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SUMMARY DISSERTATION THESIS

INTENSIFICATION OF LEGUMES PRODUCTION
IN ORGANIC FARMING BY BIOLOGICAL TREATMENT

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Summary dissertation thesis

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Abstrakt

Pěstování hrachu a sóji nabývá na významu v rámci systémů ekologického zemědělství v Evropě a v České republice. Tyto plodiny však čelí rostoucím výzvám v důsledku klimatických změn, úbytku půdní organické hmoty a biotických stresorů, včetně škůdců, chorob a konkurence plevelů, což významně ovlivňuje výnos i kvalitu semen. V této souvislosti je systematické studium a integrované využívání efektivních strategií biologické kontroly nezbytné pro snížení výnosových ztrát, optimalizaci kvality zrna a udržení zdravé půdy v rámci ekologického pěstování luskovin.

Za tímto účelem byly provedeny tříleté polní pokusy s cílem vyhodnotit účinky bakterií mléčného kvašení (LAB), mykoparazitických hub (MPF) a různých metod jejich aplikace na produkci, výnos a výskyt škůdců a chorob u těchto plodin. Tato disertační práce dále poskytuje integrovanou analýzu úlohy LAB v systémech půda-rostlina a současně hodnotí, jak interakce mezi těmito plodinami a vybranými prospěšnými mikroorganismy, včetně MPF a LAB, ovlivňuje labilní frakci půdní organické hmoty (CLSOM). Cílem bylo stanovit včasné indikátory, které přispějí k efektivním a udržitelným strategiím managementu půdy.

Disertační práce objasňuje méně prozkoumaný význam bakterií mléčného kvašení v systémech půda-rostlina. Tyto mikroorganismy hrají zásadní roli jako biofertilizéry a látky biologické kontroly, čímž zlepšují produktivitu rostlin i vitalitu půdy. Zvláštní důraz je kladen na jejich všestranné využití v rámci strategií udržitelného zemědělství a optimalizace výnosů plodin.

Nejvýznamnějším zjištěním je, že výsledky polních pokusů poskytují jasné důkazy o pozitivním vlivu bakterií mléčného kvašení a mykoparazitických hub při aplikaci ve formě moření osiva a listové aplikace u hrachu a sóje. Výsledky prokazují, že „seed priming“ (předseťová příprava osiva) pomocí LAB nebo MPF významně stimuluje raný růst u obou plodin, s obzvláště výrazným účinkem u hrachu. Dále bylo prokázáno, že integrace ošetření osiva a listové aplikace ve fázi kvetení podporuje výnos a kvalitu semen. Mykoparazitické houby navíc v polních pokusech přinesly neoptimálnější výsledky, přičemž efektivně vyvážily zvýšení výnosu zrna se zachováním vysokého obsahu proteinů. Tyto biologické agens se rovněž ukázaly jako účinná při snižování tlaku škůdců a chorob u hrachu. Na druhé straně výsledky polních pokusů poukazují na významné výzvy v podobě konkurence plevelů u sóji, zejména v raných fázích vývoje, což podtrhuje nezbytnost kombinace biologického ošetření s dalšími agrotechnickými opatřeními pro dosažení optimální účinnosti. Závěrem disertační práce se poukazuje na významný vliv udržitelných postupů hospodaření, včetně výběru plodin a aplikace mikrobiálních přípravků, na dynamiku půdní organické hmoty (SOM). Aplikace prospěšných mikroorganismů při pěstování hrachu vykazuje značný potenciál pro udržení nebo zvýšení CLSOM. Tato zjištění zdůrazňují naléhavou potřebu porozumět dynamice SOM a podporují přijetí indexu managementu uhlíku (CMI) a stabilizačních poměrů jako klíčových ukazatelů pro udržitelné hospodaření s půdou.

Celkově tato disertační práce přináší cenné a praktické výsledky výzkumu, které potvrzují účinnost biologického ošetření při pěstování hrachu a sóji v ekologickém zemědělství. Studie

dále poskytuje hluboký vhled do úlohy prospěšných mikroorganismů při zvyšování produktivity plodin a zlepšování zdraví půdy. Zároveň objasňuje vliv integrace udržitelných zemědělských postupů s efektivní aplikací mikrobiálních přípravků na dynamiku půdní organické hmoty, čímž přispívá k rozvoji robustních strategií pro udržitelné hospodaření s půdou. Zjištění poskytují vědecký a praktický základ pro začlenění prospěšných mikroorganismů a udržitelných metod managementu jako nezbytných součástí holistických systémů ekologického zemědělství.

Klíčová slova: biologické ošetření, mykoparazitické houby, bakterie mléčného kvašení, půdní organická hmota, ekologické zemědělství, hrách, sója, produkce, výnos, škůdci a choroby.

Abstract

Pea and soybean crops are increasingly important legumes in organic farming systems in Europe, particularly in the Czech Republic. However, these crops face mounting challenges from climate change, soil organic matter depletion, and biotic stressors all of which significantly impact both yield and seed quality. In this context, the systematic study and integrated application of effective biocontrol strategies are essential to closing yield gaps, optimizing grain quality, and maintaining soil health in organic legume cultivation.

Three-year field trials were conducted to evaluate the effects of lactic acid bacteria (LAB), mycoparasitic fungi (MPF), and application methods on crop production, yield, and pest and disease incidence. Furthermore, this dissertation provides an integrated analysis of the roles of LAB within soil-plant systems, while simultaneously evaluating how the interaction between these crops and selected beneficial microorganisms, including MPF and LAB, affects the labile fraction of soil organic matter (CLSOM), aiming to establish early indicators that contribute to effective and sustainable soil management strategies.

This dissertation elucidates the less-explored significance of lactic acid bacteria within soil-plant systems. These microorganisms play a vital role as biofertilizers and biocontrol agents, improving both plant productivity and soil vitality. A particular emphasis is placed on their versatility in sustainable farming strategies and crop yield optimization.

Most notably, field experiments substantiate the positive effects of lactic acid bacteria and mycoparasitic fungi when applied as seed treatments and foliar sprays to peas and soybeans. The findings demonstrate that seed treatment with LAB or MPF significantly enhanced early growth in both crops, particularly in peas. Furthermore, integrating seed treatment and foliar application at the flowering stage was demonstrated to support yield and seed quality. Moreover, the use of mycoparasitic fungi yielded the most optimal results in field trials, effectively balancing grain yield enhancement with the maintenance of high protein content. These biological agents also proved effective in mitigating pest and disease pressure in peas. However, the field results also highlight weed competition challenges for soybeans, especially during early development, and emphasize the need to combine biological treatments with other agrotechnical measures to achieve optimal efficacy. Finally, the dissertation points out the significant impact of sustainable management practices, including crop selection and microbial applications, on soil organic matter (SOM) dynamics. The application of beneficial microorganisms in pea cultivation demonstrated substantial potential to maintain or increase CLSOM. These findings highlight the critical need to understand SOM dynamics and promote the adoption of the carbon management index and stabilization ratios as key metrics for sustainable soil management.

Overall, this dissertation provides valuable and practical research findings that substantiate the efficacy of biological treatments in organic pea and soybean cultivation. Furthermore, the study provides profound insights into the role of beneficial microorganisms in enhancing crop productivity and soil health and into the impact of integrating sustainable farming practices with effective microbial applications on soil

organic matter dynamics, thereby contributing to the development of comprehensive strategies for sustainable soil management. The findings establish a scientific and practical basis for integrating beneficial microorganisms and sustainable management as essential components of holistic organic farming systems.

Keywords: biological treatment, mycoparasitic fungi, lactic acid bacteria, soil organic matter, organic farming, pea, soybean, production, yield, pests, diseases.

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Chapter 1: Introduction

1.1 Background

The strategic cultivation of leguminous crops constitutes a pivotal evolution in organic agriculture toward ecological resilience and resource efficiency. Integrating these crops is no longer optional; it is a global necessity to secure food supplies and reduce environmental damage in a changing climate. Within legumes, pea (*Pisum sativum* L.) and soybean (*Glycine max* (L.) Merr.) are particularly significant, serving as primary plant-based protein sources for human and animal nutrition while enhancing the circularity of sustainable systems. These legumes not only provide ecological value through nitrogen fixation but also strengthen soil health by capturing carbon, thereby improving soil structure and biological vitality.

Despite their foundational role, maintaining consistent, commercially viable yields in organically cultivated pea and soybean crops faces complex challenges. Weeds, pests, and diseases remain the biggest challenges to legume yield and quality. On the other hand, the ban on synthetic chemicals and the limited options for curative control after a pathogen has established in the crop impact the efficacy of pest control in organic farming. Furthermore, soil degradation and organic matter depletion have intensified, further compounding these difficulties. Addressing this complex reality, especially given the current lack of proven systemic biological solutions, constitutes a major research gap that requires comprehensive field trials. Biological control is critical because it is preventative and systemic, focusing on strengthening the soil's natural disease suppression and plant resilience before pathogens attack. This approach represents the ultimate long-term sustainable solution, as it reduces dependency on external inputs and builds a healthier, more diverse soil microbiome over successive seasons. However, the success of this strategy depends heavily on selecting strains, optimizing application techniques, and integrating microbial agents with complementary functions. While biological control has been studied extensively, optimizing the performance of these agents in the field remains essential, particularly when using different application methods in organic systems. This study provides a comprehensive evaluation of their fluctuations, the complexities of the factors involved, and their applicability to agricultural production practices.

The dissertation focuses on two critical biological agents, lactic acid bacteria (LAB) and mycoparasitic fungi (MPF). Lactic acid bacteria (LAB) serve as vital biostimulants, enhancing crop vigor by promoting growth, solubilizing sequestered nutrients, and inducing the plant's natural defenses. Mycoparasitic fungi (*Trichoderma* spp.) are essential biocontrol agents whose primary functions are mycoparasitism and antagonism. They directly parasitize and suppress major soil-borne pathogens, providing high-efficacy defense even in the absence of biotic pathogens. However, the optimal effectiveness of these biological agents hinges critically on the chosen method and timing of application, as well as crop species and prevailing field conditions. It is necessary to evaluate the differential mechanisms of action of various application methods, such as seed treatment and foliar application, when applied individually or in combination. Assessing these complex interactions in pea and soybean under field conditions is essential for both practical farming and scientific research. Furthermore, to

establish a robust foundation for this complex fieldwork, this thesis offers a novel contribution by conducting an evaluative systematic review with quantitative data analysis of the existing literature on the critical role of microorganisms in the soil-plant system, providing a comprehensive, quantitative overview of the existing knowledge base. Finally, the application of legumes, coupled with beneficial microbes, must be quantitatively assessed for its overall impact on soil organic matter and soil health. The findings will provide a scientific foundation for optimizing sustainable intensification in organic pea and soybean production.

1.2 Objectives and hypotheses

1.2.1 General objective

To evaluate the effect of biological treatments using lactic acid bacteria (LAB) and mycoparasitic fungi (MPF) on soil health, crop performance, and pest management in organic pea and soybean production systems.

1.2.2 Specific objectives

1. To investigate the critical role of LAB in the soil-plant interaction.
2. To evaluate the effect of LAB and MPF application on the dynamics of labile soil organic matter and early indicators of soil health.
3. To assess the effect of LAB and MPF application on production parameters, yield, and seed quality of pea and soybean.
4. To assess the effect of LAB and MPF application on insect pest and disease occurrence in pea.

1.2.3 Hypotheses

1. Lactic acid bacteria are expected to play a critical and beneficial role in the soil-plant system, thereby increasing productivity.
2. The application of LAB and MPF is expected to have a positive effect on the dynamics of labile soil organic matter and early indicators of soil health.
3. Application of LAB and MPF is expected to positively influence production parameters, yield, and seed quality of pea and soybean.
4. The application of LAB and MPF is expected to suppress insect pest populations and disease incidence in pea.

Chapter 2: Literature Review

Legumes are an integral part of organic cropping systems due to their ability to fix atmospheric nitrogen and transform it into a bioavailable form for the host and subsequent crops through biological nitrogen fixation (Kebede, 2021; Pandey et al., 2017; Stagnari et al., 2017). Over 70% of leguminous species establish symbiotic associations with rhizobia, yielding fixation rates of up to 200 kg N ha⁻¹ and are recognized as a viable strategy to mitigate reliance on conventional sources (Pandey et al., 2017; Shah et al., 2021). As a fundamental component of sustainable agriculture, legumes offer multifaceted benefits to modern cropping systems. They support intensification by enhancing soil structure and biological health, creating a more favorable environment for nutrient availability (Pandey et al., 2017; Watson et al., 2002). Diversified rotation through legume inclusion supports sustainable crop production by promoting nutrient cycling and increasing crop diversity (Lal, 2023; Stagnari et al., 2017). Pulse crops also serve as important break crops in cereal-dominated crop rotations, reducing weed, pest, and disease pressure and improving soil structure (Watson et al., 2017). Therefore, incorporating crop rotation into integrated pest management frameworks fosters robust crop development and minimizes problems associated with destructive pests in agricultural practices (Al-Musawi et al., 2025). In addition to rotational benefits, the inclusion of legumes in intercropping systems optimizes resource-use efficiency, enhances water retention and productivity, and minimizes environmental impacts through carbon sequestration and reduced agrochemical use (Kokkini et al., 2025). By integrating legumes into cropping systems, cropping systems can achieve greater ecological optimization and reduced dependence on inputs, thereby supporting high yield practices that fulfill global sustainability mandates (Kokkini et al., 2025). Legumes are also ecosystem service providers and environmental facilitators, as they reduce the need for synthetic N fertilization, promote soil conservation, and create more diversified and biodiverse agricultural systems.

Of the legumes, pea (*Pisum sativum* L.) and soybean (*Glycine max* (L.) Merr.) play key roles in organic cropping systems. Pea is a versatile, gluten-free legume originating from East Africa and West Asia, valued globally for its high protein content, essential bioactive compounds, and significant health benefits (Parihar et al., 2025; Karkanis et al., 2016). Soybean stands as a dominant global crop characterized by its high protein content and versatile utility in food, animal feed, and industrial sectors like biofuel (Tian et al., 2025; Gai et al., 2025). Beyond its economic impact, soybean play a vital ecological role by enhancing soil health and moisture conservation through nitrogen-fixing symbiotic associations (Gai et al., 2025). Pea and soybean became the two most widely grown protein crops and the dominant grain legumes across Europe.

Despite these advantages, developing an organic arable farming system that is self-sufficient in N supply while maintaining high yields is both important and challenging. The cultivation of legumes, specifically peas and soybeans, faces significant challenges under fluctuating pedoclimatic conditions and is increasingly vulnerable to a wide array of biotic and abiotic stressors. A primary concern is the prevalence of soilborne diseases caused by fungi, bacteria, and nematodes, which are further exacerbated by climate change, creating

environments conducive to pathogen proliferation (Grünwald et al., 2004; Liu et al., 2025). Consequently, managing these specific pests and pathogens requires complex crop rotation strategies to sustain productivity. Furthermore, in organic systems where synthetic herbicides are prohibited, soybeans encounter intense weed competition, necessitating sophisticated mechanical control methods to prevent significant yield loss.

In organic production, biological control is fundamental to organic farming systems, utilizing living agents such as bacteria, fungi, and viruses to suppress pathogens and weeds (Golijan-Pantović and Sečanski, 2022; Stenberg et al., 2021). These biological control agents (BCAs) offer high target specificity and a reduced environmental footprint (Collinge et al., 2021; Tronsmo et al., 2020). Consequently, biocontrol is gaining traction as a sustainable alternative, with many forms now widely integrated into organic cultivation (Collinge et al., 2021). In practice, biological control can be achieved when a less virulent organism outcompetes and replaces a more damaging pest within the same environment, thereby reducing overall crop damage (Stenberg et al., 2021).

Lactic acid bacteria (LAB) represent promising biocontrol agents for sustainable plant protection in organic farming systems. These bacteria exert biocontrol through the secretion of organic acids, which lower the environmental pH to inhibit pathogen growth and spore germination, thereby limiting host colonization and the production of potent antimicrobial substances such as cyclic dipeptides and reuterin, which prevent infection and enhance plant resilience (Hirozawa et al., 2023; Saragoça et al., 2024).

The antifungal properties of selected LAB strains (*Lactobacillus fermentum*, *L. plantarum*, *L. paralimentaris*, *L. pentosus*, *L. buchneri*, *Sporolactobacillus*) have been evaluated against several important plant pathogenic fungi, including *Fusarium verticillioides*, *Penicillium* sp., and *Verticillium dahliae*, as well as against the parasitic oomycete *Pythium aphanidematum* (Kharazian et al., 2017; López-Seijas et al., 2020; Simone et al., 2021). Kowalska et al. (2024) demonstrated the vigorous antagonistic activity of *Lactiplantibacillus* sp., significantly inhibiting the growth of this pathogen in microbiological media (Kowalska et al., 2024). The study by Marín et al. (2019) established that coating with *Lactobacillus plantarum* reduced Botrytis incidence on grapes while having a positive effect on berry quality.

The application of Lactic Acid Bacteria (LAB) has demonstrated significant growth-promoting effects across diverse crops. Specifically, strains of *Levilactobacillus* sp. and *Lactiplantibacillus* sp. applied during cultivation markedly increased spinach plant biomass (Kowalska et al., 2024). Similar yield enhancements have been observed in cereal crops; for instance, treating wheat and rye seeds with LAB resulted in higher grain yields and improved thousand-seed weight (Gwiazdowski et al., 2023). LAB improves nutrient bioavailability and bolsters plant resilience against environmental stressors, allowing them to withstand stress and inhibit plant nematodes (Ibrahim et al., 2022). Lactic acid bacteria have been shown to induce the production of defense-related enzymes in treated tomato seedlings. Such findings underscore the significant potential of LAB as multifunctional biostimulants in sustainable agricultural systems.

Sustainable plant disease management can be achieved through the use of mycoparasitic fungi. Numerous antagonistic fungal species have potential biocontrol activity against fungal

plant pathogens. *Trichoderma* (Hypocreales: Hypocreaceae) are effective biocontrol agents, widely used for their resilience in extreme environments, their ability to promote plant growth, and parasitization of phytopathogens through multiple mechanisms of action (Oyesola et al., 2025). Pathogen suppression by *Trichoderma* spp. results from a complex interplay of mycoparasitism, antibiosis, and competition. Furthermore, the induction of plant defensive mechanisms, mycoparasitism, and plant growth promotion, which may operate independently or together, contributes to a holistic biocontrol strategy (Mukhopadhyay and Kumar, 2020; Oyesola et al., 2025). In addition to direct antagonism, *Trichoderma* competes with pathogenic microorganisms for space and nutrients by invading their natural habitats, such as plant tissues, rhizospheres, and the phyllosphere (Halifu et al., 2019; Zaid et al., 2022). The effectiveness of various *Trichoderma* species in managing plant diseases highlights their importance for controlling numerous economically significant pathogens in agriculture (Villavicencio-Vásquez et al., 2025).

Chapter 3: Methodology

The methodology of this dissertation was produced using two distinct approaches across four peer-reviewed publications, one manuscript under review, and one manuscript in preparation. The initial methodology was a meta-analysis, which provides a systematic review of the key functional roles of lactic acid bacteria (Chapter 4.1). The subsequent methodology focuses on empirical research, combining field experiments with laboratory-based analyses (Chapters 4.2 – 4.6). These experimental phases aim to evaluate the practical applications of biological treatments on soil health dynamics, crop production, and pest management in organic production systems. By integrating a targeted review with multi-year experimental data from all publications and manuscripts, this collective scholarly contribution establishes a robust methodological foundation for optimizing biological treatments in organic agricultural practices.

3.1 Meta-analysis

The methodology involves a systematic review and meta-analysis of the functional roles of Lactic Acid Bacteria (LAB), as detailed in Chapter 4.1. This analysis establishes the mechanistic foundation that informs the subsequent experimental trials.

A systematic search was conducted in the Web of Science database for studies on Lactic Acid Bacteria (LAB) and their roles in plant-soil systems. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, studies were selected based on rigorous eligibility criteria to ensure the robustness and reliability of the synthesized dataset. Primary quantitative outcomes and key parameters related to LAB's impact on plant growth and biocontrol were retrieved to evaluate their multi-functional roles. All extracted data, including central tendencies and measures of variability, were standardized to uniform metrics to ensure seamless comparability across diverse experimental setups. Data integrity was ensured by addressing temporal pseudo-replication and organizing multiple observations into a structured dataset for robust statistical synthesis.

3.2 Experimental study

The experimental core of this dissertation was conducted to assess the efficacy of biological treatments across three primary dimensions: soil health dynamics (Chapter 4.2); crop growth, development, and yield (Chapters 4.3, 4.4, and 4.6); and pest and disease management (Chapter 4.5) in organic production systems across different seasons. All research was carried out over multiple growing seasons from 2022 to 2025 on an organic farm in Zvíkov, České Budějovice.

Trials were organized using a Randomized Complete Block Design (RCBD) with three replications per treatment. This unified framework ensured that, despite variations in target crops and biological agents, a consistent level of statistical rigor was maintained, allowing for a comparative synthesis of results across all studies. The experimental setup compared the performance of biological seed and foliar treatments, applied independently or in combination, against untreated controls to determine their impact on:

Soil carbon fractions and indices: Physicochemical properties and organic matter carbon stocks were evaluated at key phenological stages to monitor temporal fluctuations in soil quality and carbon stability indicators (Chapter 4.2).

Agronomic, physiological, and quality parameters: Pea and soybean performance was assessed through key growth and nodulation traits, yield components, and seed protein content. Additionally, physiological vigor was assessed by measuring leaf chlorophyll content (Chapters 4.3, 4.4, and 4.6).

Evaluation of pest and disease parameters: The effectiveness of biological control against biotic stress was assessed by monitoring the population dynamics of key pests, including pea leaf weevils, pea aphids, and weevils, and by evaluating root rot severity (Chapter 4.5).

3.3 Data analysis

Meta-analysis data were synthesized both qualitatively and quantitatively to provide an in-depth understanding of the multi-functional roles of LAB within the soil-plant system (Chapter 4.1). Original data from field and laboratory experiments on pea and soybean were analyzed using analysis of variance (ANOVA) to evaluate the individual and interactive effects of treatments on soil organic carbon dynamics, crop development, yield, pest and disease occurrence (Chapters 4.2–4.6). Mean comparisons were performed using post hoc tests, including Tukey's HSD and Dunnett's tests. Furthermore, multivariate principal component analysis (PCA) and correlation models were employed to examine the complex relationships among selected variants.

Chapter 4: Results and Discussion

4.1 Prominent use of lactic acid bacteria in soil-plant systems

4.1.1 Full citation of the article

Murindangabo, Y. T., Kopecký, M., Perná, K., **Nguyen, T. G.**, Konvalina, P., Kavková, M., 2023. Prominent use of lactic acid bacteria in soil-plant systems. *Applied Soil Ecology*, 189, 104955. <https://doi.org/10.1016/j.apsoil.2023.104955>

Journal metrics: Impact Factor: 4.8 (2023); 5 – Year Impact Factor: 4.9; Q2.

4.1.2 Abstract and keywords

Abstract: Lactic acid bacteria (LAB) are ubiquitous, Gram-positive, probiotic, and facultative aerophilic microorganisms. They are commonly found in wide range of environments including food-rich environments, decaying plants, milk products, the human gut, vaginal flora, and on the skin of various living organisms. These multifaceted bacteria have multiple roles including promoting food safety; promoting plant growth; improving soil, animal, and human health. They are also an integral part of sustainable farming strategies with a low risk of resistance to chemical pesticides, making them an environmentally friendly and effective way of managing pests and diseases and improving plant production. While the traditional role of LAB in food processing and human health sectors has been widely studied and documented, there is increasing attention to their additional roles that empirical evidences and research have validated such as serving as biofertilizers, biocontrol, and biostimulant agents in plant production through the production of bacteriocins, organic acids, and other compounds. However, there is still a gap in unlocking the relationship between LAB, soil, and plant hosts. Through a review of the literature and metadata, this review aims to discuss the less-explored relevance of LAB in soil-plant systems and spotlight the prospects for increased acceptance as sustainable and safe soil and plant health enhancers. The first part concentrates on analyzing the existing metadata, while the discussion part essentially focus on literature review.

Keywords: biostimulant, biocontrol, biofertilizer, effect size, lactic acid bacteria, sustainable farming.

4.1.3 Main contribution of the article

This article provides deeper insights into the ecological and agricultural roles of lactic acid bacteria (LAB) outside of their traditional roles in food processing and human health. The study demonstrates the multifunctional potential of LAB, highlighting their roles in agricultural production as biofertilizers, biocontrol agents, and biostimulants. The role of LAB in soil–plant ecosystems has historically been less explored. By focusing on these understudied interactions, this research fills a key gap in our understanding of how LAB, soil health, and plant hosts interact. It provides a more comprehensive perspective on LAB's potential to enhance soil fertility, promote plant growth, and suppress plant pathogens. These findings provide a solid scientific basis for promoting the adoption of LAB as a safe, eco-friendly alternative to improve crop yields and promote sustainable agriculture.

4.1.4 Author's contribution to the article

In this publication, the PhD candidate contributed to the screening of studies and assisted in the preparation and revision of the manuscript. The candidate's contribution accounts for approximately 15% of the total work.

4.1.5 Attached article PDF

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Prominent use of lactic acid bacteria in soil-plant systems

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ABSTRACT

Lactic acid bacteria (LAB) are ubiquitous, Gram-positive, probiotic, and facultative aerophilic microorganisms. They are commonly found in wide range of environments including food-rich environments, decaying plants, milk products, the human gut, vaginal flora, and on the skin of various living organisms. These multifaceted bacteria have multiple roles including promoting food safety; promoting plant growth; improving soil, animal, and human health. They are also an integral part of sustainable farming strategies with a low risk of resistance to chemical pesticides, making them an environmentally friendly and effective way of managing pests and diseases and improving plant production. While the traditional role of LAB in food processing and human health sectors has been widely studied and documented, there is increasing attention to their additional roles that empirical evidences and research have validated such as serving as biofertilizers, biocontrol, and biostimulant agents in plant production through the production of bacteriocins, organic acids, and other compounds. However, there is still a gap in unlocking the relationship between LAB, soil, and plant hosts. Through a review of the literature and metadata, this review aims to discuss the less-explored relevance of LAB in soil-plant systems and spotlight the prospects for increased acceptance as sustainable and safe soil and plant health enhancers. The first part concentrates on analyzing the existing metadata, while the discussion part essentially focus on literature review.

1. Introduction

LAB are low guanine-cytosine DNA, Gram-positive, microaerophilic, nonsporulating, lacking cytochromes, fermentative, rod or coccus bacteria (Bintsis, 2018). Their name is derived from the fact that the main end product of carbohydrates catabolism is lactic acid, but also produces other compounds (König and Fröhlich, 2017). They are classified into different genera including *Aerococcus*, *Alloiococcus*, *Carnobacterium*, *Enterococcus*, *Lactobacillus*, *Lactococcus*, *Leuconostoc*, *Pediococcus*, *Streptococcus*, *Tetragenococcus*, *Vagococcus*, as well as *Bifidobacterium*. Phylogenetically, the latter one, together with *Propionibacterium*, *Brevibacterium*, and the microbacteria looks like *actinomycete* (Axelsson, 2004; Pot et al., 1994). They habit rich-nutrient areas (milk, meat, fruits, vegetables, beverages), especially fermented or decomposing ones; sewage; plants; human and animal gut, respiratory and genital tracks (Raman et al., 2022). LAB are preferred for food biopreservation because they are safe to consume, improve taste, and during storage they

naturally dominate the microflora of many foods and inhibit the growth of food-spoiling bacteria (Stiles, 1996). The capacity of LAB to produce organic acids, phenolic compounds, antimicrobial (fungal, bacterial) metabolites, flavor substances, and bacteriocins (Fig. 1) has put them among the best food preservatives (Dalié et al., 2010; Delves-Broughton et al., 1996). They are used in wineries and breweries (for starting the malolactic fermentation), bakeries, and other plant and animal-based foods and drinks factories and play big roles in the production of cheese, bread, yogurt, silage, and others (Nguyen et al., 2015). Additionally, LAB have shown capabilities in reducing the malodor of decomposing organic material (DuPont and Fischer, 2012) and when consumed by livestock in their feed and/or water help promote healthy gut flora, enhance their immune systems, and aid in digestion (probiotic) (Corcionivoschi et al., 2010; Fuentes Fajardo et al., 2012). These important uses of LAB have led to a thorough study of their physiology and the bioactive compounds they produce and proven their safety and value for humans and animals health as probiotics (Garsa et al., 2014;

Abbreviations: LAB, Lactic acid bacteria; PGE, Plant growth enhancer; DNA, Deoxyribonucleic acid; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; IAA, Indole-3-acetic acid; CI, Confidence interval.

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4.2. Effects of biological treatments on labile soil organic matter dynamics and early indicators of soil health

4.2.1 Full citation of the article

Murindangabo, Y. T., Kopecký, M., Perná, K., Nguyen, T. G., Ghorbani, M., Konvalina, P., Bohatá, A., Kavková, M., Hoang, T. N., Kabelka, D., Klenotová, E., 2023. Enhancing soil organic matter transformation through sustainable farming practices: evaluating labile soil organic matter fraction dynamics and identifying potential early indicators. *Agriculture*, 13(7), 1314. <https://doi.org/10.3390/agriculture13071314>

Journal metrics: Impact Factor 3.3 (2023); 5 - year Impact Factor 3.8; Q1.

4.2.2 Abstract and keywords

Abstract: The growing global population and increasing demand for agricultural products have exerted significant pressure on agricultural systems. As a result, soil organic matter depletion and degradation have become prevalent issues, including in regions such as South Bohemia, Czech Republic, where conventional farming practices are predominant. Soil organic matter (SOM) plays a critical role in soil health, crop productivity, and the sustainability of agricultural systems, with changes occurring in both the total and labile fractions of the organic matter pools. However, changes in the total soil organic matter carbon pool (TOC) resulting from agricultural practices occur gradually and may become evident only after several years, posing challenges for timely management adjustments. Therefore, the identification of early indicators of SOM dynamics is crucial for implementing prompt corrective actions. The aim of this study was to evaluate the effects of sustainable management practices, such as cultivated crops (*Pisum sativum* and *Lupinus albus*), selected entomopathogenic and mycoparasitic fungi (MEHA) (*Trichoderma virens* and *Metarhizium brunneum*), and lactic acid bacteria (LAB) on the labile fraction of the SOM pool (C_{LSOM}) and identify potential early indicators. Our findings demonstrated that the type of crop and applied microorganisms (treatments) significantly affected the C_{LSOM} in peas, and the crop growth stages affected the TOC in both pea and lupin. Growth stages also showed an impact on the C_{LSOM} in lupin. Moreover, in both crops, the change in C_{LSOM} correlated with changes in the SOM oxidation rate constant (k), carbon lability index (LI), carbon management index (CMI), and carbon enrichment ratio (ER). Conversely, changes in the TOC did not exhibit significant correlations, except for LI and CMI, which showed a positive correlation with the TOC in peas ($p < 0.05$). Furthermore, the separate application of MEHA and LAB on seeds or leaves resulted in increased SOM carbon pools compared with the combined application. The application of these beneficial microorganisms in pea and lupin crops showed potential in maintaining or increasing C_{LSOM} , which can be assessed early through indicators such as k , LI, CMI, and ER. Contributing to the development of sustainable soil management strategies, future research should further investigate different crops and microorganisms—and the mechanisms underlying their observed relationships—and explore additional early indicators to refine and optimize sustainable agricultural practices.

Keywords: carbon lability index; carbon management index; entomopathogenic fungi; lactic acid bacteria; oxidation rate constant; soil organic matter pool dynamics.

4.2.3 Main contribution of the article

The article emphasizes the role of crop selection and microorganism-based management practices in soil organic matter dynamics and soil health in conventional farming systems. The study not only provides field evidence on the effectiveness of integrating leguminous crops with beneficial microorganisms in enhancing soil carbon levels but also establishes a methodological approach based on dynamic indicators, including the lability index (LI), carbon management index (CMI), and the organic matter oxidation rate constant. This approach enables an assessment of changes in the labile fraction of soil organic matter, an element highly sensitive to agricultural practices, thereby improving the monitoring and evaluation of changes in the organic matter pool. Furthermore, the research affords critical practical insights for agricultural systems in South Bohemia (Czech Republic), where conventional farming practices still prevail. By demonstrating the effectiveness of this integrated model for enhancing soil carbon pools, the article provides a scientific foundation for integrated soil management strategies. These findings contribute to mitigating soil degradation and advancing the development of sustainable intensive agriculture.








4.2.4 Author's contribution to the article

In this publication, the PhD candidate contributed to laboratory analyses, manuscript preparation, and manuscript revision. The candidate's contribution to the publication accounts for approximately 15% of the total work.

4.2.5 Attached article PDF

Article

Enhancing Soil Organic Matter Transformation through Sustainable Farming Practices: Evaluating Labile Soil Organic Matter Fraction Dynamics and Identifying Potential Early Indicators

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Abstract: The growing global population and increasing demand for agricultural products have exerted significant pressure on agricultural systems. As a result, soil organic matter depletion and degradation have become prevalent issues, including in regions such as South Bohemia, Czech Republic, where conventional farming practices are predominant. Soil organic matter (SOM) plays a critical role in soil health, crop productivity, and the sustainability of agricultural systems, with changes occurring in both the total and labile fractions of the organic matter pools. However, changes in the total soil organic matter carbon pool (TOC) resulting from agricultural practices occur gradually and may become evident only after several years, posing challenges for timely management adjustments. Therefore, the identification of early indicators of SOM dynamics is crucial for implementing prompt corrective actions. The aim of this study was to evaluate the effects of sustainable management practices, such as cultivated crops (*Pisum sativum* and *Lupinus albus*), selected entomopathogenic and myco parasitic fungi (MEHA) (*Trichoderma virens* and *Metarhizium brunneum*), and lactic acid bacteria (LAB) on the labile fraction of the SOM pool (C_{LSOM}) and identify potential early indicators. Our findings demonstrated that the type of crop and applied microorganisms (treatments) significantly affected the C_{LSOM} in peas, and the crop growth stages affected the TOC in both pea and lupin. Growth stages also showed an impact on the C_{LSOM} in lupin. Moreover, in both crops, the change in C_{LSOM} correlated with changes in the SOM oxidation rate constant (k), carbon lability index (LI), carbon management index (CMI), and carbon enrichment ratio (ER). Conversely, changes in the TOC did not exhibit significant correlations, except for LI and CMI, which showed a positive correlation with the TOC in peas ($p < 0.05$). Furthermore, the separate application of MEHA and LAB on seeds or leaves resulted in increased SOM carbon pools compared with the combined application. The application of these beneficial microorganisms in pea and lupin crops showed potential in maintaining or increasing C_{LSOM} , which can be assessed early through indicators such as k , LI, CMI, and ER. Contributing to the development of sustainable soil management strategies, future research should further investigate different crops and microorganisms—and the mechanisms underlying their observed relationships—and explore additional early indicators to refine and optimize sustainable agricultural practices.

Keywords: carbon lability index; carbon management index; entomopathogenic fungi; lactic acid bacteria; oxidation rate constant; soil organic matter pool dynamics

4.3 Effects of biological treatment on production parameters and seed quality of pea in organic farming

4.3.1 Full citation of the article

Nguyen, T. G., Konvalina, P., Capouchová, I., Dvořák, P., Perná, K., Kopecký, M., Hoang, T. N., Lencová, J., Bohatá, A., Kavková, M., Murindangabo, Y. T., Kabelka, D., Tran, D. K., 2025. Intensification of pea (*Pisum sativum* L.) production in organic farming: effects of biological treatments on plant growth, seed yield, and protein content. *Agronomy*, 15(8), 1792.

<https://doi.org/10.3390/agronomy15081792>

Journal metrics: Impact Factor 3.4 (2024); 5- year Impact Factor 3.8; Q1.

4.3.2 Abstract and keywords

Abstract: The adoption of biological control strategies plays a crucial role in ensuring the sustainability of organic agricultural practices. A field experiment was conducted in 2023 and 2024 to evaluate the impact of biological treatments using lactic acid bacteria (LAB) *Lactiplantibacillus plantarum* and mycoparasitic fungus (MPF) *Trichoderma virens* applied through seed treatment and foliar application separately and in combination on agronomic characteristics and pea yield in organic cultivation. Seed treatment with LAB and MPF resulted in a notable improvement in shoot length and root dry weight, while an increase in root nodule number was observed exclusively with LAB. The combined application of MPF as a seed treatment and LAB as a foliar application at the flowering stage significantly enhanced pod weight per plant, seed number per pod and per plant, and seed weight compared to treatments with LAB applied as either a foliar or seed treatment separately, as well as the untreated control. However, the yield responses to individual and combined treatments under field conditions demonstrated variability and inconsistency. Protein content ranged from 21.24% to 21.61%, and no significant differences observed between treatments. This is the first field report directly comparing the effectiveness of treatments on organic pea production. The findings offer promising avenues for assessing the long-term impacts of these treatments on the sustainable intensification of pea cultivation.

Keywords: agrotechnology; biological treatment; lactic acid bacteria; mycoparasitic fungi; pea; organic farming; yield.

4.3.3 Main contribution of the article

This study provides experimental field evidence of the individual and combined efficacy of the lactic acid bacteria *Lactiplantibacillus plantarum* and the mycoparasitic fungus *Trichoderma virens* on pea production in organic farming systems in the Czech Republic. The publication demonstrates that biological treatments can enhance pea productivity and seed quality in organic farming systems. The results suggest that improved plant development and nodulation may contribute to higher nitrogen utilization and protein accumulation. The study provides practical field evidence supporting the use of microbial inputs as tools for sustainable intensification of legume production.

4.3.4 Author's contribution to the article

In this publication, the PhD candidate contributed to establishing field trials, collecting data, performing laboratory analyses, conducting statistical analyses, and preparing the manuscript. The candidate's contribution to the publication accounts for approximately 65% of the total work.

4.3.5 Attached article PDF



agronomy



Article

Intensification of Pea (*Pisum sativum* L.) Production in Organic Farming: Effects of Biological Treatments on Plant Growth, Seed Yield, and Protein Content

Thi Giang Nguyen ^{1,2}, Petr Konvalina ^{1,*}, Ivana Capouchová ³, Petr Dvořák ³, Kristýna Perná ¹, Marek Kopecný ¹, Trong Nghia Hoang ¹, Jana Lencová ¹, Andrea Bohatá ¹, Miloslava Kavková ⁴, Yves Theoneste Murindangabo ⁵, David Kabelka ¹ and Dang Khoa Tran ²

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Abstract

The adoption of biological control strategies plays a crucial role in ensuring the sustainability of organic agricultural practices. A field experiment was conducted in 2023 and 2024 to evaluate the impact of biological treatments using lactic acid bacteria (LAB) *Lactiplantibacillus plantarum* and mycoparasitic fungus (MPF) *Trichoderma virens* applied through seed treatment and foliar application separately and in combination on agronomic characteristics and pea yield in organic cultivation. Seed treatment with LAB and MPF resulted in a notable improvement in shoot length and root dry weight, while an increase in root nodule number was observed exclusively with LAB. The combined application of MPF as a seed treatment and LAB as a foliar application at the flowering stage significantly enhanced pod weight per plant, seed number per pod and per plant, and seed weight compared to treatments with LAB applied as either a foliar or seed treatment separately, as well as the untreated control. However, the yield responses to individual and combined treatments under field conditions demonstrated variability and inconsistency. Protein content ranged from 21.24% to 21.61%, and no significant differences observed between treatments. This is the first field report directly comparing the effectiveness of treatments on organic pea production. The findings offer promising avenues for assessing the long-term impacts of these treatments on the sustainable intensification of pea cultivation.

Keywords: agrotechnology; biological treatment; lactic acid bacteria; mycoparasitic fungi; pea; organic farming; yield



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Intensification of Pea (*Pisum sativum* L.) Production in Organic Farming: Effects of Biological Treatments on Plant Growth, Seed Yield, and Protein Content. *Agronomy* **2025**, *15*, 1792. <https://doi.org/10.3390/agronomy15081792>

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1. Introduction

Legumes are of particular significance in organic farming systems, serving as one of the key tools that contribute to ecosystem resilience, support biodiversity, and ensure

4.4 Effects of biological treatment on production parameters and seed quality of soybean in organic farming

4.4.1 Full citation of the article

Konvalina, P., Nguyen, T. G., Hoang, T. N., Bohatá, A., Perná, K., Lencová, J., Capouchová, I., Dvořák, P., Procházka, P., Kavková, M., Kopecký, M., 2025. Effects of biological treatments on production and quality parameters of soybean (*Glycine max* L. Merrill). *Bangladesh Journal of Botany*, 54 (3), 687–693. <https://doi.org/10.3329/bjb.v54i30.85108>
Journal metrics: Impact Factor 0.3 (2024); 5- year Impact Factor 0.4; Q4.

4.4.2 Abstract and keywords

Abstract: Innovative approaches such as seed treatment with lactic acid bacteria (LAB), mycoparasitic fungi (MPF), and entomopathogenic fungi (EPF) can improve yield and quality. A plot experiment with the variety Abaca was conducted on organically certified plots at two climatically distinct sites in the Czech Republic. In the early growth stages, MPF and LAB treatments showed slight improvements in root length, weight, and plant dry matter. Other parameters, including plant height before harvest, thousand-grain weight, and yield, showed a positive but statistically inconclusive effect. Regarding quality, a beneficial impact of MPF and LAB on protein content in seeds was recorded. Starch and oil contents were unaffected. The differences were relatively small, suggesting that biological seed treatments support soybean yield and quality, particularly when combined with other agrotechnical measures.

Keywords: organic farming, soybean, biological treatment, production.

4.4.3 Main contribution of the article

This publication contributes the first field evaluation of integrated biological treatments in organic soybean cultivation in the Czech Republic. The findings demonstrate that combining microbial agents in seed treatments improves yield and grain quality under different field conditions. In addition, the study suggests that the performance of microbial preparations is maximized when combined with other agrotechnical measures. Overall, these findings contribute to the potential of biological inputs as part of a broader strategy to improve the sustainability of organic soybean cultivation.

4.4.4 Author's contribution to the article

In this publication, the PhD candidate contributed to establishing field trials, collecting data, performing laboratory analyses, conducting statistical analyses, and preparing the manuscript. The candidate's contribution to the publication accounts for approximately 40% of the total work.

EFFECTS OF BIOLOGICAL TREATMENTS ON PRODUCTION AND QUALITY PARAMETERS OF SOYBEAN (*GLYCINE MAX* L. MERRILL)

PETR KONVALINA*, THI GIANG NGUYEN¹, TRONG NGHIA HOANG, ANDREA BOHATÁ, KRISTÝNA PERNÁ, JANA LENCOVÁ, IVANA CAPOUCHOVÁ², PETR DVOŘÁK², PAVEL PROCHÁZKA², MILOSLAVA KAVKOVÁ³ AND MAREK KOPECKÝ

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Keywords: Organic farming, Soybean, Biological treatment, Production

Abstract

Innovative approaches such as seed treatment with lactic acid bacteria (LAB), mycoparasitic fungi (MPF), and entomopathogenic fungi (EPF) can improve yield and quality. A plot experiment with the variety Abaca was conducted on organically certified plots at two climatically distinct sites in the Czech Republic. In the early growth stages, MPF and LAB treatments showed slight improvements in root length, weight, and plant dry matter. Other parameters, including plant height before harvest, thousand-grain weight, and yield, showed a positive but statistically inconclusive effect. Regarding quality, a beneficial impact of MPF and LAB on protein content in seeds was recorded. Starch and oil contents were unaffected. The differences were relatively small, suggesting that biological seed treatments support soybean yield and quality, particularly when combined with other agrotechnical measures.

Introduction

In the organic farming system, legumes are one of the key tools that can mitigate ecosystem deficiencies, reduce nutrient imbalances, contribute to ecosystem resilience, and support biodiversity (Didora *et al.* 2022). By enhancing soil organic matter fractions to promote biological nitrogen fixation, legumes are essential components of successful organic agricultural practices. Soybean (*Glycine max* L. Merrill) has assumed a pivotal role as a globally significant crop, supplying 25% of the world's edible oil and approximately two-thirds of livestock protein concentrate and substantially contributing to food security. Organic soybean farming is driven by the growing consumer demand for organic products and the need for sustainable agricultural practices (Mishra *et al.* 2024).

In recent years, research efforts have increased to devise sustainable methods for improving soybean production (Ayilara *et al.* 2023). Several biocontrol agents have been evaluated for their usefulness to control diseases of soybeans, with varying levels of success (Hartman *et al.* 2016). The direct application of biocontrol agents is more likely to control below-ground diseases and pests (Caldwell *et al.* 2005). Mycoparasitism, the direct attack of one fungus on another using it as a nutrient source, plays a significant role in both ecological and agricultural contexts, particularly in the biological control of plant diseases (Steyaert *et al.* 2003). Entomopathogenic fungi play a vital role in insect population dynamics, making them the earliest insect pest control agents (Maina *et al.* 2018). To date, over 750 fungi species are known to infect insects and mites, which represent about all the major classes of fungi (Moorhouse *et al.* 1992, Hajek and St. Leger 1994).

*Author for correspondence: <konvalina@fzt.jcu.cz>. ¹University of Agriculture and Forestry, Hue University, Hue 49000, Vietnam. ²Faculty of Agrobiological, Food and Natural Resources, Czech University of Life Sciences Prague, Prague-Suchbát 16500, Czech Republic. ³Dairy Research Institute Ltd., Prague 16000, Czech Republic.

4.5 Effects of biological treatment on insect pests and disease occurrence

4.5.1 Full citation of the manuscript

Nguyen, T. G., Konvalina, P., Perná, K., Hoang, T. N., Lencová, J., Bohatá, A., Kabelka, D., Kavková, M., Nong, H. Q., Murindangabo, Y. T. The combination of lactic acid bacteria and mycoparasitic fungi for enhanced management of insect pests and root rot diseases in organic pea production (Submitted Crop Protection-Under review).

4.5.2 Abstract and keywords

Abstract: Insect pests and diseases represent significant biotic constraints to closing the yield gap in organic pea production. While the use of biological control agents has been extensively studied and widely applied for pest and disease management, empirical evidence from field studies remains limited, particularly in organic farming, where the absence of synthetic chemical interventions necessitates robust biological alternatives. To address this gap, field trials were conducted from 2023 to 2025 to evaluate the impact of the lactic acid bacteria (LAB) *Lactiplantibacillus plantarum* and the mycoparasitic fungus (MPF) *Trichoderma virens* on the incidence of root rot diseases and damage caused by key insect pests in pea.

Seed treatment with *L. plantarum* and *T. virens* indicated reduced damage from the pea leaf weevil (10.1–15.4%) and pea root rot (12.9–29.0%) compared to the control during the early growth stage. However, foliar application of *L. plantarum* and *T. virens* at the flowering stage showed no significant efficacy against the pea aphid. The combinations of *L. plantarum* seed treatment and *T. virens* foliar application, and the reciprocal treatment (*T. virens* seed treatment and *L. plantarum* foliar application), did not significantly enhance efficacy compared to applying *L. plantarum* or *T. virens* independently. The *L. plantarum* and *T. virens* seed treatment, followed by additional foliar application at the flowering stage, was found to be the most effective in limiting pest and root-rot disease damage while simultaneously maintaining yield and seed quality, compared to the other treatments.

Keywords: biological treatment; insect pest; *Lactiplantibacillus plantarum*; pea; root rot; *Trichoderma virens*.

4.5.3 Main contribution of the manuscript

This manuscript addresses a research gap related to the effectiveness of microbial agents under complex field conditions. The study provides field evidence on the role of beneficial microorganisms in managing insect pests and root-rot diseases in organic pea production, where conventional chemical control options are prohibited. The findings indicate that combining seed treatment with an additional foliar application at the flowering stage is the most effective strategy to reduce pest and disease pressure while maintaining yield and seed quality. The manuscript demonstrates the potential of LAB and MPF as sustainable alternatives, contributing to narrow the yield gap and overcome pest management challenges in organic production.

4.5.4 Author's contribution to the manuscript

In this publication, the PhD candidate contributed to establishing field trials, conducting data collection, performing laboratory analyses, conducting statistical evaluation, and preparing the manuscript. The candidate's contribution to the publication accounts for approximately 65% of the total work.

4.5.5 Attached manuscript (under review)

Attached is the full version of the manuscript submitted to the journal Crop Protection.

Crop Protection

The combination of lactic acid bacteria and mycoparasitic fungi for enhanced management of insect pests and root rot diseases in organic pea production --Manuscript Draft--

Manuscript Number:	
Article Type:	Full Length Article
Section/Category:	Invertebrate crop pests including insects, mites and molluscs
Keywords:	biological treatment; insect pest; Lactiplantibacillus plantarum; pea; root rot; Trichoderma virens
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Abstract:	<p>Insect pests and diseases represent significant biotic constraints to closing the yield gap in organic pea production. While the use of biological control agents has been extensively studied and widely applied for pest and disease management, empirical evidence from field studies remains limited, particularly in organic farming, where the absence of synthetic chemical interventions necessitates robust biological alternatives. To address this gap, field trials were conducted from 2023 to 2025 to evaluate the impact of the lactic acid bacteria (LAB) <i>Lactiplantibacillus plantarum</i> and the mycoparasitic fungus (MPF) <i>Trichoderma virens</i> on the incidence of root rot diseases and damage caused by key insect pests in pea.</p> <p>Seed treatment with <i>L. plantarum</i> and <i>T. virens</i> indicated reduced damage from the pea leaf weevil (10.1–15.4%) and pea root rot (12.9–29.0%) compared to the control during the early growth stage. However, foliar application of <i>L. plantarum</i> and <i>T. virens</i> at the flowering stage showed no significant efficacy against the pea aphid. The combinations of <i>L. plantarum</i> seed treatment and <i>T. virens</i> foliar application, and the reciprocal treatment (<i>T. virens</i> seed treatment and <i>L. plantarum</i> foliar application), did not significantly enhance efficacy compared to applying <i>L. plantarum</i> or <i>T. virens</i> independently. The <i>L. plantarum</i> and <i>T. virens</i> seed treatment, followed by additional foliar application at the flowering stage, was found to be the most effective in limiting pest and root-rot disease damage while simultaneously maintaining yield and seed quality, compared to the other treatments.</p>

4.6. Extended results and discussion of the effects of biological treatment on production parameters and seed quality of pea and soybean, incorporating the 2025 experimental data

4.6.1 Information of the manuscript (In preparation)

Title: Enhancing productivity and quality of organic legumes through biological treatments: A three-year comparative study of pea (*Pisum sativum* L.) and soybean (*Glycine max* L. Merrill).

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4.6.2 Abstract and keywords

Abstract: This study demonstrates that the strategic application of biological preparations represents an effective and sustainable approach to enhancing the productivity and quality of pea and soybean. LAB and MPF seed applications offer clear benefits for early pea growth, their long-term effects on soybean, which is a relatively new crop in this study region, appear more sensitive to environmental variability. Furthermore, the findings highlight that the efficacy of these biopreparations is maximized when integrated with agrotechnological measures, such as optimized weed control on early growth. Although seasonal performance varied, the comparable results between combination treatments and independent applications highlight a high degree of integration flexibility. Based on these comprehensive outcomes, MPFse x fo (mycoparasitic fungus *Trichoderma virens* applied as a combined seed and foliar treatment) is recommended as the most robust and promising strategy for optimizing yield and seed quality under field conditions. Overall, these findings provide a reliable agronomic framework for organic legume production, demonstrating that integrating biological treatments with strategic management can narrow the yield gap and foster more resilient, high-performing organic cropping systems.

Keywords: biological treatment; lactic acid bacteria; mycoparasitic fungi; pea; organic farming; soybean; yield.

4.6.3 Main contribution

The study provides an integrated assessment of the effectiveness of biological treatment in improving the performance of pea and soybean under an organic system. The findings also demonstrate the importance of combining biological treatments with appropriate agronomic practices to achieve efficient and resilient legume production. These insights provide practical guidance for designing sustainable management strategies and improving the performance of legume crops in organic farming systems.

4.6.4 Author's contribution

In this manuscript, the PhD candidate contributed to establishing field trials, conducting data collection, performing laboratory analyses, conducting statistical evaluation, and preparing the manuscript. The candidate's contribution to the manuscript accounts for approximately 65% of the total work.

4.6.5 Preliminary results and data analysis

Building on previous publications that established the initial impact of biological treatments on soybean (2022–2024) and pea (2023–2024), this study presents an expanded analysis by incorporating the 2025 experimental data. By synchronizing the data from both crops into a uniform 2023–2025 timeframe, this study not only reinforces foundational observations but also provides a more comprehensive longitudinal perspective on how biological control influences. This approach offers deeper insights into the efficacy of biological treatment application on production parameters and seed quality of pea and soybean over a multi-year duration.

Chapter 5: General Discussion and Implications

This chapter synthesizes the discussion of the studies presented in the previous chapters and highlights the scientific contributions and practical relevance of the dissertation. The findings from the individual studies are considered together to provide an integrated perspective based on multifaceted analysis. To structure this discussion, the chapter is organized into three main sections. Section 5.1 compares the study's findings with the current body of knowledge and situates them within existing research and theoretical perspectives. It highlights areas where the results confirm, refine, or extend current understanding of organic agriculture. Section 5.2 discusses the practical implications of the research findings for agricultural production. Section 5.3 addresses the main limitations of the present study and identifies remaining research gaps. It also outlines possible directions for future research on the role of beneficial microorganisms in sustainable agriculture under changing climatic conditions.

5.1 Comparison with current knowledge in the field

In the context of sustainable agriculture, beneficial microorganisms are increasingly recognized not only for their traditional roles but also as versatile agents with major impacts on the soil–plant system. The findings of this dissertation agree with existing theories and provide field evidence of their effectiveness under field organic farming conditions. These results offer new insights and practical contributions to the current understanding of the application of sustainable beneficial microorganisms at the production field scale.

The current study attempted to contribute to the scientific literature through comprehensive data analyses and to emphasize that symbiotic interactions among plants, soil, and microorganisms are central to crop health and soil fertility (Li et al., 2020; Chauhan et al., 2023). The findings of this dissertation support the conclusions of previous studies by Sadiq et al. (2019) and Raman et al. (2022) regarding the multifaceted capabilities of lactic acid bacteria (LAB). In addition to their conventional roles as biofertilizers and biocontrol agents, LAB function as potent biostimulants that enhance soil structure through the decomposition of organic matter. LAB contributes to agricultural sustainability through multiple mechanisms, including modulating soil organic matter and biochemical cycles, synthesizing beneficial metabolites, and promoting plant vigor by stimulating both shoot and root development (Kavková et al., 2023; Raman et al., 2022). This validation of LAB's ability to catalyze nutrient cycling and improve plant health under organic conditions provides crucial empirical support for the innovative antimicrobial strategies proposed by Van Esse et al. (2020). Unlike previous studies, this research provides a systematic perspective on the versatile roles of LAB, including improvements in soil structure and stimulation of growth. These findings provide stronger support for the hypotheses proposed by Lamont et al. (2017) and Raman et al. (2022) regarding the potential of biological approaches to replace harmful chemical inputs. Although the potential of LAB has been widely acknowledged, substantial gaps remain in understanding how these microorganisms function collectively as a cohesive system. The findings of this study (Chapter 4.1) address and help narrow this knowledge gap by investigating the underexplored significance of LAB in mediating interactions within contemporary soil–plant

systems. In particular, the results supplement existing discourse and provide a comprehensive understanding of LAB as a foundation of sustainable and safe agricultural practices.

Soil properties also play an important role in regulating microbial activity and the decomposition of organic matter. A study conducted by Yuan and Yao (2022) indicates that both microbial abundance and soil physicochemical properties significantly influence carbon pools and ecosystem functionality (Yuan and Yao, 2022). In addition, legumes, characterized by low carbon-to-nitrogen ratios, not only enhance soil organic matter pools (Hama et al., 2022; Sánchez-Navarro et al., 2019) but also stimulate biological activity and refine soil physical properties (da Silva et al., 2022; Halvorson et al., 1991; Woźniak and Rachoń, 2022). It contributes to increasing SOM and maintaining yields, and it addresses the soil organic carbon dilemma (van der Pol et al., 2022). Recent studies also demonstrated that management practices and changes in land cover fundamentally alter both the size and turnover rates of soil organic matter pools through the activity of soil microbial communities (Baldy et al., 1995; Fabian et al., 2017). These processes ultimately regulate nutrient cycling, soil quality, and agricultural productivity (Brock et al., 2017; Farid et al., 2014; Hoang et al., 2023; Machado et al., 2006; Widyati et al., 2022). While total soil organic matter (SOM) fluctuates with crop types and management practices, it is less sensitive than its individual components, particularly the labile fractions (Haynes, 2000; Lefroy et al., 1993; Sainepo et al., 2018). Previous research has indicated that the inherent difficulty of monitoring total organic carbon fluctuations over short time intervals has led to the suggestion that SOM subfractions are more sensitive indicators of change (Awale et al., 2017; Blair et al., 1995). Building on these foundational theories, identifying the most responsive soil organic carbon pools and their early indicators in this study would support better management decisions and help rebuild soil health, fertility, and long-term crop yields. The study shows that selecting appropriate crops and applying beneficial microorganisms can significantly affect labile soil organic matter (Chapter 4.2). Labile SOM appears to be an earlier and more responsive indicator of soil health than traditional measures in organic farming systems. These results support previous findings that beneficial microorganisms play a key role in legume-based systems for maintaining or restoring soil health. Overall, the study offers a practical approach to address the decline in soil organic matter and also provides a framework for evaluating sustainable farming practices on a broader scale.

In addition to improving soil properties, beneficial microorganisms are increasingly applied as biological control agents in organic agriculture. Previous studies have shown that biocontrol agents, notably *Trichoderma* and *Lactobacillus*, contribute to crop protection through various mechanisms and have significant growth-promoting effects in a variety of crops (Ayaz et al., 2023; Gwiazdowski et al., 2023; Kowalska et al., 2024; Lamont et al., 2017; Strejčková et al., 2018). Their effectiveness and sustainability have attracted attention because biological agents are highly specific to their targets, reduce environmental impacts, and can interact directly with pathogens in infected plant tissues (Collinge et al., 2021; Tronsmo et al., 2020). Biological control acts directly or indirectly on pests, yet maintaining consistent efficacy remains challenging. According to Collinge et al. (2021), pest and disease severity depend on environmental factors, so the successful use of BCAs requires stable formulations, appropriate application methods, and carefully designed field trials (Collinge et al., 2021). According to

El-Sharkawy et al. (2021), previous biological control strategies have primarily relied on the use of a single agent to resist plant pathogens (El-Sharkawy et al., 2021). Moreover, most studies on these biocontrol strategies have been conducted in controlled environments, leaving their effectiveness in field conditions largely unverified (Willsey et al., 2021; Xue et al., 2017).

The current study (Chapters 4.3–4.6) addresses a gap in previous research regarding the limited field-based evidence on the efficacy of beneficial microorganisms in organic legume cultivation. While most studies were conducted under controlled laboratory or greenhouse conditions, the present research demonstrates that seed treatment and foliar application of beneficial microorganisms can effectively enhance legume growth and yield. Notably, there have been no assessments of the impact of these microorganisms on pest incidence and the ability to limit pests and diseases, particularly under organic farming conditions where conventional control measures are limited. These findings agree with previous observations on the functional roles of microorganisms such as *Lactobacillus* and *Trichoderma* in promoting plant growth (Kale et al., 2022; Mastouri et al., 2010; Singh et al., 2017; Van Wees et al., 2008) and controlling pathogens (Ayaz et al., 2023; Raman et al., 2022; Yusnawan et al., 2024), while extending the evidence to real-world agricultural conditions. These results support insights into the practical applicability and consistency of these biological agents under soil, climate, and management conditions. This contribution helps decrease the gap between controlled experimental results and practical implementation in sustainable legume production systems.

5.2 Implications for agricultural practice

The results of this dissertation indicate that the application of beneficial microorganisms indicates innovative approaches to enhancing the sustainability of agricultural production, particularly in legume organic cropping systems. The integration of lactic acid bacteria and beneficial fungi, such as mycoparasitic and entomopathogenic fungi, into agronomic management practices demonstrates potential to improve soil quality, support crop growth and yield, and manage certain biotic stressors under field conditions. These findings suggest that microbial biopreparations could become a valuable complementary component of sustainable crop management strategies.

A key practical contribution of this study is the evidence that biological treatment positively influences the active fractions of soil organic matter, thereby maintaining biological functions and nutrient cycling. Utilizing indices that reflect soil carbon management and lability provides early diagnostic information regarding the impacts of management practices before significant alterations in total organic carbon (TOC) can be detected. In practical agricultural management, particularly in conventional systems where soil degradation may occur, this approach enables soil managers and farmers to assess the efficacy of sustainable practices in a shorter timeframe, allowing timely management adjustments to be implemented to preserve or enhance long-term soil fertility.

From a crop management perspective, the application of beneficial microbes through seed treatment or foliar application functions as a supportive measure for early plant vigor. Improved performance during the initial stages of plant development may facilitate more efficient root establishment, enhance nutrient uptake, and increase competitive ability against

weeds and resilience to environmental stressors during the initial phases of the cropping cycle. This is particularly significant for organic or low-input systems where chemical interventions are limited. In this context, microbial biopreparations act as biological tools supporting balanced plant development.

In addition to influencing plant growth, microbial treatments also contribute to improvements yield components and help maintain seed quality in organic cropping systems. However, field performance may be strongly influenced by environmental conditions, soil characteristics, and the accompanying agronomic practices applied in each production system. Therefore, microbial biopreparations should be viewed as part of an integrated crop management approach rather than as an independent practice. Combining biological measures with appropriate agronomic practices, such as effective weed control, optimized crop rotation, and the selection of adaptable varieties, is essential to optimize the performance of these inoculants in crop production.

The dissertation also provides practical insights into the role of microbial agents in pest and disease management in organic farming systems. The use of biological treatments may reduce pressure from certain pests and soil-borne diseases during the early stages of pea development, helping maintain crop productivity under field conditions. Although the effectiveness of biological control measures may vary across pest species, these findings suggest that integrating microbial agents into integrated pest management strategies contributes to diversifying plant protection strategies in organic systems. These approaches support current trends toward developing sustainable agricultural systems and minimizing environmental footprints.

Furthermore, the application of beneficial microorganisms in agriculture may provide several environmental benefits for agroecosystems. Microbial biopreparations can stimulate soil biological activity, enhance nutrient cycling, maintain soil fertility, and mitigate potential risks of soil and water contamination. These advantages are particularly important in the context of modern agriculture, which faces increasing challenges related to soil degradation, climate change, and the growing demand for sustainable food production.

However, the widespread adoption of microbial biopreparations in agricultural practice requires careful consideration of feasibility and transferability. Their performance fluctuates across different soil types, climatic conditions, cropping systems, and management practices. Furthermore, factors such as product cost, market accessibility, and farmer transition readiness influence practical implementation. These observations emphasize that while the thesis findings are highly applicable, deployment must account for local conditions and integrate with existing agronomic traditions. Overall, the results of this dissertation indicate that integrating microbial biopreparations based on lactic acid bacteria and beneficial fungi into appropriate agronomic management strategies can contribute to improving the sustainability of legume-based cropping systems. These findings provide an important scientific basis for developing sustainable legume production strategies that improve yield performance, quality, and support soil health.

5.3 Future research directions

The findings conducted in this dissertation have provided substantial evidence of the potential of beneficial microorganisms to improve soil health and the productivity of organic legume crops. However, numerous scientific questions remain unresolved, suggesting several avenues for future research to optimize and expand the practical application of these biological solutions in sustainable agricultural production.

Validating and stabilizing beneficial microorganism performance

Results from Chapters 4.3–4.6 indicate that the effectiveness of biological preparations in promoting early growth, yield, seed quality, and pest control depends on crop type, soil properties, climate, and field management practices. Therefore, future research should conduct trials across multiple agro-ecological regions to determine the stability of these microorganisms. In addition, optimizing application methods, such as the timing of foliar treatments at specific growth stages, is essential to evaluating stability and effectiveness. Furthermore, as suggested in Chapter 4.2, it should be expanded to assess soil organic matter dynamics under different management practices, including tillage systems, crop selection, rotations, intercropping, and integration of effective microorganisms. This approach will provide a comprehensive understanding of the efficacy and practical applicability of biological treatments.

Exploring physiological, ecological, and molecular mechanisms

Building on the agronomic findings of Chapters 4.3–4.6, future studies should explore the biological and physiological mechanisms underlying the observed field performance. In particular, research should examine the interactions between introduced microbial strains and native microbial communities in the rhizosphere, as well as the roles of microbially produced bioactive compounds in promoting plant growth, nodule formation, nutrient uptake, and pest suppression. Advanced analytical methods, including soil microbiome profiling and biological indicators, should be applied to provide a more comprehensive understanding of the impacts of beneficial microorganisms on soil-plant systems.

Assessing Long-term effects and enhancing practical applicability

Chapter 4.2 demonstrates that alterations in total soil organic carbon develop gradually over time. Therefore, long-term field experiments are essential to evaluate the sustained effects of beneficial microorganisms on carbon accumulation and the resilience of soil ecosystems. Future studies should also expand to more complex crop rotation systems, integrating legumes with cereals, to assess the residual effects of microbial treatments across consecutive cropping cycles. Furthermore, integrating beneficial microorganisms into integrated pest management (IPM) programs requires further optimization to effectively control late-season pests and maintain stable yield and seed quality (Chapter 4.5).

In addition, the strategies developed in this dissertation should be evaluated across non-legume crops and different cropping systems. Combining microbial treatments with complementary agronomic practices for optimal field performance. Research on formulation

technologies is also critical, particularly to enhance microbial stability, extend shelf life, and reduce production costs. Coupled with environment-economic and cost–benefit analyses, these efforts will support and promote the widespread adoption of biological treatments in practical agricultural systems (Chapters 4.2–4.6).

In summary, future research can be classified into short-term studies that directly validate the effectiveness of microbial combinations and optimize application methods, and long-term studies that focus on elucidating biological mechanisms, diversifying crop types and cropping systems, assessing environmental impacts, and enhancing ecosystem resilience. These research directions will not only strengthen the scientific foundation for the application of beneficial microorganisms in soil and crop management but also contribute to the development of sustainable, efficient, and resilient agricultural systems.

Chapter 6: Conclusion

This dissertation integrates research from meta-analytic studies to field experiments to provide an overarching evaluation of the roles and effects of biological treatment on soils, plants and soil-plant systems. The main conclusions from these studies are:

1. Lactic acid bacteria are versatile microorganisms with strong potential to promote plant growth, provide biocontrol, and enhance soil health in soil-plant systems and have been shown to be safe, effective, and sustainable for agricultural and environmental applications.
2. The integrated cultivation practices utilizing beneficial microorganisms significantly influence soil organic matter transformation processes. These biological treatments demonstrate the capacity to maintain or increase the labile fraction of soil organic matter, which can be assessed early using indicators such as soil organic matter oxidation rate constant, carbon lability index, carbon management index, and carbon enrichment ratio, collectively emphasizing the role of integrated microbial applications in sustainable soil management.
3. The application of the biological treatments, lactic acid bacteria and mycoparasitic fungi, enhances pea productivity and seed quality in organic farming systems. under organic cultivation conditions. These findings provide practical field evidence supporting the use of microbial inputs as tools for sustainable intensification of pea production.
4. Seed treatments with lactic acid bacteria and mycoparasitic fungi can modestly enhance early growth, yield, and seed protein content in organically cultivated soybean, highlighting their potential to improve crop performance when integrated with other agronomic practices.
5. The field studies evaluating the effects of lactic acid bacteria and mycoparasitic fungi on insect pest and disease occurrence in pea crops demonstrate that seed treatment with lactic acid bacteria and mycoparasitic fungi, followed by an additional foliar application at the flowering stage, effectively limits pest and root-rot disease damage while simultaneously maintaining yield and seed quality.
6. Field trials conducted over three years demonstrate that seed treatments with lactic acid bacteria and mycoparasitic fungi enhance early growth in both pea and soybean crops. Although seasonal performance varied, the comparable results between combination treatments and independent applications highlight a high degree of integration flexibility. Specifically, the use of mycoparasitic fungi yielded the most optimal results in field trials and is recommended as the most effective strategy for optimizing yield and seed quality under field conditions.

Future research should expand this integration by testing various tillage types, crops, and rotational sequences. Additional long-term studies would help better understand the mechanisms underlying plant growth promotion and the effectiveness of combining microorganisms with agrotechnological measures in different field conditions.

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Appendices

Appendix 1: List of publications (2023 – 2026)

1. Konvalina, P., **Nguyen, T. G.**, Bernas, J., Kabelka, D., Vo, T. T. H., Murindangabo, Y. T., Tran, D. K., Tran, T. X. P., Tran, D. H., Nguyen, T. H. Y., Hoang, T. N., 2026. Assessment of wheat grain traits under organic wheat–pea intercropping systems. *Open Agriculture* 11(1), 20250491. <https://doi.org/10.1515/opag-2025-0491> | **IF: 1.6, Q2.**
2. **Nguyen, T. G.**, Tran, T. H. D., Tran, T. X. P., Le, K. P., Hoang, V. S., 2026. Plant growth, diversity, and density of natural enemies in indian mustard (*Brassica juncea*) intercropping with French marigold, coriander, and sweet basil. *Hue Journal of Agricultural Science and Technology* 10(1), 5230–5239. (Vietnamese).
3. **Nguyen, T. G.**, Konvalina, P., Capouchová, I., Dvořák, P., Perná, K., Kopecký, M., Hoang, T. N., Lencová, J., Bohatá, A., Kavková, M., Murindangabo, Y. T., Kabelka, D., Tran, D. K., 2025. Intensification of pea (*Pisum sativum* L.) production in organic farming: Effects of biological treatments on plant growth, seed yield, and protein content. *Agronomy* 15(8), 1792. <https://doi.org/10.3390/agronomy15081792> | **IF: 3.4, Q1.**
4. Konvalina, P., **Nguyen, T. G.**, Hoang, T. N., Bohatá, A., Perná, K., Lencová, J., Capouchová, I., Dvořák, P., Procházka, P., Kavková, M., Kopecký, M., 2025. Effects of biological treatments on production and quality parameters of soybean (*Glycine max* L. Merrill). *Bangladesh Journal of Botany* 54 (3), 687–693. <https://doi.org/10.3329/bjb.v54i30.85108> | **IF: 0,3, Q4.**
5. Lam, M. T. X., Jagou, M. S., Van, G. Q., Martos, F., Nguyen, T. T. N., Van Do, T., Almeida, F. D. A., Tran, D. H., Tran, D. K., **Nguyen, T. G.**, Tran, P. D., Huynh, K., Rivière, J. N., Rouget, M., Dinh, Q. D., Le, T. A., Trinh, T. X., Deguine, J. P., Lefeuvre, P., 2025. Exploration of Hiptage (Malpighiaceae) diversity in Vietnam reveals a new species with wingless fruits. *PhytoKeys*, 256, 221. [10.3897/phytokeys.256.148573](https://doi.org/10.3897/phytokeys.256.148573) | **IF: 1.4, Q3.**
6. Hoang, T. N., Konvalina, P., Kopecký, M., Ghorbani, M., Nguyen, T. G., Bernas, J., Murindangabo, Y. T., Capouchová, I., Sangin, S., Hlásná Čepková, P., 2024. Assessing the Quality and Grain Yield of Winter Wheat in the Organic Farming Management under Wheat-legume Intercropping Practice. *Helyon*. <https://doi.org/10.1016/j.helyon.2024.e31234> | **IF: 3.4, Q1.**
7. Murindangabo, Y. T., Kopecký, M., Perná, K., Konvalina, P., Bohatá, A., Kavková, M., **Nguyen, T. G.**, Hoang, T. N., 2023. Correction to: Relevance of Entomopathogenic Fungi in Soil–Plant Systems. *Plant and Soil* 495 (1–2). <https://doi.org/10.1007/s11104-023-06325-8> | **IF: 3.9, Q1.**
8. Murindangabo, Y. T., Kopecký, M., Konvalina, P., Ghorbani, M., Perná, K., **Nguyen, T. G.**, Bernas, J., Babar Baloch, S., Hoang, T. N., Eze, F., Ali, S., 2023. Quantitative Approaches in Assessing Soil Organic Matter Dynamics for Sustainable Management. *Agronomy* 13(7), 1776. <https://doi.org/10.3390/agronomy13071776> | **IF: 3.3, Q1.**
9. Murindangabo, Y. T., Kopecký, M., Perná, K., **Nguyen, T. G.**, Ghorbani, M., Konvalina, P., Bohatá, A., Kavková, M., Hoang, T. N., Kabelka, D., Klenotová, E., 2023. Enhancing

- Soil Organic Matter Transformation through Sustainable Farming Practices: Evaluating Labile Soil Organic Matter Fraction Dynamics and Identifying Potential Early Indicators. *Agriculture* 13(7), 1314. <https://doi.org/10.3390/agriculture13071314> | **IF: 3.3, Q1.**
10. Murindangabo, Y. T., Kopecký, M., Perná, K., Nguyen, T. G., Konvalina, P., Kavková, M., 2023. Prominent use of lactic acid bacteria in soil-plant systems. *Applied Soil Ecology* 189, 104955. <https://doi.org/10.1016/j.apsoil.2023.104955> | **IF: 4.8, Q1.**
11. Hoang, T. N., Konvalina, P., Kopecký, M., Ghorbani, M., Amirahmadi, E., Bernas, J., Ali, S., **Nguyen, T. G.**, Murindangabo, Y. T., Tran, D. K., Sangin, S., 2023. Assessing Grain Yield and Achieving Enhanced Quality in Organic Farming: Efficiency of Winter Wheat Mixtures System. *Agriculture* 13(5). <https://doi.org/10.3390/agriculture13050937> | **IF: 3.3, Q1.**

Conference (proceedings abstract, paper, poster):

1. **Nguyen, T. G.**, Tran, T. H. D, Tran, T. X. P., 2025. Ecological management of insect pests in indian mustard through intercropping in Thua Thien Hue, Vietnam. 2nd International Conference on Bioprotection for Sustainable Agriculture. “Application of bioprotection in climate-resilient agriculture”. **Poster.** 28–29 August, 2025. University of Agriculture and Forestry, Hue University, Vietnam.
2. **Nguyen, T. G.**, Konvalina, P., Hoang, T. N., Kopecký, M., Perná, K., 2024. Effects of Biological Seed Treatments on Pest Occurrence, Production Parameters, and Yield of Pea (*Pisum sativum* L.) in Organic Farming. **Book of abstracts.** 5th International Multidisciplinary Conference for Young Researchers "Resilience in the face of global challenges". 3–4. October 2024, Prague, Czech Republic.
3. Tran, T. H. D, **Nguyen, T. G.**, Tran, P. D., Pham, T. T. P., Tran, T. X. P., Tran, D. H., 2023. Investigation of rearing conditions and farmer perceptions of stingless bees *Tetragonula laeviceps* (Smith) in Phu Ninh district, Quang Nam province, Vietnam. Proceedings of the 11th Vietnam National Conference on Entomology, Hanoi, November 13–14, 2023, Vietnam.

Appendix 2. Training and supervision plan during the study

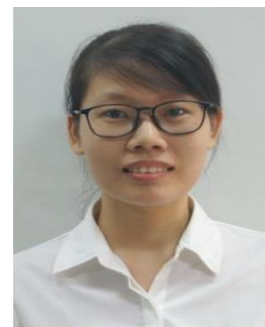
Name	Thi Giang Nguyen
Department	Agroecosystems
Supervisor	doc. Ing. Petr Konvalina, Ph.D.
Co-supervisor	MSc. Tran Dang Khoa, Ph.D. Mgr. Ing. Kristýna Perná, Ph.D.
Period	15 th September 2022 until 14 th September 2026

PhD courses	(Year/Semester)
Current Trends in Crop Production (Aktuální trendy v rostlinné výrobě)	2023/SS
Organic Plant Production (Pěstování rostlin v organickém zemědělství)	2023/WS
Čeština pro cizince (Czech for foreigners)	2023/SS
English language (Anglický jazyk pro doktorandy)	2024/SS
Plant Protection (Ochrana rostlin)	2024/SS
Diseases and abionoses of agricultural and horticultural crops (Choroby a abionózy zemědělských a zahradních plodin)	2024/SS
Scientific seminars	
Scientific seminar I (Vědecký seminář I) – 3rd Doctoral conference JU, České Budějovice, Czech Republic (November 21, 2023).	2023/WS
Scientific seminar II (Vědecký seminář II) – Doctoral seminar KAES FZT JU, České Budějovice, Czech Republic (December 11, 2023)	2023/WS
Scientific seminar III (Vědecký seminář III) – MCYR 2024, Prague, Czech Republic (October 3 rd , 2024)	2024/WS
Scientific seminar IV (Vědecký seminář IV) – Doctoral seminar KAES FZT JU, České Budějovice, Czech Republic (October 21, 2024)	2024/WS
Training	
Internship in the Czech Republic: Faculty of Agrobiolgy, Food and Natural Resources, Czech University of Life Sciences Prague (FAPPZ ČZU)	2022/WS
Internship Abroad: The University of Natural Resources and Life Sciences (BOKU University), Vienna, Austria	2024/SS
Lectures	
Organic Plant Production	2023–2025
Quality, Processing, and Marketing of Bioproduction	2024

Appendix 3. Curriculum vitae

Personal information

Name	Thi Giang
Surname	Nguyen
Title	MSc.
Date of Birth	4 th May 1990
Location	Quang Tri, Vietnam
Nationality	Vietnamese
English	English (B2 level), Vietnamese
Contact	nguyenthigiang@huaf.edu.vn/nguyet04@fzt.jcu.cz



Position

2016 – present **Lecture at the Department of Plant Protection**, Faculty of Agronomy, Hue University of Agriculture and Forestry, Hue University, Vietnam

Project participation

- 2025 – 2027 Inovativní přístupy k udržitelnému zemědělství // “Innovative Approaches to Sustainable Agriculture”. Grant Agency of the University of South Bohemia in České Budějovice – 122/2025/Z.
- 2022 – 2025 Intenzifikace ekologické produkce leguminóz prostřednictvím biologických prostředků s cílem zlepšení jejich zdravotního stavu, poskytovatel// “Intensification of Organic Legume Production through Biological Means with the Aim of Improving Their Health Status”. MZE - Ministry of Agriculture – QK22010255
- 2022 – 2024 Udržitelná a inovativní rostlinná a živočišná produkce // “Sustainable and Innovative Plant and Animal Production”. Grant Agency of the University of South Bohemia in České Budějovice – 085/2022/Z
- 2022– 2023 Identification and bioecological studies of natural enemies of *Hiptage benghalensis*. Application to biological control of invasive plants. Collaborative International Project
- 2022– 2022 Ecological management of insect pests in indian mustard through intercropping in Thua Thien Hue, Vietnam. Institution-level Research Project on Hue University of Agriculture and Forestry (Principal Investigator)
- 2022– 2024 Integrated science and technology solutions for building a sustainable production-consumption linkage of certified rice seed in Quang Nam. Quang Nam Provincial-level Project
- 2021– 2021 Evaluation of *Lasioseius* sp. as a biological control agent for panicle rice mite (*Steneotarsonemus spinki* Smiley) in Thua Thien Hue province. Institution-level Research Project on Hue University of Agriculture and Forestry (Principal Investigator)

- 2021– 2022 Application of scientific and technological advances to establish a rearing and high-value product exploitation model for the stingless bee (*Tetragonula laeviceps*) in Quang Nam province. Quang Nam Provincial-level Project (Science secretary)
- 2021– 2021 Research on completing the technical cultivation procedure for turmeric (*Curcuma longa*) in Thua Thien Hue province. Institution-level Research Project on Hue University of Agriculture and Forestry.
- 2020– 2022 Science and technology solutions for building a sustainable production linkage of VietGAP-certified high-quality rice in Quang Ngai, Vietnam. National Key Research Program Project.
- 2020– 2021 Refinement rearing protocol for the parasitoid *Neochrysocharis okazakii* Kamijoo for management of vegetable leaf miners in Thua Thien Hue province. Thua Thien Hue Provincial-level Project
- 2020– 2021 Development of an Integrated Crop Management (ICM) model for d9 soybean in cassava conversion areas of Huong Tra town, Thua Thien Hue Province. Thua Thien Hue Provincial-level Project
- 2020– 2020 Technical refinement of VietGAP-certified lotus (*Nelumbo nucifera*) production using Nghe An varieties in Thua Thien Hue. Institution-level Research Project on Hue University of Agriculture and Forestry
- 2019– 2019 Assessment of *Stethorus punctillum* as a biological control agent for *Tetranychus urticae* on cassava in controlled conditions. Institution-level Research Project on Hue University of Agriculture and Forestry (Principal Investigator)
- 2019-2019 Research on developing an institutional standard for scallion (*Allium fistulosum*) seeds in Huong Tra, Thua Thien Hue. Institution-level Research Project on Hue University of Agriculture and Forestry
- 2019 – 2019 Commercially available organic fertilizers in rice farming of central Vietnam: Assessing key producers and application by farmers. International Rice Research Institute (IRRI)
- 2017– 2018 Laboratory rearing techniques for the cassava mealybug parasitoid, *Anagyrus lopezi*, in Thua Thien Hue, Vietnam. Hue University-level Project
- 2018 – 2023 The development of integrated cultivation technologies that reduce greenhouse gas emissions for paddy rice in Asia (MIRSA3). Ministry of Agriculture, Forestry and Fisheries, Japan
- 2016 – 2018 Improving the technology of producing imported parasitic bees *Tetrastichus brontispae* Ferrier except coconut beetle *Brontispa longissima* Gestro in the central provinces. Ministry of Science and Technology, Vietnam
- 2016 – 2018 Conservation study of Huong Can tangerine in Thua Thien Hue. Ministry of Education and Training, Vietnam
- 2014 – 2015 Emerging pests and diseases of cassava in Southeast Asia: Seeking eco-efficient solutions to overcome a threat to livelihoods and industries. The International Center for Tropical Agriculture

Publications (Before September 2022)

- Tran, D. H., **Nguyen, T. G.**, Hoang, T. N., 2022. Performance and population growth rate of cassava pink mealybug, *Phenacoccus manihoti* Matile-Ferrero (*Hemiptera: Pseudococcidae*) under different potassium fertilization regimes. *Agriculture and Natural Resources* 56, 791–796.
- Tran, D. H., **Nguyen, T. G.**, Bui, N. H., 2022. Efficacy of the extract from pongam (*Pongamia pinnata*) leaves against the cassava pink mealybug (*Phenacoccus manihoti* Matile-Ferrero) under laboratory conditions. *Research on Crops* 23(1), 197–201.
- Tran, D. H., **Nguyen, T. G.**, Tran, T. X. P., Tran, T. H. D., 2022. Larvicidal activity against the cabbage webworm, *Hellula undalis* (Fabricius) (Lepidoptera: Pyralidae) of the extract from pongam leaves (*Pongamia pinnata* L.). *Legume Research: An International Journal* 45(5).
- Nguyen, T. G.**, Tran, T. H. Đ., Tran, T. X. P., Nguyen, H. L. A., 2022. Effects of intercropping on the insect pests of indian mustard (*Brassica juncea*). *Plant Protection Journal* 6(6), 36–40. (Vietnamese).
- Tran, T. H. P., Nguyen, V. T. P., Van, V. H., Ho, T. K. Đ., Doan, T. P. H., **Nguyen, T. G.**, 2022. Effect of media to the growth, flower quality, and pests of French marigold (*Tagetes patula* L.) in Thua Thien Hue Province. *Plant Protection Journal* 5(5), 36–40. (Vietnamese).
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Author Contribution Statement

Publications where Thi Giang Nguyen is a co-author

1. Prominent use of lactic acid bacteria in soil-plant systems

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The PhD candidate contributed substantially to the preparation and writing of the manuscript.

Signatures:

First Author, Yves Theoneste Murindangabo:

2. Enhancing Soil Organic Matter Transformation through Sustainable Farming Practices: Evaluating Labile Soil Organic Matter Fraction Dynamics and Identifying Potential Early Indicators.


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