues in microbial strain protecti

2. Indian

Biopesticides are pest management agents derived from natural organisms such as fungi, bacteria, viruses, protozoa, botanicals, and biochemical compounds. In India, they have become an integral component of Integrated Pest Management (IPM) and organic/natural farming. Their demand is growing due to increasing awareness of hazards posed by chemical pesticides, environmental concerns, and the push for residue-free agricultural produce.

As of right now, in India, there are 410 production units of biopesticides, 130 of which are private and 280 that are owned by the government (Nilanjana et al 2023). A total of 26 Central Integrated Pest Management Centre units, 31 ICAR/SAU (Indian Council of Agricultural Research institutions/State Agricultural Universities) units, 22 Department of Biotechnology-funded units, and various state sector units, including biocontrol laboratories, are among the units held by the government. Additionally, since 2010, the Ministry of Agriculture and Farmers

Welfare has helped roughly 32 IPM centers and 35 commercial enterprises manufacture biopesticides. The state departments of agriculture and horticulture in Gujarat, Uttar Pradesh, Karnataka, Tamil Nadu, Andhra Pradesh, and Kerala have created several advanced biocontrol facilities to speed up the development of a small number of screened prospective biocontrol agents. Microbial pesticide manufacturing is also being carried out by Indian Council of Agricultural Research (ICAR) institutions and a few state agricultural universities (SAUs). Only a limited fraction of biopesticide manufacturing facilities, including those for botanicals, microorganisms, biocontrol insects, and pheromone lures and traps, have lately migrated to northern India as most were mainly occupied in southern India.

Major government organizations engaged in the commercial manufacturing of various biopesticides include central and state agricultural institutions, as well as a number of ICAR institutes. The Central Research Institute for Dryland Agriculture, Hyderabad, Directorate of Oilseed Research (ICAR), Hyderabad, Kerala Agricultural University (KAU), Kerala, Tamil Nadu Agricultural University (TNAU), Coimbatore, Central Plantation Crops Research Institute (CPCRI), Indian Institute of Horticultural Research, Bangalore, Central Research Institute for Dryland Agriculture, Hyderabad, and Kerala Agricultural University (KAU), Kerala are known for having specialized biopesticide production units. Universities that produce biopesticides against invading pests in the northeast include Assam Agriculture University and Central Agricultural University, Manipur. The manufacturing of biopesticides is carried out in the north by the Indian Agricultural Research Institute (IARI), New Delhi, the Punjab Agricultural University (PAU), Punjab, and the G.B. Pant University of Agriculture & Technology (GBPUA & T), Uttarakhand. The Indian Institute of Sugarcane Research (IISR), the Central Institute for Subtropical Horticulture, and Lucknow's Directorate of Plant Protection Quarantine & Storage—all of which are part of the Central Integrated Pest Management Centre—are the principal government organizations engaged in the production of biopesticides. In addition to these, a number of Krishi Vigyan Kendras (KVK) and state biocontrol labs have been established with government assistance, manufacturing biopesticides to meet local demand. NAFED, the National Agricultural Cooperative Marketing Federation of India, has also begun to advocate for the use of biopesticides.

Nearly 70% of the biopesticides are produced, according to estimates, by the public sector. Several significant companies include Biotech International Ltd. (New Delhi, India), International Panaacea Ltd. (New Delhi, India), Ajay Biotech Ltd. (Pune, MH, India), Deep Farm Inputs (P) Ltd., Pune Indore Biotech Inputs & Research Pvt. Ltd., Ganesh Biocontrol System, Rajkot, GJ, India, Bharat Biocon Pvt. Ltd. (Chhattisgarh, India), Microplex Biotech & Agrochem Pvt. (Mumbai, MH, India), Excel Crop Care Ltd. (Mumbai, MH, India), Govinda Agro Tech Ltd. (Nagpur, MH, India), Kan Biosys Pvt. Ltd.,Chaitra Agri Organics, Mysore, KA, India, Jai Biotech Industries (Satpur, Nasik, MH, India), Gujarat Chemicals and Fertilizers Trading Company, Baroda, GJ, India, Gujarat Eco Microbial Technologies Pvt. Ltd., Vadodara, Indore, MP, India, Romvijay Biotech Pvt. Ltd., Harit Bio Control Lab., Pondichery Neyattinkara, KL, India, Devi Biotech (P) Ltd., Madurai, TN, Yavatmal, MH, India, T. Stanes & Company Ltd., Coimbatore, TN, India and Hindustan Bioenergy Ltd., Lucknow, UP, India. While few foreign businesses have entered the biopesticides industry, the majority of them collaborate with Indian businesses.

In India, the consumption of biopesticides makes up approximately 9% of total pesticide consumption and, by 2050, is anticipated to represent up to 50% of the entire pesticide market. The expected yearly growth rate is 2.5 percent. However, as of now, the biopesticide market has still not developed as anticipated, and it is still relatively small in comparison to the market for synthetic pesticides. The production is comparatively lower as a result of certain challenges at the industrial and policy levels. Nonetheless, the use of biopesticides for sustainable farming has been supported by the National Farmer Policy of 2007. Moreover, records show that India has increased its use of biopesticides over the past few decades. Neem, one of the most frequently used biopesticides in India, saw its consumption rise from 83 metric tons (MT) in 1994–1995 to 686 MT in 1999–2000, while *Bacillus thuringiensis* (Bt) use went from 40 to 71 MT over the same time period. The biopesticide use increased dramatically, above expectations, from 123 metric tons (MT) in 1994–1995 to 8110 MT in 2011–2012. The entire usage of biopesticides in India increased by 40% between 2014–2015 and 2018–2019 based on PPQS statistics, and, over time, reached 8847 and 8645 metric tons in 2019–2020 and 2020–2021, respectively. Meanwhile during the same time period, the consumption of chemical pesticides significantly decreased from 56,114 MT to 43,584 MT.

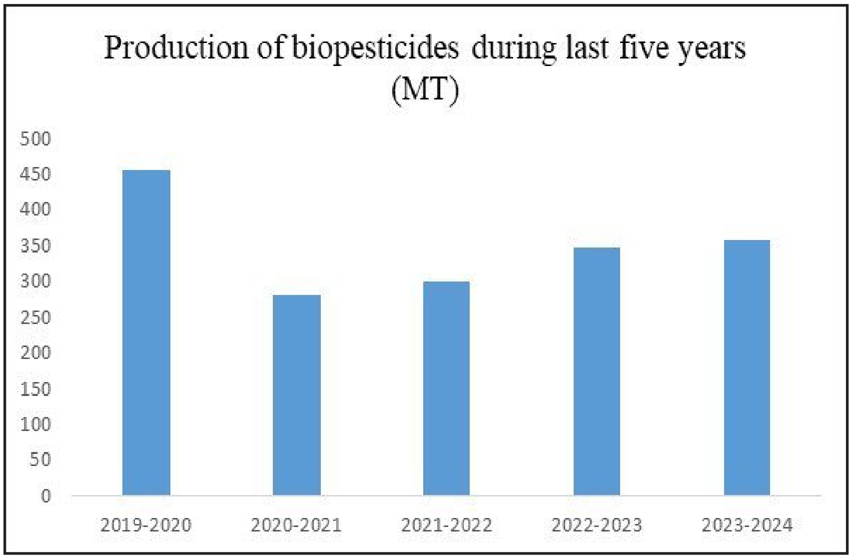


Fig. : Biopesticides consumption from 2019 to 2024 in India (Ghorband et al., 2025)

The Insecticides Act of 1968 registers and regulates biopesticides. According to the Insecticide Act of 1968, only 12 different types of biopesticides have been registered in India (Rajni, et al 2022). They are:

1. *Bacillus thuringiensis var. israelensis;*
2. *Bacillus thuringiensis var. kurstaki;*
3. *Bacillus thuringiensis var. galleriae;*
4. *Bacillus sphaericus;*
5. *Trichoderma viride;*
6. *Trichoderma harzianum*
7. *Trichoderma asperellum*
8. *Pseudomonas fluorescens;*
9. NPV of *Helicoverpa armigera;*
10. *Beauveria bassiana;*
11. NPV of *Spodoptera litura;*
12. Neem-based pesticides;
13. Cymbopogon

Indian Market Status

The biopesticide market in India has expanded significantly:

- Estimated size: ₹ 3,000–3,500 crore (2024).
- CAGR: 15–20%, higher than that of chemical pesticides.
- High adoption in horticulture, pulses, cotton, and rice under IPM.

Regulatory Framework

a. Registration Under Insecticides Act, 1968

Biopesticides must be registered with CIB&RC. However, microbial pesticides have simplified requirements due to their generally low toxicity.

b. BIS Standards

Bureau of Indian Standards provides minimum content requirements:

- *Trichoderma* spp.: 2×10^6 CFU/g (minimum), though many commercial products exceed 10^8–10^9 CFU/g.

c. Pesticide Management Bill (PMB)

The upcoming PMB aims to regulate quality, prevent counterfeit pesticides, and streamline registration. This is expected to support high-quality biopesticide producers.

Production Landscape and Industry Structure

a. Manufacturers

India has ~400–450 biopesticide manufacturers including:

- T. Stanes
- UPL BioSolutions
- IPL Biologicals
- Multiplex
- BASF BioSolutions
- Biotech International

These companies produce microbial, botanical, and biochemical biopesticides at industrial scale.

Government Schemes Promoting Biopesticides

a. National Programs

- Paramparagat Krishi Vikas Yojana (PKVY)
- National Mission on Sustainable Agriculture (NMSA)
- National Food Security Mission (NFSM) – Pulses & oilseeds
- Mission for Integrated Development of Horticulture (MIDH)
- MOVCDNER (for NE region)

b. **State Initiatives**

Many states provide subsidies for neem oil, *Trichoderma*, *Pseudomonas*, and NPV. Extension departments also promote IPM and biologicals.

Challenges in Biopesticide Sector

- High proportion of low-quality/spurious microbial products.
- Non-standardized production and contamination issues.
- Shelf-life instability, especially in hot climates.
- Difficulty in scaling up field efficacy.
- Inadequate extension service support.
- Limited cold-chain/transport facilities.

Opportunities and Future Prospects

- Biopesticides expected to reach 20–25% of pesticide usage by 2030.
- Strong potential for India to become a global hub for microbial biopesticides.
- Emerging next-gen technologies:
  - RNAi-based products
  - CRISPR-modified microorganisms
  - Microbial metabolites
  - Seed microbiome engineering
  - AI-based real-time pest forecasting

3. **Biopesticide Scenario in Pulses in country**

Pulses occupy nearly 29–30 million hectares in India and contribute significantly to nutritional security, soil fertility, and farm income. However, their productivity is constrained by a wide range of soil-borne and foliar fungal pathogens, insect pests, nematodes, and storage pests. Increasing concerns regarding pesticide residues, resistance development, environmental pollution, and consumer demand for safe food have created strong momentum for the adoption of biopesticides in pulse production systems.

Overview of Biopesticide Use in Pulses in India

Biopesticides in pulses mainly consist of:

Microbial biopesticides

- *Trichoderma* spp.
- *Pseudomonas fluorescens*
- *Bacillus subtilis*, *B. amyloliquefaciens*
- Entomopathogenic fungi (*Beauveria bassiana*, *Metarhizium anisopliae*)
- Nematophagous fungi (*Paecilomyces lilacinus*)

Botanical biopesticides

- ○ Neem seed kernel extract (NSKE)
- ○ Azadirachtin-based formulations (0.03–1%)
- ○ Pongamia, Lantana, and other plant extracts (local use)

Biochemical biopesticides

- ○ Semiochemicals (pheromone traps, lures)
- ○ Plant growth regulators of microbial origin

Current Market and Regulatory Landscape

a. Market Size & Growth

- The Indian biopesticide market is valued at ₹ 3500–4000 crore, growing at 15–20% CAGR.
- Microbial biopesticides account for over 55% of this market.
- In pulses, adoption is increasing due to:
  - ○ Residue-free requirements in export markets
  - ○ Strong government push for Natural Farming (BPKP) and Organic Agriculture (PKVY, NMSA)
  - ○ Rising failures of chemical fungicides due to resistance

Regulatory Framework

- All microbial biopesticides must be registered under Insecticides Act, 1968.
- Popular registered formulations for pulses include:
  - ○ *Trichoderma harzianum* 2% WP
  - ○ *T. viride* 1% WP
  - ○ *Bacillus subtilis* 1.5% WP
  - ○ *Pseudomonas fluorescens* 1% WP
  - ○ *Metarhizium anisopliae* 1% WP
  - ○ *Beauveria bassiana* 1.15% WP
  - ○ Azadirachtin 0.03–1% EC
- Several state bio-control laboratories and ICAR institutes have CIBRC-approved strains.

Situation in Pulse-Growing States

a. Madhya Pradesh (largest pulse producer)

- Extensive use of *Trichoderma* and *Pseudomonas* based formulation for wilt and dry root rot management.
- FPO-led production units supplying talc-based formulations.
- Integration of biocontrol agents in NFSM demonstration programs.

b. Uttar Pradesh

- ICAR–IIPR plays a central role in strain corectrization, conservation and formulation development, mass production and training.
- New formulations like Dalhanderma (*T. harzianum*), Pulse Booster (*T. afroharzianum* IIPRTh-33) and Dalhan Bioconsortia being promoted.

Maharashtra

- Strong private-sector manufacturing of entomopathogenic fungi.
- Neem-based pesticides widely used for *Helicoverpa*.

Karnataka, Telangana

- Good adoption of biofungicides through organic clusters and FPOs.
- Use of pheromone traps for *H. armigera* and *Spodoptera*.

Rajasthan

- Increased use of *Trichoderma* for wilt control due to drought-associated root rot outbreaks.

Key Drivers of Adoption

a. Rising Incidence of Soil-Borne Pathogens

Climate change has intensified dry root rot (DRR) and Macrophomina outbreaks in chickpea and pigeonpea due to:

- Higher soil temperature
- Prolonged moisture stress
- Poor soil organic matter

Biopesticides, especially *Trichoderma* and *Bacillus*, have become crucial for managing these diseases.

b. Consumer Preference for Residue-Free Pulses

Pulses are consumed whole, making pesticide residues a major concern. Exporters increasingly prefer produce grown with biologicals.

c. Chemical Pesticide Limitations

- Chemical fungicides often fail against soil-borne pathogens deeply embedded in rhizosphere.
- Insect resistance is common in *H. armigera* and bruchids.

d. Integration with Natural Farming

- Beejamrit, Jeevamrit, and cow-based liquids are used along with standard biopesticides in several states.

Challenges in Biopesticide Use in Pulses

a. Quality Issues

- Up to 30–40% of marketed biopesticides fail CFU standards.
- Short shelf-life (especially talc-based *Trichoderma*).
- Contamination and strain degradation during storage.

b. Farmer-Level Issues

- **Lack of awareness on:**
  - Correct CFU requirement (10□–10□ spores/mL)
  - Proper seed treatment methods
  - Compatibility with fungicides
- Poor soil conditions reducing microbial survival (low organic matter, pH issues).

c. Regulatory and Availability Issues

- Registration is complex and expensive for small producers.
- High-quality liquid and encapsulated formulations are limited.

Advances and Opportunities

a. Advanced Formulations

- Liquid Fermentation-Based *Trichoderma* Higher shelf-life (12–18 months), higher CFU, no contamination.
- Oil-based EC formulations Useful for *Beauveria*, *Metarhizium* under field moisture stress.
- Carrier-free water dispersible granules (WDG) More stable, consistent dose.
- Encapsulated formulations (alginate beads) Slow release, ideal for dry root rot-prone pulses.

b. Multi-strain and Multi-functional Consortia

- *Trichoderma* + *Bacillus* combinations for broader disease suppression.
- *Trichoderma* + *Rhizobium* compatibility for chickpea and pigeonpea.

c. Molecular Strain Characterization

- **Genome-informed strain selection for:**
  - VOC production
  - Chitinase/glucanase efficiency
  - Abiotic stress tolerance
- **ICAR-IIPR, NBAIM, Mau, NBAIR, Bangalore, BARC, Mumbai are leading this work.**

d. On-farm Production Units

- **Low-cost production technologies enable:**
  - SHGs
  - FPOs
  - KVKs

Impact of Biopesticides on Pulse Production

a. Field-Level Benefits

- Yield increase by 10–25% over untreated control.

- Wilt incidence reduction by 40–70%.
- Better plant stand due to improved germination and root vigor.
- Reduction in chemical pesticide usage by 30–50%.

b. Soil Health Improvement

- Increased populations of beneficial microbes.
- Enhanced nutrient availability (P and Zn solubilization).
- Better soil structure and water retention.

c. Environmental and Economic Impact

- Reduced pesticide residues in soil and grains.
- Lower cultivation cost (especially seed treatment).
- Reduced health hazards to farm families.

Microbial Technologies for pulses

In pulse crops such as chickpea, pigeonpea, lentil, mungbean, and uradbean, microbial bioformulations have demonstrated strong potential in enhancing plant vigor, improving nutrient-use efficiency, and suppressing major soil-borne diseases, thereby reducing dependence on chemical inputs. The ICAR–Indian Institute of Pulses Research (IIPR), Kanpur has been a leading institution in developing pulse-specific microbial technologies. The institute has isolated and characterized a wide array of beneficial microbes from pulse rhizospheres, including species of *Trichoderma*, *Pseudomonas*, and *Bacillus*, and formulated them into highly efficient bio-products such as Dalhanderma, Pulse Booster, Pulse Guard, Bioconsortia, Nanotrico1 and Nanotrico2, Trichoemul-1, Trichoemul-2, Dalhanmonas, Nanotrico-3, and Nanotrico-4. These formulations provide integrated benefits by promoting growth, mobilizing nutrients, inducing systemic resistance, and effectively suppressing soil-borne pathogens. Many of these technologies are patented, extensively field-validated across agro-climatic zones, and widely adopted by farmers.

In addition to IIPR, several other national institutions have contributed significantly to microbial technology development relevant to pulse-based cropping systems. These include the ICAR–National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru; ICAR–Indian Agricultural Research Institute (IARI), New Delhi; ICAR–Indian Institute of Horticultural Research (IIHR), Bengaluru; ICAR–Central Institute for Subtropical Horticulture (CISH), Lucknow; ICAR–Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad; ICAR–National Bureau of Soil Survey and Land Use Planning (NBSS&LUP); ICAR–National Research Centre on Integrated Farming (NRCIF); and State Agricultural Universities (SAUs). Together, these institutes strengthen the national innovation ecosystem by advancing microbial resource characterization, biocontrol research, soil health restoration, and integrated biological management strategies that support sustainable intensification of pulse production.

The use of bioformulations offers multiple advantages:

- **Eco-friendly:** Reduces chemical pesticide and fertilizer use, ensuring environmental safety.
- **Cost-effective:** Lowers input costs and enhances net returns to farmers.
- **Productivity enhancing:** Improves root health, nodulation, nutrient uptake, and yield.
- **Soil health improvement:** Restores microbial balance and sustains long-term soil fertility.

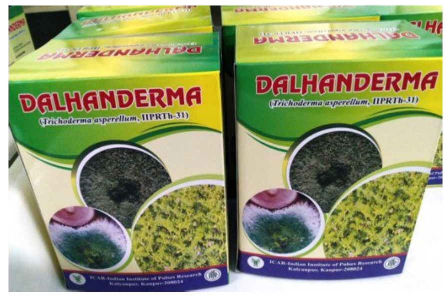
Through continuous innovation and field validation, ICAR–IIPR is promoting these bioformulations as key components of integrated nutrient and disease management strategies, contributing to climate-resilient and sustainable pulse production.

Microbial products for diseases crop management and plant growth promotion

Soil-borne fungal diseases pose one of the most persistent and economically significant constraints in agricultural production across diverse cropping systems. In pulses and other rainfed crops, pathogens such as *Fusarium spp.*, *Rhizoctonia solani*, *Macrophomina phaseolina*, *Sclerotium rolfsii*, *Phytophthora spp.*, *Pythium spp.* and *Verticillium spp.* cause widespread rots, wilts, damping-off, and blights that result in chronic yield losses and crop failures. The survival of these pathogens through resting structures—chlamydospores, sclerotia, oospores, and microsclerotia—enables them to persist in soils for years, even in the absence of the host. Their polyphagous nature, adaptability to extreme climatic conditions, and soil-mediated transmission make their management particularly challenging.

Conventional fungicides often fail to provide consistent field control due to poor translocation in soil, the emergence of resistant fungal strains, limited residual activity, and stringent regulatory restrictions. In this context, microbial products have emerged as a sustainable, eco-friendly, and scientifically robust option for the management of soil-borne fungal diseases. Beneficial microbes such as *Trichoderma*, *Bacillus*, *Pseudomonas*, *Streptomyces*, and microbial consortia have demonstrated strong antagonistic effects on a wide range of soil-borne fungal pathogens through diverse biological mechanisms. Advancements in microbial strain selection, large-scale fermentation technologies, formulation improvements, and understanding of rhizosphere ecology have significantly improved the efficacy and adoption of microbial-based solutions.

1. Dalhanderma (Developed by ICAR-IIPR)



Microbe: *Trichoderma asperellum* (IIPRTh-31)

Type: Biofungicide & Plant Growth Promoter

Crops: Chickpea, Pigeonpea, Lentil, Fieldpea, Mothbean etc

Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage & Application:

- Seed treatment: 10 g/kg seed
- Soil application: 5 kg/acre with FYM

Benefits: Controls soil-borne pathogens, enhances root growth, increases yield

Shelf Life: 12 months

Formulation Type: Talc-based / Liquid-based

Packaging: 250 g / 500 g / 1 kg

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: All

Validation: AICRP on chickpea, and pigeonpea for three years and ICAR-IIPR regional centres.

Toxicological data required for CIB&RC registration: Applied for registration

Commercialization: Available for licencing

- Patent (202311080189)

Benefits:

Effective against a wide range of soil and seed borne diseases of pulses

Enhanced growth of the plants

Increased seed germination

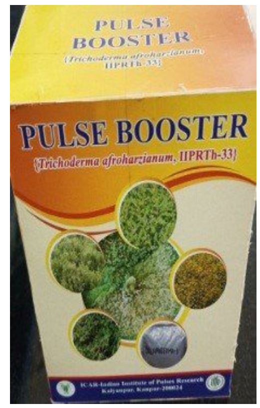
Increased grain yield under field condition

2. Pulse Booster (Developed by ICAR-IIPR)

Microbe: *Trichoderma afroharzianum* (IIPRTh-33)

Type: Biofungicide & Plant Growth Promoter

Crops: Pulse crops



Mode of Action: Mycoparasitism, enzyme production induced resistance

Dosage & Application:

- Seed treatment: 10 g/kg seed
- Soil application: 2 kg/acre with FYM

Benefits: Controls soil-borne pathogens, enhances root growth, increases yield

Shelf Life: 12 months

Formulation Type: Talc-based / Liquid-based

Packaging: 250 g / 500 g / 1 kg

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: All

Validation: AICRP on chickpea and pigeonpea for three years and ICAR-IIPR regional centres.

Toxicological data required for CIB&RC registration: yet to be generated

Commercialization: Available for licencing

- Patent (57904)

Benefits:

Effective against a wide range of soil and seed borne diseases of pulses

Enhanced growth of the plants

Increased seed germination

Increased grain yield under field conditions

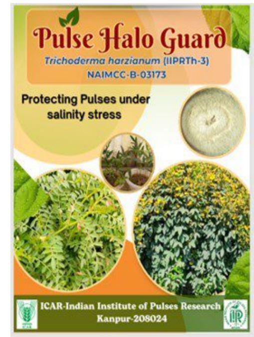
3. Pulse guard (Developed by ICAR-IIPR)

Microbe: *Trichoderma harzianum* IIPRTh-3

Type: Biofungicide & Plant Growth Promoter

Crops: Chickpea, Pigeonpea, Lentil, Fieldpea, Mungbean, Blackgram.

Mode of Action: Mycoparasitism, enzyme production, induced resistance



Dosage & Application:

- Seed treatment: 10 g/kg seed
- Soil application: 2 kg/acre with FYM

Benefits: Controls soil-borne pathogens, enhances root growth, increases yield

Shelf Life: 12 months

Formulation Type: Talc-based

Packaging: 250 g / 500 g / 1 kg

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: All

Validation: AICRP on chickpea and pigeonpea for three years and ICAR-IIPR regional centres.

Toxicological data required for CIB&RC registration: yet to be generated

Commercialization: Available for licencing

Benefits:

Effective against a wide range of soil and seed borne diseases of pulses

Enhanced growth of the plants

Increased seed germination

Increased grain yield under field condition

4. **Dalhan Bio-consortia (Developed by ICAR-IIPR)**

Microbe: *Trichoderma asperellum+Bacillus subtilis* (IIPRTh-31+IIPRSHEP-6)

Type: Biofungicide & Plant Growth Promoter

Crops: Chickpea, Pigeonpea, Lentil, Fieldpea, Mungbean, Blackgram.

Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage & Application:

- Seed treatment: 10 ml/kg seed
- Soil application: 1litre/acre with FYM

Benefits: Controls soil-borne pathogens, enhances root growth, increases yield

Shelf Life: 12 months

Formulation Type: Liquid-based

Packaging: 250 ml / 500 ml / 1 l

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: All

Validation: ICAR-IIPR Main Research Farm.

Toxicological data required for CIB&RC registration: yet to be generated

Commercialization: Available for licencing

Benefits:

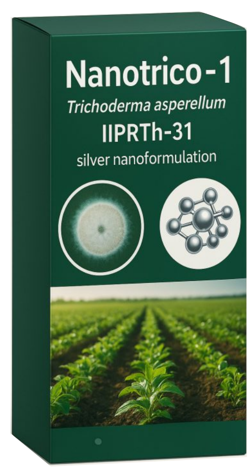
Effective against a wide range of soil and seed borne diseases of pulses

Enhanced growth of the plants

Increased seed germination

Increased grain yield under field conditions

5. **Nanotrico-1 (Developed by ICAR-IIPR)**



Microbe: *Trichoderma asperellum* IIPRTh-31

Type: Biofungicide & Plant Growth Promoter

Crops: Pulses

Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage & Application:

- Seed treatment: 10 ml/kg seed
- Soil application: 1litre/acre with FYM

Benefits: Controls soil-borne pathogens, enhances root growth, increases yield

Shelf Life: 12 months

Formulation Type: Liquid-based

Packaging: 250 ml / 500ml / 1 l

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date

○ Keep away from chemicals

Target agroecological zones/states: All

Validation: ICAR-IIPR Main Research Farm and New Research Farm

Toxicological data required for CIB&RC registration: yet to be generated

Commercialization: Available for licencing

- Patent (11089189)

Benefits:

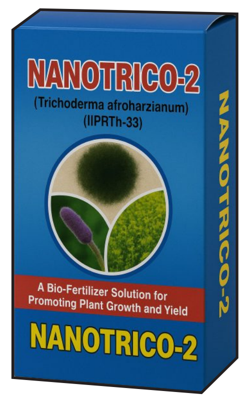
Effective against a wide range of soil and seed borne diseases of pulses

Enhanced growth of the plants

Increased seed germination

Increased grain yield under field conditions

6. **Nanotrico-2 (Developed by ICAR-IIPR)**



Microbe: *Trichoderma afroharzianum* IIPRTh-33

Type: Biofungicide & Plant Growth Promoter

Crops: Pulses

Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage & Application:

- Seed treatment: 10ml /kg seed
- Soil application: 1Litre/acre with FYM

Benefits: Controls soil-borne pathogens, enhances root growth, increases yield

Shelf Life: 12 months

Formulation Type: Liquid-based

Packaging: 250 ml / 500ml / 1litre

Storage & Handling

○ Store in cool, dry place

○ Avoid direct sunlight

○ Use before expiry date

○ Keep away from chemicals

Target agroecological zones/states: All

Validation: ICAR-IIPR Main Research Farm and New Research Farm

Toxicological data required for CIB&RC registration: yet to be generated

Commercialization: Available for licencing

Benefits:

Effective against a wide range of soil and seed borne diseases of pulses

Enhanced growth of the plants

Increased seed germination

Increased grain yield under field conditions

7. **Trichoemul-1 (Developed by ICAR-IIPR)**

Microbe: *Trichoderma asperellum* (IIPRTh-31)

Type: Biofungicide & Plant Growth Promoter

Crops: Chickpea, Pigeonpea, Lentil, Fieldpea etc.

Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage & Application:

- Seed treatment: 10 ml/kg seed
- Soil application:1 litre /acre with FYM

Benefits: Controls soil-borne pathogens, enhances root growth, increases yield

Shelf Life: 12 months

Formulation Type: Emulsion based

Packaging: 250 ml / 500 ml / 1litre

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: All

Validation: ICAR-IIPR Main Research Farm and New Research Farm

Toxicological data required for CIB&RC registration: yet to be generated

Commercialization: Available for licencing

Benefits:

Effective against a wide range of soil and seed borne diseases of pulses

Enhanced growth of the plants

Increased seed germination

Increased grain yield under field condition

8. **Trichoemul-2 (Developed by ICAR-IIPR)**

Microbe: *Trichoderma afroharzianum* IIPRTh-31

Type: Biofungicide & Plant Growth Promoter

Crops: Chickpea, Pigeonpea, Lentil, Fieldpea etc.

Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage & Application:

- Seed treatment: 10 ml/kg seed
- Soil application: 1 Litre/acre with FYM

Benefits: Controls soil-borne pathogens, enhances root growth, increases yield

Shelf Life: 12 months

Formulation Type: Emulsion based

Packaging: 250ml / 500 ml / 1 litre

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: All

Validation: ICAR-IIPR Main Research Farm and New Research Farm

Toxicological data required for CIB&RC registration: yet to be generated

Commercialization: Available for licencing

Benefits:

Effective against a wide range of soil and seed borne diseases of pulses

Enhanced growth of the plants

Increased seed germination

Increased grain yield under field conditions

9. **Dalhanmonas (Developed by ICAR-IIPR)**

Microbe: *Pseudomonas guariconsesnsis,* IIPRMKCP-9

Type: Biofungicide & Plant Growth Promoter

Crops: Chickpea, Pigeonpea, Lentil, Fieldpea etc.

Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage & Application:

- Seed treatment: 8 ml/kg seed
- Soil application: 0.5litre/acre with FYM

Benefits: Controls soil-borne pathogens, enhances root growth, increases yield

Shelf Life: 12 months

Formulation Type: Liquid-based

Packaging: 250 ml / 500 ml / 1 litre

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: All

Validation: ICAR-IIPR Main Research Farm and New Research Farm

Toxicological data required for CIB&RC registration:

Commercialization: Available for licencing

Benefits:

Effective against a wide range of soil and seed borne diseases of pulses

Enhanced growth of the plants

Increased seed germination

Increased grain yield under field conditions

10. **Nanotrico-3 (Developed by ICAR-IIPR)**

Microbe: *Trichoderma asperellum,* IIPRMUCK-1

Type: Biofungicide& Plant Growth Promoter

Crops: Chickpea, Pigeonpea, Lentil, Fieldpea, Rajmash etc.

Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage & Application:

- Seed treatment: 10 ml/kg seed
- Soil application: 1Litre/acre with FYM

Benefits: Controls soil-borne pathogens, enhances root growth, increases yield

Shelf Life: 12 months

Formulation Type: Liquid-based

Packaging: 250 ml / 500 ml / 1litre

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: All

Validation: ICAR-IIPR Main Research Farm and New Research Farm

Toxicological data required for CIB&RC registration: yet to be generated

Commercialization: Available for licencing

- Patent (202511033926)

Benefits:

- Effective against a wide range of soil and seed borne diseases of pulses
- Enhanced growth of the plants
- Increased seed germination
- Increased grain yield under field conditions

11. Nanotrico-4 (Developed by ICAR-IIPR)

Microbe: *Trichoderma asperellum,* IIPRMUCK-1

Type: Biofungicide& Plant Growth Promoter

Crops: Chickpea, Pigeonpea, Lentil,Fieldpea,Rajmash etc.

Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage & Application:

- Seed treatment: 10 ml/kg seed
- Soil application: 1 Litre/acre with FYM

Shelf Life: 12 months

Formulation Type: Liquid-based

Packaging: 250 ml / 500 ml / 1Litre

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date

- Keep away from chemicals

Target agroecological zones/states: All

Validation: ICAR-IIPR Main Research Farm and New Research Farm

Toxicological data required for CIB&RC registration: yet to be generated

Commercialization: Available for licencing

- Patent (202511033926)

Benefits:

- Effective against a wide range of soil and seed borne diseases of pulses
- Enhanced growth of the plants
- Increased seed germination
- Increased grain yield under field conditions

12. Pusa 5SD (Developed by ICAR-IARI, New Delhi)

Microbe: *Trichoderma harzianum* IARI P-4 (MTCC 5371)

Type: Biofungicide & Plant Growth Promoter

Crops: Chickpea;

Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage and Application:

- Seed treatment at 4g/kg of seed

Shelf Life: 25 months at 25+8°C

Formulation Type: Wettable powder

Packaging: 500Gm

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: All

Validation: AICRP on chickpea at 8 locations for three years; ICAR-IARI, New Delhi; JNKVV, Jabalpur, Madhya Pradesh; RAK College of Agriculture, Sehore, Madhya Pradesh; ARS, Durgapura, Jaipur, Rajasthan; ARS, Badnapur, Maharastra; GAU, Junagadh, Gujarat; College of Agriculture, Indore, Madhya Pradesh and PRSS, SKUAST, Samba, Jammu & Kashmir

Toxicological data required for CIB&RC registration: yet to be generated

Commercialization: Patent granted in 2018 ; Available for licencing

Benefits:

Effective against a wide range of soil and seed borne diseases

Enhanced growth of the plants

Increased seed germination

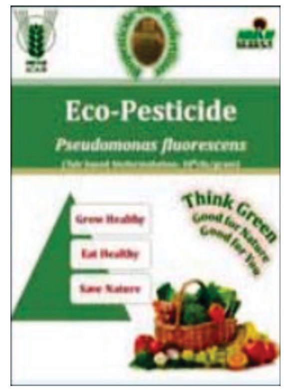
Increased grain yield under field conditions

13. **Eco pesticide (Developed by NBAIM, Mau)**

Microbe: *Pseudomonas fluorescens* (NAIMCC-SB-0053)

Type: Biofungicide & Plant Growth Promoter

Crops: Chickpea



Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage & Application: Seed treatment(10g/kg of seed)

Shelf life: 12 months at 25-35°C

Formulation Type: Wettable Powder

Packaging:500Gm

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: Uttar Pradesh

Validation: Field trials at AICRP Chickpea locations

Toxicological data required for CIB&RC registration yet to be generated

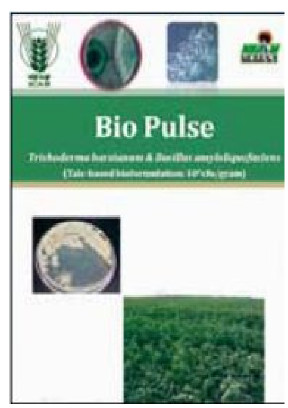
Commercialization: Available for licensing

Benefits:

45-55% reduction in disease

15-25% reduction in usage of chemical pesticides

14. **Bio pulse (Developed by NBAIM, Mau)**



Microbe : *Trichoderma harzianum* (NAIMCC-SF-0036) and *Bacillus amyloliquefaciens* (NAIMCC-SB-0052)

Type: Biofungicide & Plant Growth Promoter

Crop: Chickpea, lentil, Pea, Pigeon pea

Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage &Application: Seed treatment (10 g/kg seeds)

Shelf life: 12 months at 25-35°C

Formulation type: Wettable Powder

Packaging:500 gm

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: Uttar Pradesh, Bihar and Chhattisgarh **Validation**: Four KVKs of Madhya Pradesh at Hamirpur, Chhattarpur, Tikamgarh and Panna on chickpea; KVK Ghazipur, Uttar Pradesh on chickpea; KVK Azamgarh, Uttar Pradesh on rice; ICAR-NBAIM, Mau, Uttar Pradesh on tomato, wheat and maize; farmers' fields at Mau, Uttar Pradesh on chickpea, pea, lentil, vegetables and wheat; farmers' fields at Begusarai, Hazaribagh and Bhabhua, Bihar on papaya

Toxicological data required for CIB&RC registration: already generated

Commercialization: Available for licensing

Benefits:

Reduce the wilt incidence by 40-75% in chickpea, 30-55% in lentil, 45-60% in pea, 25-40% in pigeonpea and 60-75% reduction in damping off/seedling mortality in papaya

Yield increase in chickpea, pea and lentil by 10-15%

15. **Maru Sena 3 (Developed by ICAR-CAZRI, Jodhpur)**

Microbe: *Bacillus firmus* ICARCAZRI AZ-1 (MCC 0122)

Type: Biofungicide & Plant Growth Promoter

Crop: Legume crops

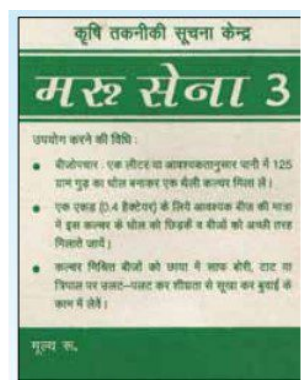
Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage and application: (30 g/ kg seed with jaggery for seed treatment solution) before sowing

Shelf life: 6 months at 25-35°C

Formulation Type: Carrier based formulation

Packaging:500gm



Storage and handling:

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: Arid and semi arid region of Rajasthan **Validation:** Experimental farm at ICAR-CAZRI, Jodhpur; farmers' fields at Nagaur and Jodhpur, Rajasthan for three years

Toxicological data required for CIB&RC registration: yet to be generated

Commercialization: Patent granted in 2019 (Patent No. 309385)

Available for licensing

Benefits:

37-54% reduction in plant mortality

23.2-31.6% yield increase

16. Mishrit Maru Sena (Developed ICAR-CAZRI, Jodhpur)

Microbe: *Trichoderma harzianum* ICAR-CAZRI AZNF-5 (MCC 1723) and *Bacillus firmus* ICAR-CAZRI AZ-1 (MCC 0122)

Type: Biofungicide & Plant Growth Promoter

Crops: Legume and oil seed

Mode of action: Mycoparasitism, enzyme production, induced resistance

Dosage & Application: Seed treatment (10 g/kg seed with jaggery) and soil application (1 kg/ha with 40 kg FYM) before sowing

Type: Carrier based formulation; 1 × 108 cfu/g of each

Shelf life: 4 months at 55°C

Formulation Type: Powder based

Packaging 500 g

Storage and handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: Arid and semi arid regions of Rajasthan Validation: Experimental farms at ICAR-CAZRI, Jodhpur; farmers' fields at Pali and Jodhpur, Rajasthan for two years

Toxicological data required for CIB&RC registration yet to be generated

Commercialization: Patent granted in 2019 (Patent No. 326803)

Available for licensing

Benefits

37-56.4% reduction in plant mortality

20-23% yield promotion

For insect pest management

17. Mycoguard BpL (Developed by ICAR-II OR Hyderabad)

Microbe: *Beauveria bassiana* (ITCC 4513)

Type: Biofungicide & Plant Growth Promoter

Crop: Pigeonpea

Mode of action: Mycoparasitism, enzyme production, induced resistance

Dosage and application: Two to three foliar sprays at 0.3 mL/L of water at 10 days interval; Water required for each spray: 700 to 1000 L/ha

Shelf life: 24 months at 25-35°C (1 × 1012 cfu/ Ml)

Formulation type: Liquid suspension concentrate

Packaging:500ML

Storage and handling:

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: Maharashtra, Gujarat, Telangana and Andhra Pradesh

Validation: AICRP-Pigeon pea and ICAR-IIOR experimental farms at Hyderabad, Telangana for three years

Toxicological data required for CIB&RC registration: already generated

Commercialization: Commercialized in 2014; Available for licensing

Benefits:

24-45% reduction in pod damage

21-33% increase in yield

18. Shatpada Aphid Kill (Developed by ICAR-NBAIR Bangalore)

Microbe: *Beauveria bassiana* ICAR-NBAIR Bb-5a (NAIMCC-F-00396)

Type: Biofungicide & Plant Growth Promoter

Crop: Cowpea

Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage & Application: Three foliar sprays at 5 mL/L of water at 15 days interval after pest incidence; Water required for each spray: 200 L/ha

Shelf life: 12 months at 25-35°C (1 × 108 cfu/mL)

FormulationType: Oil formulation

Packaging:500ML

Storage and handling:

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: Karnataka y Validation: In Bengaluru, Karnataka during 2017 and 2018

Toxicological data required for CIB&RC registration yet to be generated

Commercialization: Available for licensing

Benefits:

50-83% pest reduction

20-33% increase in yield

19. Shatpada Sucking Pest Kill (Developed by ICAR-NBAIR, Banglore)

Microbe: *Lecanicillium lecanii* ICAR-NBAIR Vl-8 (NAIMCC-F-01851)

Type: Biofungicide & Plant Growth Promoter

Crops: Cowpea

Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage and Application: Three foliar sprays at 5 mL/L of water at 15 days interval after pest incidence; Water required for each spray: 900 L/ha

Shelf life: 12 months at 25-35°C (1 × 108 cfu/mL)

Formulation type: Oil formulation

Packaging:500ml

Storage and handling:

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date
- Keep away from chemicals

Target agroecological zones/states: Karnataka Validation: Bengaluru, Karnataka for two years

Toxicological data required for CIB&RC registration yet to be generated

Commercialization: Available for licensing

Benefits:

75-78% pest reduction

24-27% increase in yield

20. IIPR Lep-Kill (Developed by ICAR-IIPR)

- **Microbe:** *Bacillus thuringiensis* IIPRF-8
- **Type:** Biopesticide
- **Crops:** Pigeonpea, Blackgram etc

Mode of Action: Mycoparasitism, enzyme production, induced resistance

Dosage & Application: The biopesticide can be applied at 20-21ml/L at time of flowering or podding in pigeonpea, blackgram etc.

- **Shelf Life:**
- **Formulation Type:**Liquidbased
- **Packaging:** 500ml/1L

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date

Keep away from chemicals

Target agroecological zones/states:All

Validation: ICAR-IIPR Main Research Farm and New Research Farm

Toxicological data required for CIB&RC registration: yet to be generated

Commercialization: Available for licensing

Benefits: This biopesticide is found effective for managing the lepidopteran insects like gram pod borer (*Helicoverpa armigera* Hubner), Spotted pod borer (*Maruca vitrata* Fabricius) and Bihar hairy caterpillar (*Spilosoma obliqua* Walker).

21. IIPR Pulse Guard (Developed by ICAR-IIPR)

Microbe: combination of indigenous *Bacillus thuringiensis* strains.

- **Type:** Biopesticide
- **Crops:** Chickpea, blackgram etc.

Mode of Action: Mycoparasitism, enzyme production, induced resistance

- **Dosage & Application:** 20-21ml/L at time of flowering or podding.
- **Shelf Life:**
- **Formulation Type:** Liquid
- **Packaging:** 500ml/1L

Storage & Handling

- Store in cool, dry place
- Avoid direct sunlight
- Use before expiry date

Keep away from chemicals

Target agroecological zones/states:All

Validation: ICAR-IIPR Main Research Farm and New Research Farm

Toxicological data required for CIB&RC registration: yet to be generated

Commercialization: Available for licensing

Benefits: This biopesticide is found effective for managing the lepidopteran insects like gram pod borer (*Helicoverpa armigera* Hubner), Spotted pod borer (*Maruca vitrata* Fabricius) and Bihar hairy caterpillar (*Spilosoma obliqua* Walker).

Bio-efficacy and Field Application

The bio-efficacy of newly developed microbial products such as Dalhanderma, Pulse Booster, and other pulse-focused biocontrol formulations has been consistently validated through multi-location laboratory, greenhouse, and field evaluations. Dalhanderma, a Trichoderma-based formulation optimized for pulse crops, has demonstrated strong antagonistic activity against major soil-borne fungal pathogens including *Fusarium udum*, *Macrophomina phaseolina*, *Rhizoctonia bataticola*, and *Sclerotium rolfsii*. Its superior mycoparasitic ability, VOC-mediated suppression, and induced systemic resistance contribute to significant reductions in wilt, collar rot, and dry root rot incidence across diverse agro-climatic zones. Similarly, Pulse Booster, formulated using *Trichoderma afroharzianum* IIPRTh-33, enhances root colonization, mobilizes nutrients, and improves plant vigor under stressed soil conditions while simultaneously suppressing pathogen proliferation. Field application trials conducted in pigeonpea, chickpea, and mungbean have shown 20–40% reduction in disease severity and 12–25% improvement in yield when these products are applied as seed treatment (5–10 g/kg seed), seedling dip, or soil application (2.5–5.0 kg/ha with compost or FYM). Importantly, integration of these microbial formulations with organic amendments and biofertilizers further enhances their persistence and activity in the rhizosphere, ensuring extended protection throughout the crop growth period. The consistent field performance and eco-friendly nature of Dalhanderma and Pulse Booster highlight their potential as reliable components of integrated disease management (IDM) strategies for pulse crops, addressing the complex challenges posed by soil-borne fungal pathogens while promoting soil health and sustainable productivity.

Transforming Soil and Crop Health through Microbial Technologies

The introduction of microbial technologies by the ICAR–Indian Institute of Pulses Research (IIPR), Kanpur has created a paradigm shift in pulse-based cropping systems by promoting sustainable and environmentally sound practices. Through years of dedicated research, validation, and field demonstrations, IIPR has successfully developed and popularized a range of bioformulations that have significantly improved soil fertility, plant health, and farmers' income while reducing chemical dependency.

The adoption of bioformulations such as Dalhanderma, Pulse Booster, Pulse Guard, Bioconsortia, Nanotrico-2 (Th-31 and Th-33), Trichoemul, Pulsemonas, Nanotrico-3 and Nanotrico-4 has shown tangible results across diverse soil types and climatic zones of India. These products are now increasingly integrated into farmers' practices, contributing to the sustainability of pulse-based and cereal-based production systems.

1. Enhancing Crop Productivity and Soil Fertility

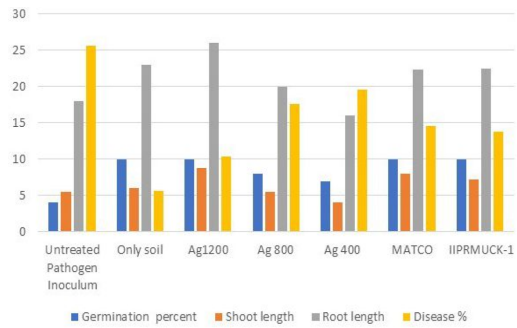
Extensive field testing under multi-location trials has consistently demonstrated 15–30% yield enhancement in pulses such as chickpea, pigeonpea, lentil, and mungbean with the application of IIPR bioformulations compared with untreated or chemically treated plots. The bioformulations stimulate early seed germination, promote robust root and shoot growth, and improve nutrient absorption efficiency.

The use of *Trichoderma*- and *Pseudomonas*-based formulations improves soil enzymatic activity (dehydrogenase, phosphatase, and urease), microbial biomass carbon, and nitrogen mineralization, leading to long-term soil rejuvenation. Farmers have reported noticeable improvements in soil texture, water-holding capacity, and nutrient retention after two to three consecutive seasons of bioformulation use.

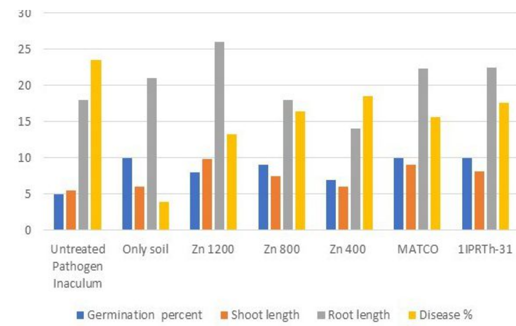
In chickpea–wheat and pigeonpea–groundnut cropping systems, the inclusion of Dalhanderma and Pulse Booster not only enhanced the yield of pulses but also improved soil fertility and benefited the succeeding cereal crop, making them an integral component of soil health restoration programs.

2. Managing Soil-Borne Diseases Effectively

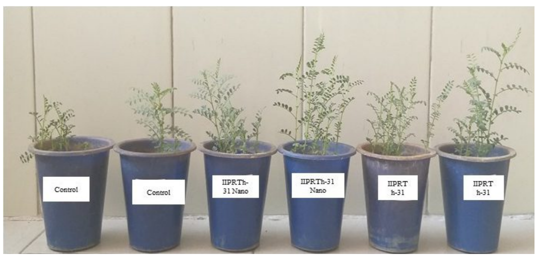
Soil-borne pathogens such as *Fusarium udum*, *F. oxysporum*, *Rhizoctonia bataticola*, and *Phytophthora*



Effect of *Trichoderma* Ag nanoparticles on the growth of chickpea crop

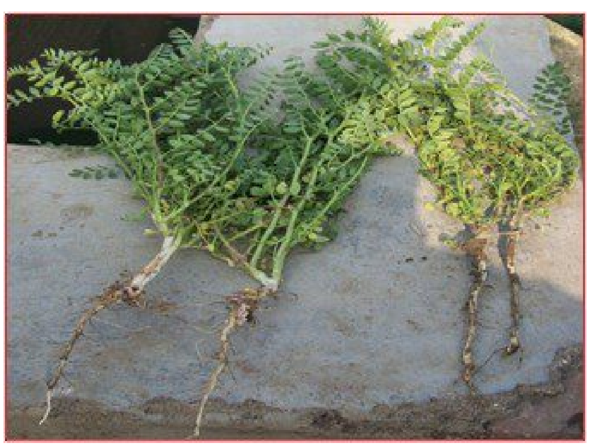


Effect of *Trichoderma* Zn nanoparticles on the growth of *Foc*



Effect of different Trichogenic Zn nanoparticle concentrations on Chickpea plant growth

Effect of Dalhanderma on the reduction of disease severity caused by Foc



Root Development by the application of Trichoemuel-1

Nodule development by the application of pulsemonas in chickpea

Plant growth increase by the application of Pulse guard

cajani cause significant yield losses in pulses. Application of IIPR-developed *Trichoderma asperellum* (IIPRTh-31) and *T. afroharzianum* (IIPRTh-33) based formulations effectively reduced disease incidence by up to 60% in on-station and on-farm trials.

The dual action of these bioagents—mycoparasitism and induced systemic resistance—helps protect plants during early root infection stages and maintains vigor during critical growth phases. Farmers from Bundelkhand and Vidarbha regions reported substantial reductions in wilt and root rot incidence, translating into 25–35% yield gain without the need for expensive fungicides.

Control

Treatment

Field results also revealed that bioformulation-treated plots showed faster recovery after drought stress due to improved root proliferation and soil microbial activity, underscoring their role in climate-resilient agriculture.

3. Broader Applicability Across Crops and Ecosystems

Although primarily developed for pulses, IIPR's microbial formulations have demonstrated cross-compatibility with several other crops. Their use in wheat, rice, barley, and fodder legumes has improved seedling vigor, tillering, and nutrient uptake. The integration of bioformulations in cereal–pulse rotations maintains soil microbial balance and reduces residual toxicity caused by chemical fertilizers and pesticides.

Dalhanderma (Treated & Control) Lentil

Dalhanderma (Treated & Control) Chickpea

Bioconsortia (Treated & Control) Lentil **Pulse booster (Treated & Control) Chickpea**

In rice–wheat systems of eastern Uttar Pradesh, the use of Trichoemul and TrichoIron Nano improved root biomass and nutrient use efficiency, leading to improved yields in both crops while maintaining long-term soil productivity. These successes highlight the versatility and broad-spectrum efficacy of IIPR microbial technologies across diverse cropping patterns.

Shelf Life, Storage and Quality Assurance

Shelf-life Requirements

Shelf-life reflects the period during which a biopesticide retains the minimum required viable count and functional activity.

Regulatory bodies like CIB&RC (India), EPA (USA), and OECD recommend:

- Minimum shelf-life: 6–12 months for commercial biopesticides.
- Desired viable count at expiry:
  - Fungal biopesticides (e.g., *Trichoderma*, *Beauveria*, *Metarhizium*): $\geq 1 \times 10^7$ CFU/g (solid) or 1×10^8 CFU/mL (liquid)
  - Bacterial biopesticides (e.g., *Pseudomonas*, *Bacillus*): $\geq 1 \times 10^8$ CFU/g or CFU/mL

Shelf-life Testing Includes

- Periodic CFU viability testing (monthly/quarterly)
- Monitoring pH, moisture, viscosity, and physical stability
- Assessing retention of antagonistic or pesticidal activity
- Storage at both ambient (25–30°C) and accelerated (40°C) conditions.

2. Storage Conditions for Biopesticides

Proper storage is critical for maintaining viability and product stability:

A. Temperature

- Store at a cool, dry place (25–30°C)
- Avoid > 40°C, which causes rapid microbial death
- Refrigerated storage (4–10°C) extends shelf-life but is optional unless specified
- Avoid repeated freeze–thaw cycles

B. Protection From Environmental Factors

- Keep away from direct sunlight, which degrades spores and cells
- Protect from humidity, which can cause clumping in powder formulations
- Store liquids in UV-protected (amber/HDPE) bottles
- Store solids in moisture-proof laminated pouches

C. Packaging Requirements

- Containers must be air-tight, leak-proof, and chemical inert
- Labels must include:
  - ✓ Strain name and accession number
  - ✓ CFU count

- ✓ Manufacturing & expiry date
- ✓ Batch number
- ✓ Dosage and safety instructions

3. Quality Assurance (QA) Conditions

QA ensures the product meets regulatory and biological standards. CIB&RC and FAO set the following key QA parameters:

A. Viable Count

- The most critical QA parameter
- Must meet minimum CFU at manufacturing and at expiry
- Testing involves serial dilution plating on selective media

B. Purity and Contamination Check

- Product must be free of other bacteria, fungi, and pathogens
- Tested by streaking on NA/PDA and microscopic examination

C. Moisture Content (Powder Formulations)

- Should be < 8–10%
- High moisture leads to contamination and loss of viability

D. Physical Stability

- No clumping, caking or liquefaction in powders
- No phase separation or sedimentation in liquids
- Should retain free-flowing or uniform consistency

E. pH and Viscosity (Liquid Formulations)

- pH should remain in 6.0–7.5
- Viscosity should remain stable for proper dispensing

F. Carrier Quality

- Carrier must be:
  - ✓ Sterile
  - ✓ Non-toxic
  - ✓ Neutral pH
  - ✓ High adsorption capacity
  - ✓ Free from heavy metals and hazardous contaminants

G. Functional Activity

- Antagonistic activity (dual culture assay)
- Enzyme/secondary metabolite production (e.g., siderophores, antibiotics)
- Pest/pathogen kill rate must remain within acceptable limits

H. Accelerated Stability Test (Recommended)

- Store at 40°C for 14–28 days
- Reduction in CFU should not exceed one log unit

Summary Table

Parameter	Requirement
Shelf-life	6–12 months
Viable count	Fungi: $\geq 10^7$ CFU/g; Bacteria: $\geq 10^8$ CFU/mL
Storage temperature	25–30°C ideal; <40°C max
Moisture (powder)	<8–10%
Packaging	Moisture-proof, UV-protected, airtight
QA tests	CFU, purity, pH, viability, stability

Shelf-Life Evaluation

✓ Store formulations at room temperature (25–30°C).

✓ Check viability monthly for 6–12 months.

✓ Record minimum acceptable CFU:

Powder: $\geq 1 \times 10^7$ CFU/g

Liquid: $\geq 1 \times 10^8$ CFU/mL

Registration, Policy & Biosecurity Issues of Biopesticides in India

Biopesticides have emerged as a crucial component of sustainable crop protection in pulse-based production systems. However, their wider adoption depends on a robust regulatory framework, product quality assurance, and adherence to biosecurity standards. In India, the regulation of biopesticides is governed primarily by the Insecticides Act, 1968, and is overseen by the Central Insecticides Board & Registration Committee (CIBRC). Although microbial pesticides are promoted as safer alternatives to chemical pesticides, they must meet mandatory safety, efficacy, and quality standards before commercialization.

1. Registration of Biopesticides in India

1.1 Regulatory Authority

- Central Insecticides Board & Registration Committee (CIBRC) under the Ministry of Agriculture & Farmers Welfare.
- **Functions include:**
  - Approving strains, formulations, labels, and leaflets.
  - Ensuring safety and efficacy.
  - Monitoring manufacturing units.
  - Framing guidelines for bio-control agents.

1.2 Categories of Registration

Biopesticides can be registered under the following categories:

A. Section 9(3) – Regular Registration

- For new active ingredients or formulations not previously registered in India.
- Requires complete toxicology, eco-tox, bio-efficacy data, and shelf-life studies.

B. Section 9(3B) – Provisional Registration

- Provided for limited period (two years) for products that have potential but incomplete data.
- Mostly applicable to new microbial strains or novel formulations.

C. Section 9(4) – Me-too Registration

- Granted when the active ingredient/formulation is already registered, and the applicant uses the same specification and label claims.
- **Commonly used by private manufacturers for:**
  - *Trichoderma harzianum*
  - *T. viride*
  - *Pseudomonas fluorescens*
  - *Bacillus subtilis*
  - Neem-based pesticides

1.3 Data Requirements for Biopesticide Registration

1.3.1 Microbial Identification & Characterization

- **Species-level identification using:**
  - Morphology
  - Biochemical tests
  - Molecular identification (ITS, TEF1α, RPB2, 16S rRNA)
- **Authentication from:**
  - ICAR Institutes
  - NBAIM (Nodal Institute for Microbial ID)
  - International repositories

1.3.2 Bio-efficacy Studies

- Multi-location trials on target crop (e.g., chickpea or pigeonpea) against specific pathogens.
- 2–3 seasons of data.
- Data generated at accredited:
  - SAUs
  - ICAR Institutes
  - GLP-certified labs

1.3.3 Toxicology & Environmental Safety

Mandatory for humans, animals, and environment:

- Acute oral/dermal/inhalation toxicity
- Eye and skin irritation tests
- Pathogenicity test (in rodents)
- Impact on non-target organisms:
  - Earthworms
  - Honey bees
  - Aquatic organisms

1.3.4 Shelf-Life & Quality Data

- Must meet minimum CFU:
  - Talc-based: 10^7 CFU/g
  - Liquid: 10^8–10^9 CFU/mL
- Shelf life:
  - Talc: 6–12 months

- Liquid: 12–24 months

2. Policy Framework for Biopesticides in India

2.1 National Policies Supporting Biopesticide Adoption

2.1.1 National Mission on Sustainable Agriculture (NMSA)

Promotes biologicals, including biofungicides, biofertilizers, and microbial consortia.

2.1.2 Paramparagat Krishi Vikas Yojana (PKVY)

Supports production and use of biopesticides in organic clusters.

2.1.3 National Organic Farming Policy (2020)

Emphasizes eco-friendly inputs, microbial pesticides, and residue-free food.

2.1.4 Bharat Krishi (Natural Farming) Policy

Encourages microbial-based inputs and cow-based biopesticides.

2.1.5 ICAR & SAU Guidelines

- Promote on-farm production of *Trichoderma* and *Pseudomonas*.
- Encourage mass multiplication units at KVKs, FPOs, and SHGs.

2.2 Government Support Systems

- Subsidies for bio-inputs under NFSM-Pulses.
- FCO (Fertilizer Control Order) allows registration of biofertilizers and bio-stimulants.
- Guidelines for Bio-input Resource Centres (BRCs) under NABARD-funded FPOs.

2.3 Policy Gaps

- No separate, simplified policy for small-scale microbial producers.
- Lack of uniform QC norms across states.
- Limited field-level monitoring of CFU standards.

3. Biosecurity Issues in Biopesticide Development and Use

3.1 Strain Authenticity & Mislabeling

- One of the most serious problems in India.
- Many commercial products contain:
  - Wrong species
  - Mixed cultures
  - Low CFU
  - Contaminants
- Leads to poor field performance in pulses.

Solution

- DNA-based authentication (ITS, TEF, RPB2).
- Mandatory QR codes linking to strain data.

3.2 Contamination During Production

Common contaminants:

- *Aspergillus*
- *Penicillium*
- *Rhizopus*
- Unwanted *Bacillus* spp.

Impact: reduces efficacy, introduces plant pathogens into soil.

Mitigation:

- **HEPA filters, sterile fermentation, QC at every stage.**

3.3 Risk of Introducing Exotic Strains

- **Import of non-native biocontrol organisms can:**
    - Disturb soil microbial ecology.
    - Outcompete native beneficial strains.
    - Introduce new pathogens.

Hence, CIBRC mandates origin data and environmental impact studies.

3.4 Horizontal Gene Transfer (HGT) Concerns

Although rare, microbes like *Bacillus* and *Pseudomonas* may exchange plasmids in soil, potentially:

- Altering pathogenicity
- Reducing bio-efficacy
- Creating unknown ecological impacts

3.5 Antibiotic Resistance Genes (ARGs)

Some strains of *Pseudomonas* and *Bacillus* may carry ARGs

Solutions:

- Proper genomic screening
- Avoiding strains with strong ARG profiles
- Mandatory NCBI sequence submission

3.6 Use of Indigenous vs Imported Strains

Indigenous strains are preferred because:

- Better ecological fit

- Lower biosecurity risk
- Higher persistence in soil under Indian conditions

ICAR institutes routinely develop and validate region-specific strains for pulses (e.g., IIPRTr33, IIPRTh31).

4. Quality Control (QC) and Biosecurity Enforcement

4.1 Standards

- BIS and CIBRC have minimum standards for:
  - CFU count
  - Purity
  - Packaging
  - Moisture
  - pH
  - Contamination

4.2 Testing Laboratories

- IBSC (Institutional Bio-Safety Committee)
- RCGM (Review Committee on Genetic Manipulation) for molecular strains
- State Pesticide Testing Labs (PTL)
- ICAR testing facilities

5. Key Issues Faced by Biopesticide Producers

1. High registration costs (□5–10 lakhs or more per strain).
2. Repeated data requirements even for similar strains.
3. Lack of standard fermentation facilities among small manufacturers.
4. CFU degradation during transportation in high-temperature states.
5. Lack of harmonized guidelines for liquid, encapsulated, and WDG formulations.

Process and Methodology

Preparation of Carrier Material

- ❖ High-grade, pharmaceutical- or fertilizer-grade talc powder is used as the carrier.
- ❖ The talc is autoclaved at 121 °C for 30 minutes on two consecutive days (or dry-heat sterilized at 160 °C for 1 hour) to eliminate contaminants.
- ● The sterilized talc is cooled to room temperature and passed through a fine mesh (60–80) to obtain uniform particle size.

Preparation of Microbial Inoculum

- ✓ The fungal or bacterial culture is grown on a suitable solid or liquid medium until it reaches optimum sporulation or cell density.
- ✓ For fungi (e.g., *Trichoderma*), sporulated plates are harvested with sterile distilled water containing 0.01% Tween-80 to obtain a spore suspension (10□–10□ CFU/mL).
- ✓ For bacteria, broth cultures are typically grown to 10□–10□ CFU/mL.

Mixing of Inoculum with Carrier

- ❖ A sterile mixing tray or blender is used.
- ❖ Sterilized talc is spread evenly, and the microbial suspension is added gradually.
- ❖ Sterile carboxymethyl cellulose (CMC) at 1% may be added as a sticker/binder to enhance adhesion of cells/spores to talc particles.
- ❖ The mixture is thoroughly blended to obtain a uniform, free-flowing powder containing 10□–10□ CFU/g of the microbial agent.

Drying

- ■ The mixture is shade-dried at room temperature (25–28 °C) to adjust the moisture level to 8–12%.
- ■ Direct sunlight is avoided to prevent loss of viability.

Quality Check

- ➢ The final product is evaluated for:
    - ○ Viable cell/spore count (CFU/g)
    - ○ Moisture content
    - ○ pH
    - ○ Absence of contaminants
- ➢ Typically, a minimum of 10□–10□ CFU/g is required for a stable formulation.

Packaging and Storage

- ✓ The dried talc-based formulation is packed in sterilized, moisture-proof LDPE or aluminum-laminated pouches.
- ✓ Store at 4–15 °C in dry, shaded conditions.
- ✓ Shelf life generally ranges from 6–12 months, depending on the microbial species and storage.

General Procedure for Oil-Based Liquid Microbial Formulation

1. **Selection and Preparation of Oil Base**
   - ❖ A food-grade, stable oil such as mineral oil, paraffin oil, neem oil, or vegetable oil is selected as the carrier.
   - ❖ The oil base is sterilized by filter sterilization (0.22 µm filter) or by heating at 80–100 °C for 30–45 minutes depending on oil type.
   - ❖ The sterilized oil is cooled to room temperature before use.

2. **Preparation of Microbial Inoculum**
   - ✓ The microbial culture (fungus or bacterium) is grown in an appropriate broth medium until optimal growth is achieved.
   - ✓ For fungal cultures (e.g., *Trichoderma*), a spore suspension of 10□–10□ spores/mL is prepared using sterile distilled water with a wetting agent (0.01% Tween-80).
   - ✓ For bacterial cultures, the broth is grown to 10□–10□ CFU/mL.

3. **Emulsification / Incorporation of Microbial Biomass**
   - ✓ The microbial suspension is added slowly into the sterilized oil while stirring continuously at low speed.
   - ✓ Emulsifying agents such as Span 80 or Tween 80 (0.1–0.5%) may be added to ensure stability and prevent phase separation.
   - ✓ Homogenization is carried out gently to ensure uniform distribution of cells/spores in the oil base without damaging the microbial propagules.

4. **Adjustment of Viable Cell/Spore Count**
   - ❖ The final formulation is adjusted to a viable count of 10□–10□ CFU/mL depending on the microbial species and regulatory standards.
   - ❖ Viability is verified through serial dilution plating.

5. **Stability and Quality Checks**

   The formulation is checked for:
   - ❖ Viable count (CFU/mL)
   - ❖ pH (if applicable)
   - ❖ Viscosity
   - ❖ Absence of contaminants
   - ❖ Phase stability (no separation after 24–72 h)

   Stability enhancers (e.g., antioxidants or emulsifiers) may be added if required.

6. **Packaging and Storage**
   - ❖ The oil-based liquid formulation is filled into sterilized, airtight HDPE or PET bottles under aseptic conditions.
   - ❖ Containers are stored at room temperature (20–30 °C) away from direct sunlight.
   - ❖ Shelf life typically ranges from **6 to 12 months**, depending on microbial species and storage conditions.

Success Stories and Impact

Economic Benefits and Farmer Experiences

The economic analysis of large-scale demonstrations under institute and AICRP programs showed an increase in net returns by ₹8,000–12,000 per hectare when IIPR bioformulations were used. The reduction in chemical input cost (particularly fungicides and fertilizers) and the improvement in yield jointly contributed to this increase in profitability.

Farmers in Jhansi, Lalitpur, Hamirpur, and Mahoba districts adopted *Dalhanderma* and *Pulse Booster* in chickpea and pigeonpea cultivation and reported 30–35% higher yields compared with conventional practices. Testimonials indicate better seed germination, healthier plants, and stronger nodulation in treated crops. The visible reduction in disease incidence encouraged community-level adoption through farmers' groups and Krishi Vigyan Kendras (KVKs).

Women farmers' self-help groups in Bundelkhand region have also been trained in on-farm preparation and application of bioformulations, promoting local entrepreneurship and self-reliance.

The consistent field performance and farmer acceptance of IIPR's microbial technologies underscore their potential as core components of integrated nutrient and disease management strategies. By reducing chemical dependence, restoring soil biodiversity, and enhancing resilience to abiotic stresses, these bioformulations are paving the way for climate-smart pulse production systems.

As India moves toward achieving sustainable agricultural intensification, the microbial technologies developed by ICAR–IIPR stand as success stories of science-led innovation—offering a scalable, farmer-friendly, and environmentally safe approach to soil and crop health management.

Registration, Patents, Trademark and Copyright of Developed Microbial Technologies

The microbial technologies developed at ICAR–Indian Institute of Pulses Research (IIPR), Kanpur are protected through appropriate intellectual property rights (IPR) mechanisms to ensure recognition, authenticity, and safe dissemination to end users. These protections safeguard scientific innovation, encourage responsible commercialization, and uphold the institute's commitment to quality and transparency.

1. Registration of Technologies

All bioformulations developed by ICAR–IIPR have been scientifically validated field-tested across different agro-climatic zones under All India Coordinated Research Projects (AICRPs) before large-scale release and distribution to farmers.

2. Trademark and Patent Protection

To maintain product identity and prevent unauthorized duplication, several microbial formulations have been registered under distinct trademarks. Patents have been filed for key innovations, including unique microbial strains, nanoformulation processes, and composite bioconsortia. For example:

- *Dalhanderma* and *Pulse booster* trademark have been filed are protected with the Indian Patent Office.
- Nano-based and emulsion-based bioformulations such as Nanotrico-1, Nanotrico-2, Nanotrico-3 and Nanotrico-4 are covered under process and composition claims. Trademark registration under the Trade Marks Act, 1999 ensures legal ownership of names such as Dalhanderma, Pulse Booster, Pulse Guard, and Bioconsortia, distinguishing them as ICAR–IIPR proprietary technologies.

3. Copyright and Institutional Ownership

All textual, visual, and digital materials related to IIPR microbial technologies—including product manuals, packaging labels, and communication materials—are protected under Copyright Act, 1957. Reproduction, distribution, or modification of these contents without authorization from ICAR–IIPR is prohibited. The copyright ownership rests with ICAR–Indian Institute of Pulses Research, Kanpur.

4. Licensing and Commercialization

To promote wider accessibility while maintaining quality assurance, IIPR licenses its technologies to interested public and private organizations through Memoranda of Agreement (MoA) under the ICAR's Institute Technology Management Unit (ITMU) framework. Licensed firms are permitted to produce and market the formulations under supervision and quality control guidelines issued by the institute. This model of regulated commercialization ensures both farmer benefit and institutional accountability.

Patents/ Trademark of ICAR-IIPR, Kanpur

Patent

1. A Novel Heavy Metal-Tolerant Microbial Strain, *Trichoderma asperellum* (202311052705).
2. A Method of preparation of Pigeonpea Milling By-product Agar Medium for Fungal growth of Phytophthora (202311067694)
3. A Method of utilization of *Trichoderma* species as pesticide tolerance (202511000419)
4. A Method for synthesis of fungi infused biogenic silver nanoparticle formulation (202311080189)
5. Antimicrobial activity of *Trichoderma* fused Zinc and Iron Nanoparticles against chickpea wilt (202511033926)

Copyright/Trademarks

1. DALHANDERMA (6045788/2024)
2. Pulses booster (6774012/2024)


ICAR
INDIAN COUNCIL OF AGRICULTURAL RESEARCH
Certified that
Dr. R.K. Mishra
(Lead Developer)
Associate Developers
Dr. Naimuddin, Dr. Sonika Pandey
Dr. Monika Mishra, Dr. Krishna Kumar
Dr. Bansa Singh, Dr. N.P. Singh
of
ICAR-Indian Institute of Pulses Research
Kanpur
has developed the technology
Pulse booster
(T. afroharzianum, IIPRTh-33)
16th July, 2024
New Delhi
(D.K. Yadava)
Assistant Director General (Seed)
(Tilak Raj Sharma)
Deputy Director General (Crop Science)


ICAR
INDIAN COUNCIL OF AGRICULTURAL RESEARCH
Certified that
Dr. R.K. Mishra
(Lead Developer)
Associate Developers
Dr. Naimuddin, Dr. Sonika Pandey
Dr. Monika Mishra, Dr. P.R. Saabale
Dr. Bansa Singh, Dr. Uma Sah
Dr. N.P. Singh
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Assistant Director General (Seed)
(Tilak Raj Sharma)
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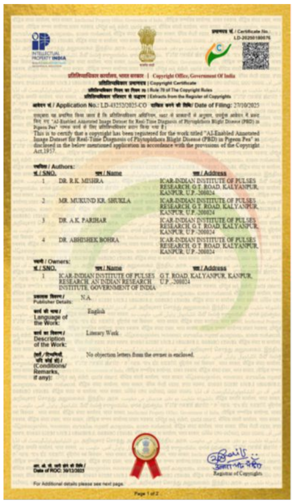
आर.के. मिश्रा
सोनिका पाण्डेय
अभिषेक बोहरा
PULSE BOOSTER
ICAR-Indian Institute of Pulses Research, Kanpur-208 024


ICAR
INDIAN COUNCIL OF AGRICULTURAL RESEARCH
Certified that
Dr. R.K. Mishra
(Lead Developer)
Associate Developers
Dr. Sonika Pandey
Dr. Monika Mishra
Dr. Sandeep Kumar
Dr. U.S. Rathore
Dr. Manjunatha L.
Dr. Krishna Kumar
of
ICAR-Indian Institute of Pulses Research
Kanpur
has developed the technology
Dalhan Bio-consortia
(D.K. Yadava)
(Tilak Raj Sharma)


ICAR
INDIAN COUNCIL OF AGRICULTURAL RESEARCH
Certified that
Dr R.K. Mishra
(Lead Developer)
Associate Developers
Dr Prasoon Verma, Dr Man Mohan Deo
Dr Abhishek Tiwari, Dr G.P. Dixit
of
ICAR-Indian Institute of Pulses Research
Kanpur (Uttar Pradesh)
has developed the technology
Pigeonpea milling by-product agar (PMBA):
A novel and cost-effective media for isolation
and culturing of Phytophthora cajani causing
stem blight diseases of pigeonpea
16th July, 2025
New Delhi
(Poonam Jasrotia)
Assistant Director General
(Plant Protection & Biosafety)
(D.K. Yadava)
Deputy Director General
(Crop Science)


दलहनडर्मा
कोडर्मा आधारित बहुगुणी जैव सूत्रीकरण
DALHANDERMA
भाकृअनुप-भारतीय दलहन अनुसंधान संस्थान
कानपुर - 208 024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(Rule 74 of The Patents Rules)
पेटेंट सं. / Patent No. : 579011
आवेदन सं. / Application No. : 202511000419
फाइल करने की तारीख / Date of Filing : 02/01/2025
पेटेंटी / Patentee : ICAR- INDIAN INSTITUTE OF PULSES RESEARCH
Raj K. Mishra, Sonika Pandey and G.P. Dixit
It is hereby certified that a patent has been granted to the patentee for an invention entitled A METHOD OF UTILIZATION OF TRICHODERMA SPP. AS PESTICIDE TOLERANT SPECIES as disclosed in the above mentioned application for the term of 20 years from the 2nd day of January 2025 in accordance with the provisions of the Patents Act,1970.
Date of Grant : 27/01/2026
Controller of Patents
Note. - The fees for renewal of this patent, if it is to be maintained, will fall / has fallen due on 2nd day of January 2027 and on the same day in every year thereafter.


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खोज प्रमाणपत्र/SEARCH CERTIFICATE
(Under Rule 22 (1) of the Trade Marks Rules, 2017)
(FOR USE UNDER SECTION 45(1) OF THE COPYRIGHT ACT, 1957)
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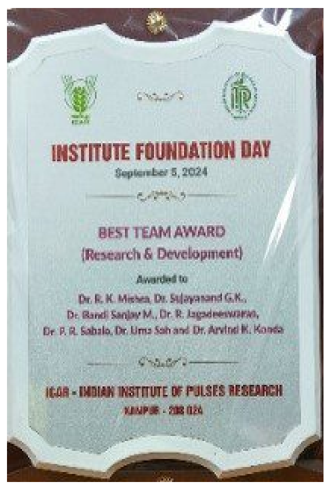
IN THE MATTER Of Copyright Registration of an artistic Work depicted below of ICAR-INDIAN INSTITUTE OF PULSES RESEARCH G.T. Road, Kalyanpur, Kanpur, Uttar Pradesh–208024, India
I have made the search from the Records of the Register of Trade Marks for the artistic work applied by you and it is certified that no Trade Marks(except the applicant's own Trade Mark) has been registered or applied for registration under the Trade Marks Act 1999 as per Computer Record of this office.
Dated this Monday 13th day of October 2025
Label As Annexed
(B.RAJAMANICKAM)
ASSTT. REGISTRAR OF TRADE MARKS.
Page1 of 2


INSTITUTE FOUNDATION DAY
September 5, 2024
BEST TEAM AWARD
(Research & Development)
Awarded to
Dr. R. K. Mishra, Dr. Sujayanand G.K., Dr. Bandi Sanjay M., Dr. R. Jagadeeswaran, Dr. P. R. Sabale, Dr. Uma Sah and Dr. Arvind K. Konda
ICAR - INDIAN INSTITUTE OF PULSES RESEARCH
KANPUR - 208 024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[See Rule 22(1)]
RECEIPT


Certificate
Microbial Germplasm Registration
ICAR
It is certified that the microbial germplasm Trichoderma afroharzianum IIPRTh33 (Reg. No. NAIMCC-R-6)
developed by
Dr. R. K. Mishra
Division of Crop Protection, ICAR-IIPR, Kanpur, Uttar Pradesh
has been registered by Microbial Germplasm Registration Committee (MGRC) of Indian Council of Agricultural Research (ICAR) on December 28th, 2021.
Member Secretary
MGRC, ICAR-NBAIM
Chairman, MGRC
DDG (CS), ICAR


Certificate
Microbial Germplasm Registration
ICAR
It is certified that the microbial germplasm Trichoderma asperellum IIPRTh31 (Reg. No. NAIMCC-R-5)
developed by
Dr. R. K. Mishra
Division of Crop Protection, ICAR-IIPR, Kanpur, Uttar Pradesh
has been registered by Microbial Germplasm Registration Committee (MGRC) of Indian Council of Agricultural Research (ICAR) on December 28th, 2021.
Member Secretary
MGRC, ICAR-NBAIM
Chairman, MGRC
DDG (CS), ICAR


Indian Council of Agricultural Research.
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Pulse booster
#OneProductOneDay #Farmer #OneICAR #variety #ICAR @PMOIndia
@ChouhanShivraj @mpbhagirathbjp
@PIB_India @mygovindia @AgriGoI @DDKisanChannel
@Dept_of_AHD
Pulse booster
PULSE BOOSTER
A talc-based formulation of Trichoderma afroharzianum (IIPRTh-33) for plant growth promotion and diseases suppression in pulse crops.
Shelf Life of developed formulation is up to 18 months.
Recommended dose for seed treatment is 10gm/kg of seed.
ICAR-National Bureau of Agriculturally Important Microorganisms, Mau
director.nbaim@icar.gov.in
+91-0547-2970727


ICAR
Dalhanderma
Talc-based formulation of Trichoderma asperellum, isolated from chickpea fields in Bundelkhand, U.P.
No harmful residue in soil, maintains nutrient balance and soil microbes.
14+ months shelf life, withstands temperatures above 40°C.
Contains beneficial genes (ech-42 and xyn-2).
Effective dose: 10g/kg for seed treatment.
Strong defense against Fusarium (F. oxysporum and F. udum), with protection rates between 80-84%. Improves soil fertility and microbial populations, enhancing crop yield
Can reduce heavy metals (Cd, Pb, Cr, Zn) in
DALHANDERMA


Indian Council of Agricultural Research's post
Indian Council of Agricultural Research
18 July 2024
Dalhan Bio-Consortia #ICAR #OneProductOneDay #Technology #OneICAR
DALHAN BIO-CONSORTIA
Developed with the co-cultivation technology of Trichoderma asperellum (IIPRTh-31) and Bacillus subtilis (SHEP-6).
Can be used for spraying as well as seed treatment.
Effective in managing soil borne pathogens and increasing plant growth.
Acts as Plant Growth Enhancer and microbial enrichment for pulse crops.
BIOCONSORTIA
ICAR-Indian Institute of Pulses Research, Kanpur
director.iipr@icar.gov.in
+91 0512-2580986

Recognition, Partnerships and Scaling-Up Stategies

Many of the microbial technologies developed at IIPR are patented and have received national recognition for their innovation and field relevance. The institute has established public–private partnerships to ensure large-scale production and distribution of these formulations through licensed manufacturers and agri-entrepreneurs.






Regular training programs, farmer field days, and capacity-building initiatives through KVKs, AICRP centers, and Atma projects have helped in spreading awareness and adoption. Technology demonstrations under the National Food Security Mission (NFSM) and the ICAR Farmer FIRST Programme have further validated their large-scale impact.

Through these efforts, IIPR bioformulations are now reaching thousands of farmers across more than 15 states, ensuring improved soil health, enhanced productivity, and sustainable profitability. The increasing market demand and farmer satisfaction reflect the success of these innovations in the real-world agricultural landscape.

Microbial Repository and Resource Management

The microbial repository at ICAR–Indian Institute of Pulses Research (ICAR–IIPR), Kanpur, serves as an important national resource for beneficial microorganisms associated with pulse crops. The repository currently houses a rich collection of 160 *Trichoderma* isolates and 24 plant growth–promoting rhizobacteria (PGPR) strains, representing diverse agro-ecological regions of India. All isolates have been molecularly characterized to ensure authenticity and genetic identity. *Trichoderma* isolates were characterized using the translation elongation factor 1-alpha (tef1-α) gene, while PGPR strains were identified using 16S rRNA gene–based primers.

The repository supports research on biocontrol, plant growth promotion, stress tolerance, and host–microbe interactions in pulse crops. Several elite and promising microbial cultures from this collection have been deposited at the National Bureau of Agricultural Insect Resources (NBAIM), Mau, ensuring long-term conservation, accessibility, and compliance with national microbial germplasm regulations. The ICAR–IIPR microbial repository thus plays a crucial role in strengthening sustainable pulse production and advancing microbial-based technologies in Indian agriculture.

In addition to marker-based identification, whole genome sequencing of two important *Trichoderma* species, *T. asperellum* and *T. afroharzianum*, has also been completed and submitted to public genomic repositories (submission/assembly accession numbers: JAJAWE000000000.1and JAJAWF000000000.1). These genome resources strengthen functional genomics, comparative analysis, and strain improvement efforts.

The following Microbial stock of *Trichoderma* species and PGPRs have submitted to NCBIdatabase

Table 1: *Trichoderma* isolates with corresponding species, source crops and their NCBI accession numbers

Sl. No.	NAME OF ISOLATES	Species	GENBANK ACC. No.(ITS)	GENBANK ACC. No.(Tef)
1	IIPR-1	*T. harzianum*	MK841000	MN226900
2	IIPR-2	*T. asperellum*	MK855322	MN226901
3	IIPR-5	*T. asperellum*	MK841001	MN226922
4	IIPR-6	*T. asperellum*	MN416772	MN226923
5	IIPR-7	*T. harzianum*	MK841002	MN226924
6	IIPR-8	*T. asperellum*	MK841003	MN226902
7	IIPR-CK-3	*T. asperellum*	MK841004	MN226903
8	IIPR-CK-2	*T. asperelloides*	MN416773	MN226904
9	IIPRUCK-1	*T. brevicompactum*	MN416774	MN226905
10	IIPRUCK-2	*T. asperellum*	MK841005	MH822549
11	IIPRKB-PP	*T. asperellum*	MK841006	MN226925
12	IIPRCH-CK-1	*T. asperellum*	MN416775	MN226906
13	IIPRCH-CK-2	*T. asperellum*	MK841007	MN226907
14	IIPRB-CK	*T. harzianum*	MK841008	MN226926
15	IIPRHCK-2	*T. harzianum*	MK841009	MN226927
16	IIPRHCK-3	*T. harzianum*	MK841010	MN226928
17	IIPRPP.K-NG	*T. harzianum*	MK855323	MN226929

18	IIPRMU-CK-2	*T. brevicompactum*	MK855324	MT058875
19	IIPRCH-CK-3	*T. asperellum*	MK841011	MH822547
20	IIPRPP-F1-2	*T. asperellum*	MK855325	MN226908
21	IIPRPP-F1-4	*T. harzianum*	MN416776	MN226930
22	IIPRSMF	*T. longibrachiatum*	MK841012	MN226909
23	IIPRMLKP	*T. asperellum*	MK855326	MN226910
24	IIPRTLKP-1	*T. atrobrunneum*	MK855327	MN226881
25	IIPRPPIIPR-2	*T. harzianum*	MK841013	MH822546
26	IIPRTLKP-2	*T. harzianum*	MK855328	MN226911
27	IIPRMGKP-3	*T. aureoviride*	MK855329	MN226912
28	IIPRMGKP-4	*T. harzianum*	MK855330	MH822545
29	IIPRMLF-2	*T. longibrachiatum*	MK855331	MN226913
30	PPIIPR-1	*T. longibrachiatum*	MN416777	MN226882
31	IIPRPPNM-4	*T. harzianum*	MK849894	MN597957
32	IIPRPPNM-2	*T. asperellum*	MK841014	MN226914
33	IIPRTLF-2	*T. asperellum*	MK841018	MN226915
34	IIPRPPNM-1	*T. harzianum*	MK849895	MH822544
35	IIPRPPNM-6	*T. harzianum*	MK849896	MH822543
36	IIPRPPNM-7	*T. harzianum*	MK841015	MN226916
37	IIPRMGBSP-1	*T. harzianum*	MK849897	MN226883
38	IIPRMGKP-3	*T. aureoviride*	MK841016	MN226917
39	IIPR58	*T. asperellum*	MN416771	MN226918
40	IIPR59	*T. longibrachiatum*	MK849898	MN226921
41	IIPR60	*T. longibrachiatum*	MN416778	MN226931
42	IIPR61	*T. longibrachiatum*	MN416779	MN226884
43	IIPR62	*T. asperellum*	MK849899	MN226932
44	IIPR64	*T. afroharzianum*	MN416780	MN226885
45	IIPR65	*T. asperellum*	MK849900	MN226933
46	IIPR66	*T. asperellum*	MK849901	MN226934
47	IIPR67	*T. asperellum*	MK849902	MN226935
48	IIPR68	*T. asperellum*	MK841017	MH822541
49	IIPR69	*T. asperellum*	MN416782	MN226936
50	IIPR71	*T. asperellum*	MK849903	MH822542
51	IIPR72	*T. longibrachiatum*	MK849904	MN226886
52	IIPR74	*T. asperellum*	MK849905	MN226937
53	IIPR75	*T. asperellum*	MN416781	MN226938
54	IIPR76	*T. asperellum*	MK849906	MN226887
55	IIPR77	*T. asperellum*	MK849907	MN226888
56	IIPR80	*T. asperellum*	MK841018	MN226939

57	IIPR81	*T. asperellum*	MK841019	MN226940
58	IIPR82	*T. asperellum*	MK849908	MN226941
59	IIPR83	*T. asperellum*	MK841017	MN226889
60	IIPR84	*T. asperellum*	MK841016	MN226890
61	IIPR86	*T. asperellum*	MK841015	MN226891
62	IIPR87	*T. asperellum*	MN416770	MN226892
63	IIPR88	*T. asperellum*	MK841020	MN226942
64	IIPRCPT92	*T. asperellum*	MK841021	MN226919
65	IIPRCPT94	*T. asperellum*	MK841023	MN226893
66	IIPRCPT95	*T. asperellum*	MK841024	MN226920
67	IIPRCPT98	*T. asperellum*	MK841025	MN226894
68	IIPRCPT 99	*T. asperellum*	MK841026	MN226895
69	IIPRCPT100	*T. asperellum*	MK841027	MN226896
70	IIPRCPT101	*T. asperellum*	MK841028	MN226897
71	IIPRCPT103	*T. virens*	MK841029	MN226898
72	IIPRCPT105	*T. asperellum*	MK841030	MN226899
73	IIPR-4	*T. harzianum*	OP777411	OP886819
74	IIPRUCK-1	*T. harzianum*	OP783859	OP886820
75	IIPRPPF-1	*T. harzianum*	OP783860	OP886821
76	IIPRPPF-2	*T. harzianum*	OP783861	
77	IIPRMGKP-2	*T. harzianum*	OP783862	OP886822
78	IIPRPPNM-5	*T. harzianum*	OP783863	
79	IIPR-70	*T. asperellum*	OP783864	OP886823
80	IIPRPPKP-1	*T. harzianum*	OP783865	OP886824
81	IIPR-85	*T. harzianum*	OP783866	OP886828
82	IIPR-79	*T. asperellum*	OP783867	OP886827
83	IIPR-78	*T. asperellum*	OP783868	
84	IIPR-73	*T. asperellum*	OP783869	OP886826
85	IIPR-9	*T. asperellum*	OP783870	OP886825
86	IIPRMLKP-1	*T. harzianum*	OP783871	OP886829
87	IIPRJ-1	*T. harzianum*	OP783872	
88	IIPRTR-12	*T. asperellum*	OP783873	
89	IIPRHP-1	*T. harzianum*	OP783874	
90	IIPRBCT-7	*T. asperellum*	OP783875	
91	IIPRT-7	*T. harzianum*	OP783876	
92	IIPRPPKP-2	*T. harzianum*	OP783877	OP886845
93	IIPRPPNM-3	*T. harzianum*	OP783878	
94	IIPRMGKP-5	*T. harzianum*	OP783879	OP886844
95	IIPRMGKP	*T. asperellum*	OP783880	OP886836

96	IIPR-10	*T. asperellum*	OP783881	OP886837
97	IIPRBPLTRI-2	*T. harzianum*	OP783882	OP886838
98	IIPRMGKP-1	*T. harzianum*	OP783883	OP886839
99	IIPRTRIS-5	*T. harzianum*	OP783884	OP886840
100	IIPRCPT-97	*T. asperellum*	OP783885	OP886841
101	IIPRCPT-91	*T. asperellum*	OP783886	OP886842
102	IIPRPPF1-3	*T. asperellum*	OP783887	OP886843
103	IIPR-3	*T. asperellum*	OP783888	OP886830
104	IIPRCPT-102	*T. asperellum*	OP783889	OP886831
105	IIPRCPT-104	*T. harzianum*	OP783890	OP886832
106	IIPRTh1	*T. harzianum*	KX681707	MH822538
107	IIPRTh2	*T. harzianum*	KX681708	MT133523
108	IIPRTas1	*T. asperellum*	KX681709	MH822535
109	IIPRTh-3	*T. harzianum*	KX681710	MT239390
110	IIPRTas2	*T. asperellum*	KX681711	MT239396
111	IIPRTas3	*T. asperellum*	KX681712	MH822534
112	IIPRTas4	*T. asperellum*	KX681713	MH822533
113	IIPRTh4	*T. harzianum*	KX681714	MH822531
114	IIPRTas5	*T. asperellum*	KX681715	MH822533
115	IIPRTh5	*T. harzianum*	KX681716	MT239391
116	IIPRTas6	*T. asperellum*	KX681717	MT239393
117	IIPRTas7	*T. asperellum*	KX681718	MH822532
118	IIPRTh6	*T. harzianum*	KX681719	MH822550
119	IIPRTh7	*T. harzianum*	KX681720	MT133520
120	IIPRTas8	*T. asperellum*	KX681721	MH822540
121	IIPRTh8	*T. harzianum*	KX681722	MT239395
122	IIPRTas9	*T. asperellum*	KX681723	MT133521
123	IIPRTh9	*T. harzianum*	KX681724	MH822548
124	IIPRTlg1	*T. longibrachiatum*	KX681725	MW504037
125	IIPRTh10	*T. harzianum*	KX681726	MH822537
126	IIPRTh11	*T. harzianum*	KX681727	MT239397
127	IIPRTas10	*T. asperellum*	KX681728	MT090037
128	IIPRTas11	*T. asperellum*	KX681729	MH822539
129	IIPRTh12	*T. harzianum*	KX681730	MT090035
130	IIPRTh13	*T. harzianum*	KX681731	MT133522
131	IIPRTh14	*T. harzianum*	KX681732	MH822552
132	IIPRTas12	*T. asperellum*	KX681733	MT239392
133	IIPRTlg2	*T. longibrachiatum*	KX681734	JN716392
134	IIPRTg3	*T. longibrachiatum*	MH511661	MW504038

135	IIPRTh15	*T. harzianum*	MH511662	MH822536
136	IIPRTh16	*T. harzianum*	MH511663	MH822551
137	IIPRTh17	*T. harzianum*	MH511664	MT090036
138	IIPRTh18	*T. harzianum*	MH511665	MH822528
139	IIPRTas13	*T. asperellum*	MH511666	MT239394
140	IIPRTas14	*T. asperellum*	MH511667	MW504042
141	IIPRTh19	*T. harzianum*	MH511668	MN597958
142	IIPRTh20	*T. harzianum*	MH511669	MW201699
143	IIPRTh21	*T. harzianum*	MH511670	MW504039
144	IIPRTas15	*T. asperellum*	MH511671	MH822529
145	IIPRTh22	*T. harzianum*	MH511672	MW504036
146	IIPRTh23	*T. harzianum*	MH511673	MW504034
147	IIPRTh31	*T. asperellum*	MK968811	MN232100
148	IIPRTh32	*T. harzianum*	MN186845	MN393156
149	IIPRTh33	*T. afroharzianum*	MN186847	MN414456
150	IIPRTh34	*T. harzianum*	MN186858	MN414457
151	IIPRTh35	*T. harzianum*	MN186862	MN947653
152	IIPRTh36	*T. harzianum*	MN186868	MN947654
153	IIPRTh37	*T. harzianum*	MN186870	MN414458
154	IIPRTh38	*T. harzianum*	MK970735	MN414459
155	IIPRTh39	*T. harzianum*	MK976003	MN414460
156	IIPRTh40	*T. harzianum*	MK976736	MN414461
157	IIPRTh41	*T. harzianum*	MK977583	MN414462
158	IIPRTh42	*T. harzianum*	MK968774	MN414463
159	IIPRTh43	*T. harzianum*	MN252549	MN414464
160	IIPRTh44	*T. asperellum*	MN186841	MN947652

Table 2: PGPRS with corresponding species, source crops and their NCBI accession numbers

Sl No	Isolate name	Bacterial scientific name	NCBI Acc. No
1	IIPRAJCP-6	*Bacillus amyloliquefaciens*	MK841518
2	IIPRDSCP-1	*Bacillus subtilis*	MK863575
3	IIPRDSCP-10	*Bacillus tequilensis*	MK863576
4	IIPRRLCP-5	*Bacillus safensis*	MK863577
5	IIPRCDCP-2	*Bacillus subtilis*	MK863578
6	IIPRAMCP-1	*Bacillus safensis*	MK863579
7	IIPRMKCP-10	*Bacillus haynesii*	MK863580
8	IIPRANPP-3	*Bacillus amyloliquefaciens*	MK863581
9	IIPRKARP-5	*Enterobacter soli*	MT436391
10	IIPRAJCP-2	*Enterobacter cloacae*	MT436392

11	IIPRDSCP-11	*Acinetobacter calcoaceticus*	MT436393
12	IIPRDSCP-9	*Bacillus valezensis*	MT436394
13	IIPRMKCP-3	*Serratia marcescens*	MT436395
14	IIPRMKCP-1	*Pseudomonas aeruginosa*	MT436396
15	IIPRMKCP-5	*Pseudomonas fluorescens*	MT436397
16	IIPRMKCP-9	*Pseudomonas guariconensis*	MT436398
17	IIPRMKCP-8	*Bacillus megaterium*	MT436399
18	IIPRMWCP-9	*Geceealupaeji*	MT436400
19	IIPRKUCOP-10	*Pseudomonas putida*	MT436401
20	IIPRAMCP-4	*Klebsiella aerogenes*	MT436402
21	IIPRKCP-7	*Enterobacter cloacae*	MT436403
22	IIPRAMCP-5	*Bacillus cereus*	MT436404
23	IIPRSHEP-6	*Bacillus subtilis*	MN872223
24	IIPRSBA-89	*Bacillus altitudinis*	MT641195

Microbial Germplasm submitted to NBAIM Mau

Sl. No.	Culture ID	NAIMCC No
1	IIPRTaf-64	NAIMCC-F-04299
2	IIPRTas-12	NAIMCC- F-04300
3	IIPRTas-9	NAIMCC- F-04301
4	IIPRTas-13	NAIMCC- F-04302
5	IIPRTas-74	NAIMCC- F-04303
6	IIPRTh-10	NAIMCC- F-04304
7	IIPRTh-3	NAIMCC- F-04305
8	IIPRTh-38	NAIMCC- F-04306
9	IIPRTh-32	NAIMCC- F-04307
10	IIPRTlg-72	NAIMCC- F-04308
11	IIPRTlg-59	NAIMCC-F-04309
12	IIPRTg-3	NAIMCC- F-04310
13	IIPRT-103	NAIMCC- F-04311

Sl. No.	Culture ID	NAIMCC No
14	IIPRTh-1	TF-3117
15	IIPRTh-2	TF-3118
16	IIPRTh-13	TF-3119
17	IIPRTh-17	TF-3120
18	IIPRTh-20	TF-3122
19	IIPRTh-31	NMAICC-R-5
20	IIPRTh-33	NMAICC-R-6
21	IIPRSBa89	NAIMCC-B-03172
22	IIPRMKCP-9	NAIMCC-B-03173
23	IIPRAJCP-6	NAIMCC-B-03174
24	IIPRANPP-3	NAIMCC-B-03175
25	IIPRMKCP-10	NAIMCC-B-03176
26	IIPRMKCP-9	NAIMCC-B-03177

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