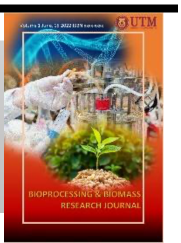
Bioprocessing and Biomass Technology

Journal homepage: https://bioprocessing.utm.my



Review Article

Harnessing the Potentialities of Probiotics, Prebiotics and Synbiotics Application for Agriculture Industry: A Mini Review

Siti Zulaiha binti Zailani[a], Nurin Syakirah Binti Abd Rahim[a,b], Aizi Nor Mazila Ramli [a,b,*]

[a] *Faculty of Industrial Sciences and Technology, Universiti Malaysia Pahang, Lebuhraya Tun Abdul Razak, 26300 Gambang, Pahang, Malaysia*
[b] *Bio Aromatic Research Centre of Excellence, Universiti Malaysia Pahang, Lebuhraya Tun Abdul Razak, 26300 Gambang, Pahang, Malaysia*

ARTICLE INFO

Article History:
Received 14 October 2024
Received in revised form 21 November 2024
Accepted 25 November 2024
Available online 31 December 2024

Keywords:
Probiotic,
Prebiotic,
Synbiotic

ABSTRACT

The agricultural industry significantly drives global economic growth. However, the undeniable impacts of intensive use of chemical fertilizers, pesticides, and intensified farming practices contribute to soil erosion. Synbiotics, a combination of prebiotic and probiotic offer an alternative approach to preserve and improve the quality of soil. The main objective of this review is to provide comprehensive overview of the application of the synbiotic approach to the productivity of the agriculture. The review covers soil fertility factors, as well as the roles of synbiotic, prebiotic and probiotic in enhancing the growth of plant in agriculture. Biofertilizers, consisting of organic matter and beneficial microbes, establish a symbiotic relationship with plants, enhancing both soil health and plant growth. The combination of probiotic and prebiotic can generate high production of agriculture yield.

INTRODUCTION

In accordance with a report released by Food and Agricultural Organization (2022), there is a sharp increase in the number of people that are facing malnutrition, crisis on shortage of food as well as unable to fulfil the food supplies for family needs from 2019 to 2020. With growing population in the world, lacking agriculture resources brought to world hunger that causes significant number of death. Production of agriculture should be enhanced in terms of productivity in order to untangle the food insecurity problem. Nonetheless, the undeniable impacts of intense use of chemical fertilizer, pesticide, and intensified farming lead to soil erosion (Mushtaq et al., 2021). Soil erosion refers to the degradation of soil nutrient content and organic matter, which is most likely to happen rapidly in topsoil, the most upper layer of soil. Declination of soil organic matter and nutrient affects the cultured crops production and yield which leads to replacement of new batch of soil in order to retain the crops productivity. However, aggressive disposal of soil further increases the production of agricultural wastes (Maximillian et al., 2019). Thus, the practices on producing sustainable food sources that maximise the product yield while causing zero impact to the environment are encouraged to resolve the issues (Thomas et al., 2022).

In research led by Basu et al. (2021), it is stated that there is unavoidable loss of 60 to 80% fertilizer as consequences of leaching and evaporation. In order to rectify the loss of nutrient, maintaining high amount of soil microbes is able to preserve, recycle the soil nutrient and exhibit a pest-suppressive property. Probiotics is one of the microbial-based inoculant type which consists only one species or multiple species of microbial communities that are able to propose positive impact on soil microbial activity (Santos et al., 2019). Probiotics contain beneficial microbes that enhance soil nutrient availability and stability by increasing the production of bioactive compounds and facilitating the conversion of organic waste into inorganic forms that are more readily available for plant uptake. A study conducted by Adewole & Ilesanmi. (2011) has concluded that the treatment with the highest

---

*Corresponding Author
E-mail address: aizinor@ump.edu.my
DOI address
ISBN/©UTM Penerbit Press. All rights reserved

concentration of bio-soil amendment led to the optimum growth of okra. This finding further confirms that the supplementation of probiotics enriches soil quality.

The non-digestible substrates that serve as a nutrient source for these beneficial microorganisms are known as prebiotics (Gibson et al., 2017). As explained by Huang et al. (2019), prolonged use of inorganic fertilizers leads to loss of microbial diversity in soil. In this context, prebiotics are able to restore the microbial richness of soil by selectively promoting the growth of probiotics. Some of these microbes possess novel antimicrobial properties, which make them valuable in suppressing soil-borne diseases and inhibiting plant pathogens like *Phytophthora*, *Pythium*, *Rhizoctonia*, and *Fusarium* (Du et al., 2021). By harnessing prebiotics in agriculture, probiotics are able to thrive and play their roles in facilitating plants' nutrient uptake by breaking down organic matter into small, simple forms (Woo & Pepe, 2018).

Synbiotics are a combination of prebiotics and probiotics which have been proposed to have a synergistic impact by inhibiting the growth of pathogenic bacteria and promoting the growth of beneficial organisms Gyawali et al. (2019). Probiotics and prebiotics complement each other's positive effects. For example, prebiotics increase microbial diversity and soil microbial health by encouraging the growth of soil microorganisms already present in the soil-plant system and improve soil structure, biochemical activity, and microbial population and diversity, especially in degraded soils. Synbiotics have the potential to improve soil quality through various mechanisms (Lou et al., 2017). Probiotics in synbiotics introduce beneficial microorganisms to the soil, contributing to increased microbial diversity.

SOIL FERTILITY

Soil constitutes the outermost layer of the Earth's surface. It has nonnegligible roles in facilitating the exchange and transfer of mass and energy among the atmosphere, hydrosphere, biosphere, and lithosphere (Ferreira et al., 2022). Soil formation and soil degradation are two intrinsic and significant natural processes as they play a vital role in influencing soil fertility (Adhikary, 2020). As defined by Kome et al. (2019), soil fertility refers to the capability of soil to supply sufficient nutrients in appropriate proportions to sustain the growth and development of plants. It serves as a key factor in sustaining all living forms on Earth as it accounts for over 95% of global food production (Borrelli et al., 2020). The concept of soil quality has been evolving throughout the years and its new definition describes soil as a finite, non-renewable resource (Muñoz-Rojas, 2018).

Recently, the major concern in agriculture is the deterioration of soil health and quality. Bhatt et al. (2019) stressed that organic fertilizer is relatively low in nutrient content but is effective in enhancing biological and physical attributes of soil. In contrary, inorganic fertilizer encompasses all nutrients in readily available forms, but its extravagant and prolonged use leads to soil degradation and environmental pollution. Despite that soil can be regenerated via natural processes, the formation requires a significant amount of time as the organic matter mainly comes from decomposition of biomass and plant residues (World & Group, 2018). As outlined in the study by Delang, (2018), soil degradation may lead to a variety of drastic consequences including depletion of soil nutrients, acidification, declined crop yield, reduced livestock production, and elevated frequency of landslides and floods. According to (Heger et al., 2018), empirical research indicates that poverty is correlated with the deterioration of soil fertility. This is primarily because the environmental or agricultural sectors constitute a significant proportion of the income in rural areas. Thus, soil quality serves as the basis of the productivity of agricultural sectors, which is crucial in ensuring food security and alleviating poverty globally (Stewart et al., 2020).

FACTORS INFLUENCING SOIL FERTILITY

Understanding soil fertility and plants' nutritional requirements provides valuable insights for optimizing fertilizer usage in agriculture (Wang et al., 2019). The attributes affecting soil fertility include physical, chemical, biological, as well as mineralogical properties, which are all interactive in influencing plant health.

Physical

Physical indicator included bulk density, water holding capacity and soil porosity. Water holding capacity is closely related to soil moisture as the higher the water holding capacity, the more moisture content retains in the soil. Water holding capacity is influenced by the number of pores, pore-size distribution, and the specific surface area of the soil (Vengadaramana & Jashothan, 2012). According to Sofo et al. (2019), this capability is essential to support plant or crop growth and sustain their survival particularly in drought seasons. Higher water holding capacity act as a water storage that supplied water for plant growth, when necessary, in specific emergency condition. Apart from water holding capacity, porosity in soil will be one of the factors affect moisture content. Three classes of soil porosity are grouped based on their respective size which included macrospore, mesopore and microspore (Jim & Ng, 2018). Macrospore is the porosity class that execute the best aeration and water infiltration in soil contributed by its diameter of 60 µm or more. Pore that falls within of 0.2 to 60 µm are considered as mesopore that most utilised as moisture reservoir. The smallest pore is classified as microspore which has a diameter less than 0.2 µm aids in moisture retaining in soil environment. Soil texture and its structure are influenced by the soil porosity which highly dependent on the particle size distribution.

Bulk density is one of soil fertility characteristic that highly rely on the structure and texture of soil. Hence, it is considered as a key factor on determine soil porosity and its moisture content (Al-Shammary et al., 2018). Owe to the ratio of soil dried mass to volume increase indicated increase in bulk density, it proposes a negative impact on the soil included aeration, root growth, denitrification process and soil community according to report of (Hikouei et al., 2021). Referring to study from (Krohn et al., 2021), as a conducive soil environment, soil with lower bulk density will perform better nutrient-holding ability compared to that with higher bulk density.

Chemical

Organic carbon, nitrogen, phosphorus, potassium, and soil pH is the main concerns in maintaining soil fertility. Understanding the dynamics of soil organic carbon is beneficial to sustainable agriculture. Soil organic carbon can be divided into labile organic carbon and stable organic carbon, with the former serving as an essential source of nutrients for both plants and soil microorganisms (Yuan et al., 2021). Owe to its enhancing capability on essential nutrient availability, improving productivity of soil microbes and physical properties of soil, it is regarded as a fundamental element in soil.

Most of the plant molecules which comprised of amino acids, ATP, chlorophyll, and nucleic acids require nitrogen building blocks. Nitrogen monomer converted into essential complex molecules by biosynthesis in soil community. Soil microbial activity is profoundly affected by the availability of nitrogen and carbon, which are the two elements that dynamically linked (De Notaris et al., 2020). The presence of nitrogen in soil is important for promoting root development, maintaining nutrient levels, and enhancing absorption of other nutrients (De Notaris et al., 2020).

Plants usually uptake phosphorus for growth in the form of inorganic orthophosphate ions (Hallama et al., 2019). Nevertheless, most phosphate that naturally present in soil environment will be in organic and insoluble forms that are not readily absorbable for plant. Even though by introducing foreign inorganic and soluble phosphorus into the soil the foreign phosphorus will be fixed rapidly and converted back its organic and insoluble form. This insoluble phosphorus will accumulate in the soil surface that led to limited phosphorus nutrient. For such circumstances, based on Milić et al. (2019) study, to increase the concentration of soluble phosphorus that available for plant uptake, incorporate organic matter into soil and promote adsorption competition will be an alternative.

About 69% of the NPK balance comes from potassium, which is the seventh most prevalent element in the Earth's crust due to the 1.5 times more removal of potassium by plants compared to nitrogen (Pandurang Gurav, 2018). Potassium is remarkably necessary for plants to develop roots and regulate turgor pressure that involved in stomata functions during photosynthesis (Sustr et al., 2019). Proteins, carbohydrates, lipids, and organic acids metabolism required the stimulation of potassium according to (Sattar et al., 2019).

According to Kome et al. (2019), the mineralogical composition of soil exerts direct influence on the soil's ability to restore its nutritional content, which has been reduced as a consequence of plant nutrient uptake, fixation, and leaching. The vast majority of elements that are essential for plant growth, including calcium, magnesium, sulphur, and manganese, can be naturally found in soil. The type of ions involved in the ion exchange reactions determines a significant part of the cation exchange capabilities of soil, which is vital in regulating the availability of nutrient elements for plant uptake.

Beside of elemental composition in soil, pH value is a critical effect that used to maintaining the biogeochemical process in soil. The optimal soil pH value varies depending on the type of crops being planted and is essential to be determined. Commonly, the pH range that fall within 5.5 to 6.5 is ideal for maximising the availability of nutrients in most of the plants but there will be some exception (Msimbira & Smith, 2020). Slight alteration of soil pH value brings impacts on organic matter mineralisation, enzyme activities, degradation of pollutants and microbial growth (Neina, 2019). Based Hong et al. (2018), soil acidification has the potential to exacerbate the loss of cation nutrients, which in turn lowers the availability of critical nutrient elements and leads to decreased plant production.

Biological

Soil biodiversity is inclusive of the abundance and variety of living organisms in the soil ecosystem which directly contribute to its soil quality and fertility that bring consequences to plant health and growth (Wiesmeier et al., 2019). Microbial community with various mechanisms diversified the soil nutrient content. Nitrogen fixation, decomposition of organic matter, convert soil nutrient into absorbable state for plant uptake. Biosynthesis molecule from soil microbe play a role in degradation of complex molecule into smaller molecules that are easier for plant absorption (Burns et al., 2013). Some microbes interact to form a synergic relationship that can effect on nutrient availability, disease suppression and growth (Ma et al., 2019).

Microorganisms possess the ability to promptly respond to changes in soil environment, making them valuable indicators for assessing soil quality and fertility (Dominchin et al., 2021). Nevertheless, their presence in soil is indispensable due to their physiological roles. According to (Guo et al., 2023), approximately 34% of nitrogen is utilised by plants while the remaining is reduced by denitrification or lost to soil and water. Nitrogen cycling is one of the most intensely studied roles of soil microorganisms. As illustrated in **Figure 1**, it involves the conversion of atmospheric nitrogen to plant-available organic nitrogen, which is then returned to the atmosphere. A complete nitrogen cycling process comprises five stages, which are nitrogen fixation, nitrification, assimilation, ammonification, and denitrification. During nitrogen fixation, nitrogen-fixing bacteria like *Rhizobium* and *Bacillus* reduce atmospheric dinitrogen to inorganic nitrogen compounds with the use of nitrogenase (Rosenblueth et al., 2018).

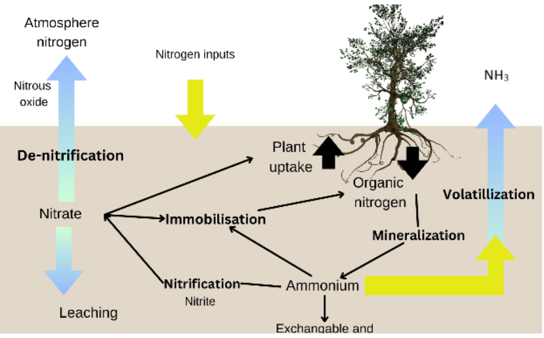


Figure 1 The conversion of atmospheric nitrogen to plant-available organic nitrogen, which is then returned to the atmosphere.

Nitrifying bacteria like *Nitrosococcus* and *Nitrosomonas* transform the ammonia into nitrates through the nitrification process (Eubeler et al., 2010). Nitrates, ammonia, and ammonium resulted from nitrogen fixation and nitrification are assimilated by plants with the aid of root (Lindström & Mousavi, 2020). During ammonification, the organic nitrogen found in plant residues or secreted by plants as waste products are converted by prokaryotes and fungi into ammonia which are subsequently released into the soil. Finally, nitrates are processed into nitrogen by denitrifying bacteria like *Pseudomonas* and *Clostridium* in a process known as denitrification. The nitrogen gas is then returned to the atmosphere (Eubeler et al., 2010). **Table 1** shows several organisms involved in the cycling of nitrogen.

Table 1 Examples of organisms involved in the cycling of nitrogen

Process	**Principle**	**Organisms**	**References**
Nitrogen fixation	The complex process of reducing an N_2 molecule to an N molecule needs significant energy which one of the plants need for development and metabolism. (Rashid et al, 2016)	*Rhizobium*, *Pseudomonas*, *Bacillus*, and *Azospirillum*	(Igiehon & Babalola, 2018)
Nitrification	The biological conversion of ammonia or ammonium to nitrite and then nitrite to nitrate. (Rahimi et al., 2020)	*Nitrosomanas*, *Nitrobacter*, *Nitrospira*, and *Nitrosospira*	(Chen et al., 2018)
Ammonification	The process of ammonium (NH4+) being released from organic nitrogen molecules. (Cáceres et al, 2018)	*Proteus* and *Bacillus*	(Behrendt et al., 2015)
Denitrification	Denitrification is the process of removing ION from tributaries to the atmosphere and transforming it into the biologically less reactive form of N_2. (Kim et al, 2016)	*Pseudomonas*, *Polaromonas*, and *Cellulomonas*	(Jang et al., 2019)

PROBIOTICS IN AGRICULTURE

With growing population in the world, lacking agriculture resources due to pest and plant disease can be trickled by promoting of fertilizer and pesticide. Nonetheless, the undeniable impact of using chemical fertilizer and pesticide is that they will erode the soil quality as well as pollute the environment (Mushtaq et al., 2021). Scientists have found an alternative to replace chemical fertilizer that potentially increasing crop production while retaining the soil quality at the same time (Woo & Pepe, 2018). Probiotics are living organisms that execute a beneficial effect on the host organisms when present in adequate amount. Complex activities performed by the probiotics interact with plant at microscopy level in the soil environment is proved to boost plant health and soil quality (Santos et al., 2019). Probiotics must establish the following characteristics to be defined as beneficial microbes on the treated crop. These included aids in niche colonisation, create an induced systemic resistance in host organisms and perform antagonistic traits on pathogenic microbes. Plenty of studies have obtained positive outcomes of the probiotics effect on yield production and soil fertility. Study have found that the above properties are achieved by three generalised mechanisms: (a) replace the soil nutrient; (b) convert the nutrient in available state for plant uptake; (c) elevated the accessibility of plant towards the nutrient elements (Menendez & Garcia-Fraile, 2017).

Plant Nutrient Uptake

Plant nutrient uptake is highly improved by as nitrogen-fixing microbes which included genera members of *Rhizobium*, *Bacillus*, *Paenibacillus*, *Azotobacter* and *Gluconoacetobacter*. This nitrogen-fixing bacteria able to facilitate the uptake process of essential and limited nutrients, nitrogen, phosphorus, and iron. Nitrogen-fixing microbe capable to capture atmospheric nitrogen and conversion is needed in a plant-absorbable state (Kumar et al., 2017). Studies have shown that Azotobacter performed nitrogen fixation in rice crop and have been tested for biofertilizer usage in cereal included wheat, barley, oat and maize while *Gluconoacetobacter*, *Azospirillum*, and *Herbaspirillum* sugar cane have been a positive nitrogen fixing microbes in sugar cane. Significant concentration of *Azoarcus*, *Azospirillum* and *Burkholderia* is found in rice crops root escalated the nitrogen concentration at the surroundings. *Lactobacillus plantarum* secrete organic acid such as succinic acid solubilize the phosphorus that ease for plant uptake on phosphorus nutrient. Secretion of indole-3-acetic acid (IAA) synthesized from *Rhodobacter sphaeroides* has known to propose a better nutrient uptake by plant roots (Nimnoi et al., 2014). Last but not least, genera *Rhizobium* and *Bradyrhizobium* is found in roots of rice and wheat association have obtained an increasing trend in the yield's nutrient content (Xavier et al., 2023).

Enhancing Overall Crops Growth

Probiotics that live within the soil community have the ability to produce an essential compound known as phytohormone that crucial in plant development. Auxins, gibberellins, cytokinin and ethylene are commonly seen key phytohormone that involve in most of the plant biological activities. Auxin, indole-3-acetic acid (IAA) is an essential component in coordinates the activities in bacterial community found in soil environment. Cytokinin promotes root apical dominance, vascular differentiation as well as cambium sensitivity, and cytokinesis. Seeds are germinated and emerge, develop leaf and steam, flowering, and fruiting with the regulations of phytohormone gibberellins (Wang & Komatsu, 2022). Ethylene has the overlapped effects found in gibberellins which are developing fruits and flowers as well as promotes seed germination. Gibberellins and ethylene different in a way that ethylene does stimulate secondary root formation and elongation of root hair. Each of the phytohormone propose their significant importance in regulation of plant activities (Arif et al., 2020).

Bacillus spp. have been reported to exert auxin producing ability in the development of potato, rice and cucumber that promotes the crops' growth (Saxena et al., 2020). Thuja seedling incorporated with *Bacillus subtilis* propose better resistance to drought stress while *Bacillus cereus* a gibberellins-producing strain escalated the yield growth of red pepper plants (Lastochkina et al., 2020). *Paenibacillus polymyxa* was also reported as a good phytohormone producer by Bent et al. (2001) that it elevated the IAA concentration level in pine. Crops included pepper, tomato, strawberry, red carnation, lettuce, and carrot shown an increment in term of growth by supplement of auxin-producing probiotics strains – Rhizobial strains such as *Rhizobium leguminosarum* (Brígido et al., 2017). Tomato plants treated with gibberellin-producing microbes, *Sphingomonas* sp. LK11, an enhancement in plant growth was derived from the outcome of the study (Kong et al., 2015).

Lactobacillus plantarum increase the soil nutritional content and diversify the soil microbial community. In study carried out by Liu et al. (2023), the soil inoculated with *Lactobacillus plantarum* shows an increment on water-soluble carbohydrates, protein and dry matter compared to the controls. The diversified microbial community and elevated soil nutrient will boost the crop quality and growth. The similar outcome was observed in Kang et al. (2015), which the inoculation of *Lactobacillus plantarum, Rhodobacter sphaeroides* and *Saccharomyces cerevisiae* on shoot and root length as well as the dry weight of cucumber crops shown an escalation via the increment secretion of IAA. This combination even elevated 17 amino acid contents in soil.

Establish a beneficial soil community

A healthy soil community can hinder the microbial activities carried out by soil pathogen. Accumulation of beneficial probiotics in soil community direct or indirectly avoid spreading of pathogenic microbes. The probiotics' ability to synthesize antimicrobial substances such as antibiotic, siderophore and cell wall degrading enzymes contribute to the elimination of harmful microbes in soil (Chandran et al., 2021). Generally, *Bacillus* spp., *Pseudomonas* spp., *Acinetobacter* spp., and *Paenibacillus* spp. have exhibit the above properties, but *Bacillus* spp. and *Pseudomonas* spp. are frequently proved for their antagonistic properties against pathogenic microbial activity in several literatures.

Bacillus spp. produce antibiotic that are necrotic to Gram-positive, Gram-negative bacteria, and pathogenic fungi community. Bacillus subtilis is proved to inhibit several soybeans seed pathogenic fungi which included *Colletotrichum truncatum*, *Macrophomina phaseolina*, *Rhizoctonia solani*, *Phomopsis* sp., and *Sclerotinia sclerotiorum* (Araújo et al., 2005). Production of hydrolytic enzyme which included Chitinase and β-glucanase in *Pseudomonas* spp. aids in suppression of *Rhizoctonia solani* and *Phytophthora capsica* that ae considered the most seen pathogenic microbes in soil community. The *fluorescens*, *putida* and *rothia* species of *Pseudomonas* provoke the defence system against disease produced by *Furasium udum* and *Spodoptera litura*, respectively by the existing of hydrolytic enzymes and siderophore (Kumar et al., 2010). In addition, *Lactobacillus plantarum* was used to treat in pepper seedling process shown a significant improvement in resistance on the leaf spot disease that caused by *Cercospora capsici*. The treated seedling has lower severity of *Cercospora* leaf spot compared to the untreated seedling (Adedire et al., 2019). *Lactobacillus* spp. do exhibit antifungal and antibacterial activity that eliminates harmful pathogen in soil community (Jegadeesh et al., 2018). *Lactobacillus casei* is considered a preferred probiotics as it elevated the amino acids and nutrient content in fresh waste from agriculture. *Lactobacillus casei* inoculated in fresh waste of grape berries shown remarkable improvement of 325.5% of total free amino acid compared to the controls (Zhao et al., 2023).

A study found out that the co-existence of both *Bacillus* spp. and *Pseudomonas* spp. exhibit a mutualism and positive interaction in the coculture medium. The synergy of the co-existing probiotics provides an insight on producing fertilizers and pesticides. The bioactive compounds produced by both *Bacillus* spp. and *Pseudomonas* spp. act as mediators that controls, suppress and eradicate the destructive community brought by pathogens in soil community (Lyng & Kovács, 2023). The cocultivation of both *Bacillus* spp. and *Pseudomonas* spp. in monoculture execute an additive effect in the bioactive compounds that enhances overall plant immunity towards pathogen.

Thereby, the beneficial impact of probiotics validates their applicability as biofertilizer, whether using a single strain or multiple strains that combine different beneficial effects. Eliminating pathogenic microbes in soil community elevated the quality of soil microbial biomass without eroding the soil quality.

PREBIOTICS IN AGRICULTURE

The concept of prebiotics has evolved over the past few decades. As explained by Kaur et al. (2021), the termination was first introduced to the public in 1995 as non-digestible food ingredients that can selectively promote the growth of specific bacteria in the gastrointestinal tract, leading to improved human health. Presently, the definition has been revised to substances that are selectively utilized by microorganisms in the host's body, exerting health benefits while preserving the overall beneficial effects mediated by the microflora.

Prebiotics are renowned for their remarkable ability to promote the growth of probiotics and enhance their metabolic activities while retarding the growth of pathogenic microorganisms (Lockyer & Stanner, 2019). While some can be synthesized by digesting polysaccharides, prebiotics are naturally occur in a wide range of food including onion, garlic, oats, barley, and almond (Davani-Davari et al., 2019). According to Khangwal and Shukla (2019), some of the common prebiotics, such as inulin, galactooligosaccharide (GOS), and fructooligosaccharide (FOS), have been produced in large scale while the production of other prebiotics like xylooligosaccharide (XOS) and arabinoxylooligosaccharide (AXOS) are still undergoing development phase.

Nonetheless, apart from their benefits to human health, several studies suggested that prebiotics exhibit several potential applications in agriculture such as facilitating nutrient uptake by plants, altering soil microbial communities, accelerating the process of decomposition, and retarding soil diseases (Yousfi et al., 2021). Vassileva et al. (2020) reported that prebiotics are advantageous in stimulating the growth of soil microorganisms that are already present in the soil, thereby enhancing the diversity and health of soil microorganisms. There are numerous types of prebiotics. The vast majority of them are oligosaccharide carbohydrates, but there are also some of the prebiotics that are not classified as carbohydrates. Some of the commonly known prebiotics include inulin, FOSs, GOSs, and XOSs. The chemical structure of fructans, GOSs, and XOSs is shown in **Table 2**.

Besides, prebiotics can also improve the soil structure, metabolic activity, and microbial population and diversity (especially in damaged soils) (Strachel et al., 2017). Moving to details, prebiotics are natural non-digestible fibers that serve as a food source for beneficial bacteria in the gut, primarily the probiotics. These fibers are resistant to digestion where they are selectively fermented by specific bacteria (Davani-Davari et al., 2019). Hence, they act as substrates for the growth and activity of beneficial bacteria leading to a balanced and diverse gut microbiota.

Table 2 Chemical structure of fructans, galactooligosaccharides and oxylooligosaccharides

Types of Prebiotics	Chemical Structure	Source of prebiotics
Fructans	fructose joined by β (2-1) linkage	Linear inulin (Jerusalem artichoke, chicory) Inulin neoseries (Onion, asparagus, agave), Linear levan (Rye grass), Mixed levan (Wheat, rye barley) Levan neoseries (Oat) (Wang & Cheong, 2023)
Galactooligosaccharides	galactose and glucose bound by β (1-3) and β (1-4) linkages	Human's milk and cow's milk (Ashwini et al., 2019)
Xylooligosaccharides	xylose units linked by β (1-4) linkages	Xylan (Oats, birch wood, corn cobs)

The majority of prebiotics are a subset of carbohydrate groups and mostly oligosaccharide carbohydrates (Davani-Davari et al., 2019). Oligosaccharides are carbohydrates made up of 3-10 monosaccharide units connected by O-glycosidic bonds and can be classified based on their chemical composition as Pectic-oligosaccharides (POS), xylooligosaccharides (XOS), arabinoxylooligosaccharides (AXOS), fructooligosaccharides (FOS) and isolmaltooligosaccharides (IMO) (Vazquez-Olivo et al., 2019). **Table 3** described the characteristics of prebiotic compound. Oligosaccharides can be divided into digestible and nondigestible, the latter is made up of monosaccharides connected by non-hydrolyzable glycosidic linkages (Vazquez-Olivo et al., 2019).

Table 3 Characteristics of prebiotic compound

Prebiotics	Characteristics	References
FOS	- oligomers of fructose - generic structure: α-D-Glu-(1-2)-[β-D-Fru-1-2-] n, where n is 2 to 4 - composition β (2-1) fructans - can be easily dissolved in hot water	(Taiseer et al., 2014)
Inulin	- a polysaccharide which plants store as a nutrient. It is a small-molecule FOS - polymers of fructose - generic structure: α-D-Glu-(1-2)-[β-D-Fru-1-2-]n, where n is up to 60 - composition β(2-1) fructans - defined as a polydisperse carbohydrate material consisting mainly, if not exclusively, of β-(2-1) fructosyl-fructose links - can be easily dissolved in hot water	(Figueroa-González et al., 2019)
GOS	- general structure, α-D-Glu-(1-4)-[β-D-Gal-1-6-]n, where n is from 2 to 5 - produced by the enzymatic transgalactosylation of lactose with β-galactosidase] - GOS tolerate high temperatures and low pHs	(Figueroa-González et al., 2019)
Lactulose	- disaccharide with structure, β-D-Gal-D-(1-4) D-Fru	(Martins et al., 2019)

Fructans

Fructans include inulin and FOSs. The structure of fructans is a linear chain of fructose linked by the β (2-1) glycosidic bond. FOSs are also referred to as oligofructose or oligofructan. They can be found in wheat, oats, artichoke, garlic, onion, and bananas. Owing to their bifidogenic properties, FOSs are often utilised as a nutrient source by *Bifidobacterium* (Dou et al., 2022). Inulin is a polymer of fructose which is joined by the β (2-1) glycosidic bond. It is primarily found in chicory root and is reported to facilitate nourishment of probiotics including *Streptococcus*, *Lactobacillus*, and *Bifidobacterium* (El-Kholy et al., 2020). Despite that, as clarified by Scott et al. (2014), the types of bacteria stimulated is dependent on the chain length of fructans, hence marking the potentials of this compound in promoting the growth of other bacterial species. Other microorganisms that are capable of producing exoinulinases for the hydrolysis of inulin include *Aspergillus*, *Bacillus*, *Penicillium*, *Pseudomonas*, *Kluyveromyces*, *Xanthomonas*, and *Chrysosporium* (Mutanda et al., 2014).

Galactooligosaccharides

This category includes oligolactose, oligogalactose, and oligogalactosyllactose (Martins et al., 2019). In the industry, GOSs are usually produced commercially through transgalactosylation with the use of β-galactosidases during the hydrolysis of lactose (Botvynko et al., 2019). They contain a terminal glucose residue and galactose units that are joined together by glycosidic bonds via a process known as transgalactosylation catalysed by β-galactosidase. Similar to FOSs, GOSs are proclaimed to stimulate *Lactobacillus* and *Bifidobacterium* (Stewart et al., 2020). Rinninella et al. (2019) also revealed that GOSs pose positive effects on the growth of *Bacteroidetes*, *Enterobacteria*, and *Firmicutes*.

Xylooligosaccharides

XOSs are composed of xylose units linked by β (1-4) glycosidic bonds (Nordberg Karlsson et al., 2018). While they are abundant in milk, honey, bamboo shoots, fruits, and vegetables, XOSs can also be produced from the hydrolysis of xylan via enzymatic, chemoenzymatic or chemical means. Agricultural residues like corn cobs, wheat bran, wheat straw, rice hulls, barley hulls, and brewery spent grains are commonly utilised as a source of xylan in large-scale production of XOSs (Jain et al., 2015). Nordberg Karlsson et al. (2018) reported that *Bifidobacterium* and *Lactobacillus* are capable of utilising XOSs from food material, validating the prebiotic properties of this compound. Moreover, XOSs are proven to have stimulating effects on *Bacteroides*, *Enterococcus*, and *Weissella* (Palaniappan et al., 2021).

Other Oligosaccharides

As described by Jiang et al. (2020), in vitro studies have discovered a type of starch which is not digestible by amylase but is fermented by probiotics. This compound is termed the resistant starch. They are naturally present in potato, banana, ground beans and grains. According to DeMartino & Cockburn. (2020) the primary degraders of resistant starch are *Bifidobacterium* and *Ruminococcus*. Apart from that, another study showed that the presence of resistant starch is able to elevate the concentration of *Bacteroidetes*, *Akkermansia*, and *Allobaculum* (Tachon et al., 2013).

Pectic oligosaccharides (POSs) refer to carbohydrates derived from pectin. Hence, cellulosic components and cell walls of vascular plants are abundant in POSs. The prebiotic characteristic of POSs on the growth of *Lacticaseibacillus*, *Limosilactobacillus*, and *Bifidobacterium* was reported by Foti et al. (2022). Consumption of POSs also promote the growth of *Lactobacillus*, *Faecalibacterium*, *Eubacterium*, and *Roseburia* (Tan et al., 2018).

Soybean oligosaccharides (SBOSs) are primarily found in soybean. These molecules are considered bifidogenic as they demonstrate considerable efficacy in improving the growth of *Bifidobacterium* and *Lactobacillus* (Pérez-López et al., 2016). When digested, they are degraded into short-chain fatty acids that serve as an energy source which supports the growth of probiotics (Kim et al., 2023). While carbohydrates are more commonly described as prebiotics, there are certain compounds, like flavanols derived from cocoa, that are not categorised as carbohydrates but are still considered as prebiotics. A study conducted by Tzounis et al. (2011) proposed the prebiotic properties of flavanols in stimulating lactic acid bacteria.

The majority of naturally occurring prebiotics are present in a number of fruits and vegetables, including tomatoes, beans, grains, asparagus, onions, raw garlic, etc (Shie-lih et al., 2020). Most prebiotic compounds come from its wastes such as peel, stem, and roots (Zhang & Cai, 2023; Soua et al., 2020; de Albuquerque et al., 2020). Table 4 showed some of the studies of potential prebiotics from different sources agricultural.

Interestingly, agriculture by-products are a good source to obtain prebiotic compounds as they are low-cost and abundant raw materials (Vazquez-Olivo et al., 2019). The agriculture by-products contain rich sources of added value ingredients that can serve as prebiotics including fibre-rich fraction (Sah et al., 2016). Furthermore, most of these fiber compounds remain undigested during the digestive process which is one of the characteristics of prebiotics (Redondo-Cuenca et al., 2023).

Table 4 Sources of prebiotic compounds from agricultural

Sources of prebiotics	Research-based	References
Palm flesh, palm embryo, jackfruit flesh, jackfruit seed, and okra pod	Thailand	(Wichienchot et al., 2011)
Mushroom	-	(Thatoi et al., 2018)
Rapeseed	United Kingdom	(Wang et al., 2015)
Rind of banana, sweet lime, apple, tomato, and guava	India	(Chatterjee & GA Manuel, 2016)
Asparagus	Spain	(Redondo-Cuenca et al., 2023)

SYNBIOTICS IN AGRICULTURE

The combination of probiotics and prebiotics in a synbiotic is designed to create a mutually supportive environment, enhancing the survival and effectiveness of the beneficial microorganisms. Synbiotic combines probiotics and prebiotics that work synergistically to provide health benefits to the host organism, often the human body. The term "synbiotic" is derived from the words "synergy" (working together) and "biotic" (relating to living organisms) (Mahmud & Chong, 2021).

Compost and animal manure can be regarded as synbiotic products since they contain microorganisms, some of which have beneficial properties; furthermore, PBM could be added to the compost as an inoculant (Adam et al., 2016). Symbiotic organisms include the members of *Rhizobiaceae* which forms symbiotic relationship with leguminous plants (Mahanty et al., 2016). Based on the above considerations, strategies for microbial management of soil to increase its fertility can be based on prebiotics, probiotics and it is better with synbiotic. Prebiotics and probiotics combined, known as "synbiotics," are thought to have a synergistic effect by preventing the growth of pathogenic bacteria and fostering the development of beneficial organisms (Gyawali et al., 2019). Through promoting the growth of soil microorganisms already present in the soil system, the prebiotics enhance microbial variety and soil microbial health, and these two always cooperate to promote and enhance each other's beneficial effects. This allows the available microbes to grow and multiply continuously.

Moreover, solid-state fermentation-based inoculants can be categorized as synbiotics as well. The SFF is rich with multiple organic matters which include probiotic and prebiotic substances. The mineralized organic substances function as carriers and prebiotics. Meanwhile, the plant-beneficial microorganism functions as a biocontrol and probiotic in plant growth. SFF is crucial to the bioconversion of agricultural waste (Vassilev et al.,2018). The nutritious substrate in SSF is important for the synthesis of a variety of bioproducts, including organic acids, biofuels, enzymes, and biosurfactants. This can lead to results in biocontrol and biofertilizer products for the agriculture industry (Vassilev et al.,2018).

Overall, the synbiotic effect is a promising area of research that can be applied to soil treatment. However, further studies are required to better understand the mechanisms of action and the optimal conditions for utilizing substrate mushroom spent as a synbiotic agent. Thus, we aim from this study to investigate how the synbiotic effect of mushroom spent can be applied to soil treatment.

APPLICATION OF BIOFERTILIZER IN AGRICULTURE INDUSTRY

Biofertilizer is microbial formulations that can enhance plant growth (Mahmud & Chong, 2021). Biofertilizer composed of organic material that can be recycled back into the environment. An example of biodegradable matter is empty fruit bunch biomass (Mahmud & Chong, 2021), cheese cotton whey (Moghana & Sumathy, 2020) and fruit wastes (Devi & Sumathy, 2017). Formulation of biofertilizer composed of beneficial microorganisms, where both organic matter and microbes will possess dual effects (Li et al., 2022). Both of them interact symbiotically with plants (Mahmud & Chong, 2021).

Biofertilizers consist of one or more living microorganism colonize the rhizosphere to enhance soil productivity by fixing atmospheric nitrogen and solubilizing various nutrients, thereby providing direct or indirect benefits to crop growth and yield through multiple mechanisms (Allouzi et al., 2022). Biofertilizers contribute nutrients through natural processes, including nitrogen fixation, phosphorus solubilization, and the stimulation of plant growth, along with the production of growth-promoting substances (Sneha et al., 2018). Nitrogen fixation is when nitrogen-fixing microorganisms converted the atmospheric nitrogen into ammonia, which can be easily assimilated by plants through the process of biological nitrogen fixation (BNF) (Mahanty et al., 2016). Microbes solubilize inorganic phosphorus into soluble forms of monobasic and dibasic phosphorus, which in turn enhances plant yield (Allouzi et al., 2022).

In Malaysia, the use of microbial inoculants in industry dates back to the late 1940s, and the most widely used biofertilizer is mycorrhiza inoculums (Lim & Matu, 2015). Research on biofertilizers in China started in 1958 with the collection, isolation, and screening of rhizobia strains for legume inoculation (Atieno et al., 2020).

It was reported that the combination of three bacterial biofertilizer namely *Pseudomonades, Bacillus lentus* and *A. brasilense* increased the expression of antioxidant enzymes (Mahanty et al., 2016). Antioxidants are crucial for soil remediation because they reduce the oxidative stress brought on by reactive oxygen species (ROS) in the soil which are generated by a variety of factors such as UV radiation, pollution, and plant metabolism (Zandi & Schnug, 2022). All these ROS can cause damage to the soil structure, microbial communities, and plant growth.

Thailand has researched beneficial microorganisms resulting in the addition of 30-50 strains to the repository every year and several biofertilizers comprising rhizobia, P-solubilizing bacteria (PSB) and other plant growth-promoting rhizobacteria (PGPR) have also been developed. Co-inoculation with *bradyrhizobia* and PGPR results in a higher quantity of the most effective nodules, improved plant yield, and enhanced nitrogen fixation (Prakamhang et al., 2015). However, their production has only been carried out on a modest scale, due to the restricted funding of research projects and the small participation of the private sector, which has led to a low level of farmer adoption of these technologies (Atieno et al., 2020). Besides, the local environment and plant species have a significant impact on the distribution and functioning of soil microorganisms. Because of this, the application of biofertilizer in the field does not always manage plant diseases or encourage plant growth (Li et al., 2022). Several biofertilizers on the market have not been thoroughly tested scientifically, resulting in subpar products that have little or no effect on crop yields and soil fertility. The farmers end up losing confidence in these products and going back to the traditional method of applying chemical fertilizers (Atieno et al., 2020). Inoculating plants with biofertilizers such as *R. leguminosarum, Rhizobium sp. IRBG 74*, and *Bradyrhizobium sp. IRBG 271* resulted in a higher single-leaf photosynthetic rate (Mahanty et al., 2016).

Table 5 Effect of chemical fertilizer on agriculture

Effect of chemical fertilizer	References
Accelerate the soil acidification, contaminate the groundwater and the surrounding environment, and damage plant roots, thereby increasing their vulnerability to harmful diseases.	(Mahmud & Chong, 2021)
Pollute soil and water, destroy fauna and microbial communities, reduce soil fertility, and increase crop disease susceptibility.	(Atieno et al., 2020)
Contaminate water, lose nutrients, and deteriorate the soil.	(Chojnacka et al., 2020)
Damage the ecosystem, human health, and living environments.	(Yi et al., 2020)
Harmful to human health such as infant methemoglobinemia, polluted air and groundwater resulting from eutrophication, and damage to crop roots that prevents plants from absorbing nutrients.	(Ajeng et al., 2020)

The phosphorus needs to be soluble whether in the form of monobasic or dibasic for the plants to absorb as nutrients for growth (Mahanty et al., 2016). Despite of numerous amounts phosphorus found in the soil, they are insoluble and unavailable to the plant growth. Insoluble phosphorus can come in two different forms, inorganic or organic. In addition, most of the time the soluble inorganic phosphorus used as chemical fertilizers becomes immobilized after being applied to the field. Hence, it becomes unavailable to the plants and gets wasted. Therefore, a crucial role is played by bacteria that can solubilize inorganic phosphorus as a workable alternative to supply phosphorus to the plants such as *Enterobacter sp.* (Mendoza-Arroyo et al., 2020). The bacteria play a big part to synthesize the low molecular weight organic acids such as gluconic and citric acids into solubilize inorganic phosphorus (Teles et al., 2024). The hydroxyl and carboxyl groups present in low molecular weight organic acids can chelate the cations bound to phosphate resulting in the conversion of insoluble phosphorus to its soluble form.

CONCLUSION

The main purpose of the study is to examine of how the prebiotic, probiotic and synbiotic approach enhances agricultural productivity. Prebiotics restore soil microbial richness by selectively promoting probiotic growth.

Harnessing prebiotics in agriculture allows probiotics to thrive, facilitating nutrient uptake in plants by breaking down organic matter into simpler forms. The prebiotic, probiotic and symbiotic approach are commonly applied in the human gut but has seen limited application in agriculture. The potential of prebiotic, probiotic and symbiotic approach must be maximized. The prebiotic, probiotic and symbiotic approach are commonly applied in the human gut but has seen limited application in agriculture. The potential of prebiotic, probiotic and symbiotic approach must be maximized. Future research should prioritize evaluating the efficacy of prebiotic, probiotic, and synbiotic processes in biofertilizer, as well as lowering their costs to achieve competitiveness with inorganic fertilizers.

Acknowledgement

The authors gratefully acknowledged Universiti Malaysia Pahang Al-Sultan Abdullah for the financial assistant through research grant Nos. RDU223010 and PDU223211.

References

Adam, E., Groenenboom, A. E., Kurm, V., Rajewska, M., Schmidt, R., Tyc, O., Weidner, S., Berg, G., De Boer, W., & Salles, J. F. (2016). Controlling the Microbiome: Microhabitat Adjustments for Successful Biocontrol Strategies in Soil and Human Gut. *Frontiers in Microbiology*, *7*(JUL), 1–6. https://doi.org/10.3389/fmicb.2016.01079

Adedire, O. M., Pitan, A., Farinu, A. O., & Ogundipe, W. F. (2019). The Biocontrol of Soil Transmitted Cercospora capsici with *Lactobacillus plantarum*. *Journal of Advances in Microbiology*, *18*(3), 1–8. https://doi.org/10.9734/jamb/2019/v18i330173

Adewole, M. B., & Ilesanmi, A. O. (2011). Effects of soil amendments on the nutritional quality of okra (Abelmoschus esculentus [L.] Moench). *Journal of Soil Science and Plant Nutrition*, *11*(3), 45–55. https://doi.org/10.4067/S0718-95162011000300004

Adhikary, R. (2020). Causes and Effect of Soil Erosion and its Preventive Measures. *Advanced Agriculture*, *August*. https://doi.org/10.30954/ndp-advagr.2020.19

Ajeng, A. A., Abdullah, R., Malek, M. A., Chew, K. W., Ho, Y. C., Ling, T. C., Lau, B. F., & Show, P. L. (2020). The Effects of Biofertilizers on Growth, Soil Fertility, and Nutrients Uptake of Oil Palm (*Elaeis Guineensis*) under Greenhouse Conditions. *Processes*, *8*(12), 1–16. https://doi.org/10.3390/pr8121681

Al-Shammary, A. A. G., Kouzani, A. Z., Kaynak, A., Khoo, S. Y., Norton, M., & Gates, W. (2018). Soil Bulk Density Estimation Methods: A Review. *Pedosphere*, *28*(4), 581–596. https://doi.org/10.1016/s1002-0160(18)60034-7

Allouzi, M. M. A., Allouzi, S. M. A., Keng, Z. X., Supramaniam, C. V., Singh, A., & Chong, S. (2022). Liquid Biofertilizers as a Sustainable Solution for Agriculture. *Heliyon*, *8*(12), e12609. https://doi.org/10.1016/j.heliyon.2022.e12609

Araújo, F. F., Henning, A. A., & Hungria, M. (2005). Phytohormones and Antibiotics Produced by *Bacillus subtilis* and Their Effects on Seed Pathogenic Fungi and on Soybean Root Development. *World Journal of Microbiology and Biotechnology*, *21*(8–9), 1639–1645. https://doi.org/10.1007/s11274-005-3621-x

Arif, Y., Sami, F., Siddiqui, H., Bajguz, A., & Hayat, S. (2020). Salicylic Acid in Relation to Other Phytohormones in Plant: A Study Towards Physiology and Signal Transduction under Challenging Environment. *Environmental and Experimental Botany*, *175*(November 2019), 104040. https://doi.org/10.1016/j.envexpbot.2020.104040

Ashwini, A., Ramya, H. N., Ramkumar, C., Reddy, K. R., Kulkarni, R. V., Abinaya, V., ... & Raghu, A. V. (2019). Reactive mechanism and the applications of bioactive prebiotics for human health. *Journal of microbiological methods*, *159*, 128-137.

Atieno, M., Herrmann, L., Nguyen, H. T., Phan, T., Nguyen, N. K., Srean, P., Than, M. M., Zhiyong, R., Tittabutr, P., Shutsrirung, A., Bräu, L., & Lesueur, D. (2020). Assessment of Biofertilizer Use for Sustainable Agriculture in the Great Mekong Region. *Journal of Environmental Management*, *275*, 111300. https://doi.org/10.1016/j.jenvman.2020.111300

Basu, A., Prasad, P., Das, S. N., Kalam, S., Sayyed, R. Z., Reddy, M. S., & Enshasy, H. El. (2021). Plant growth promoting rhizobacteria (Pgpr) as green bioinoculants: Recent developments, constraints, and prospects. *Sustainability (Switzerland)*, *13*(3), 1–20. https://doi.org/10.3390/su13031140

Behrendt, U., Augustin, J., Spröer, C., Gelbrecht, J., Schumann, P., & Ulrich, A. (2015). Taxonomic characterisation of Proteus terrae sp. nov., a N 2 O-producing, nitrate-ammonifying soil bacterium. *Antonie Van Leeuwenhoek*, *108*, 1457-1468.

Bent, E., Tuzun, S., Chanway, C. P., & Enebak, S. (2001). Alterations in Plant Growth and in Root Hormone Levels of Lodgepole Pines Inoculated with *Rhizobacteria*. *Canadian Journal of Microbiology*, *47*(9), 793–800. https://doi.org/10.1139/cjm-47-9-793

Bhatt, M. K., Labanya, R., & Joshi, H. C. (2019). Influence of Long-term Chemical fertilizers and Organic Manures on Soil Fertility - A Review. *Universal Journal of Agricultural Research*, *7*(5), 177–188. https://doi.org/10.13189/ujar.2019.070502

Borrelli, P., Robinson, D. A., Panagos, P., Lugato, E., Yang, J. E., Alewell, C., Wuepper, D., Montanarella, L., & Ballabio, C. (2020). Land Use and Climate Change Impacts on Global Soil Erosion by Water (2015-2070). *Proceedings of the National Academy of Sciences of the United States of America*, *117*(36), 21994–22001. https://doi.org/10.1073/pnas.2001403117

Botvynko, A., Bednářová, A., Henke, S., Shakhno, N., & Čurda, L. (2019). Production of Galactooligosaccharides using Various Combinations of the Commercial Β-Galactosidases. *Biochemical and Biophysical Research Communications*, *517*(4), 762–766. https://doi.org/10.1016/j.bbrc.2019.08.001

Brígido, C., Glick, B. R., & Oliveira, S. (2017). Survey of Plant Growth-Promoting Mechanisms in Native Portuguese Chickpea Mesorhizobium Isolates. *Microbial Ecology*, *73*(4), 900–915. https://doi.org/10.1007/s00248-016-0891-9

Burns, R. G., DeForest, J. L., Marxsen, J., Sinsabaugh, R. L., Stromberger, M. E., Wallenstein, M. D., Weintraub, M. N., & Zoppini, A. (2013). Soil Enzymes in a Changing Environment: Current Knowledge and Future Directions. *Soil Biology and Biochemistry*, *58*, 216–234.

https://doi.org/10.1016/j.soilbio.2012.11.009

Cáceres, R., Malińska, K., & Marfà, O. (2018). Nitrification within composting: A review. *Waste Management*, *72*, 119-137.

Chandran, H., Meena, M., & Swapnil, P. (2021). Plant Growth-Promoting Rhizobacteria as a Green Alternative for Sustainable Agriculture. *Sustainability (Switzerland)*, *13*(19), 1–30. https://doi.org/10.3390/su131910986

Chatterjee, E., & GA Manuel, S. (2016). Effect of Fruit Pectin on Growth of Lactic Acid Bacteria. *Journal of Probiotics & Health*, *04*(02). https://doi.org/10.4172/2329-8901.1000147

Chen, M., Chen, Y., Dong, S., Lan, S., Zhou, H., Tan, Z., & Li, X. (2018). Mixed nitrifying bacteria culture under different temperature dropping strategies: Nitrification performance, activity, and community. *Chemosphere*, *195*, 800-809.

Chojnacka, K., Moustakas, K., & Witek-Krowiak, A. (2020). Bio-based Fertilizers: A Practical Approach Towards Circular Economy. In *Bioresource Technology* (Vol. 295). https://doi.org/10.1016/j.biortech.2019.122223

Davani-Davari, D., Negahdaripour, M., Karimzadeh, I., Seifan, M., Mohkam, M., Masoumi, S. J., Berenjian, A., & Ghasemi, Y. (2019). Prebiotics: Definition, Types, Sources, Mechanisms, and Clinical Applications. *Foods*, *8*(3), 1–27. https://doi.org/10.3390/foods8030092

de Albuquerque, T. M. R., Borges, C. W. P., Cavalcanti, M. T., Lima, M. dos S., Magnani, M., & de Souza, E. L. (2020). Potential Prebiotic Properties of Flours from Different Varieties of Sweet Potato (*Ipomoea batatas* L.) Roots Cultivated in Northeastern Brazil. *Food Bioscience*, *36*(March), 100614. https://doi.org/10.1016/j.fbio.2020.100614

De Notaris, C., Olesen, J. E., Sørensen, P., & Rasmussen, J. (2020). Input and Mineralization of Carbon and Nitrogen in Soil from Legume-Based Cover Crops. *Nutrient Cycling in Agroecosystems*, *116*(1), 1–18. https://doi.org/10.1007/s10705-019-10026-z

Delang, C. O. (2018). The Consequences of Soil Degradation in China: A Review. *GeoScape*, *12*(2), 92–103. https://doi.org/10.2478/geosc-2018-0010

DeMartino, P., & Cockburn, D. W. (2020). Resistant Starch: Impact on the Gut Microbiome and Health. *Current Opinion in Biotechnology*, *61*, 66–71. https://doi.org/10.1016/j.copbio.2019.10.008

Devi, V., & Sumathy, V. J. H. (2017). Production of Biofertilizer from Fruit Waste. *European Journal of Pharmaceutical and Medical Research,* 4(9), 436-443.

Dominchin, M. F., Verdenelli, R. A., Berger, M. G., Aoki, A., & Meriles, J. M. (2021). Impact of N-fertilization and Peanut Shell Biochar on Soil Microbial Community Structure and Enzyme Activities in a Typic Haplustoll under Different Management Practices. *European Journal of Soil Biology*, *104*(July 2020). https://doi.org/10.1016/j.ejsobi.2021.103298

Dou, Y., Yu, X., Luo, Y., Chen, B., Ma, D., & Zhu, J. (2022). Effect of Fructooligosaccharides Supplementation on the Gut Microbiota in Human: A Systematic Review and Meta-Analysis. *Nutrients*, *14*(16). https://doi.org/10.3390/nu14163298

Du, J. X., Li, Y., Ur-Rehman, S., Mukhtar, I., Yin, Z., Dong, H., Wang, H., Zhang, X., Gao, Z., Zhao, X., Xin, X., & Ding, X. (2021). Synergistically promoting plant health by harnessing synthetic microbial communities and prebiotics. *IScience*, *24*(8), 102918. https://doi.org/10.1016/j.isci.2021.102918

El-Kholy, W. M., Aamer, R. A., & Ali, A. N. A. (2020). Utilization of Inulin Extracted from Chicory (*Cichorium Intybus* L.) Roots to Improve the Properties of Low-Fat Synbiotic Yoghurt. *Annals of Agricultural Sciences*, *65*(1), 59–67. https://doi.org/10.1016/j.aoas.2020.02.002

Eubeler, J. P., Bernhard, M., & Knepper, T. P. (2010). Environmental Biodegradation of Synthetic Polymers II. Biodegradation of Different Polymer Groups. *TrAC - Trends in Analytical Chemistry*, *29*(1), 84–100. https://doi.org/10.1016/j.trac.2009.09.005

Ferreira, C. S. S., Seifollahi-Aghmiuni, S., Destouni, G., Ghajarnia, N., & Kalantari, Z. (2022). Soil degradation in the European Mediterranean region: Processes, status and consequences. *Science of the Total Environment*, *805*, 150106. https://doi.org/10.1016/j.scitotenv.2021.150106

Figueroa-González, I., Rodríguez-Serrano, G., Gómez-Ruiz, L., García-Garibay, M., & Cruz-Guerrero, A. (2019). Prebiotic Effect of Commercial Saccharides on Probiotic Bacteria Isolated from Commercial Products. *Food Science and Technology*, *39*(3), 747–753. https://doi.org/10.1590/fst.07318

Foti, P., Ballistreri, G., Timpanaro, N., Rapisarda, P., & Romeo, F. V. (2022). Prebiotic Effects of Citrus Pectic Oligosaccharides. *Natural Product Research*, *36*(12), 3173–3176. https://doi.org/10.1080/14786419.2021.1948845

Gibson, G. R., Hutkins, R., Sanders, M. E., Prescott, S. L., Reimer, R. A., Salminen, S. J., Scott, K., Stanton, C., Swanson, K. S., Cani, P. D., Verbeke, K., & Reid, G. (2017). Expert consensus document: The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of prebiotics. *Nature Reviews Gastroenterology and Hepatology*, *14*(8), 491–502. https://doi.org/10.1038/nrgastro.2017.75

Guo, K., Yang, J., Yu, N., Luo, L., & Wang, E. (2023). Biological Nitrogen Fixation in Cereal Crops: Progress, Strategies, and Perspectives. *Plant Communications*, *4*(2), 100499. https://doi.org/10.1016/j.xplc.2022.100499

Gyawali, B., Ramakrishna, K., & Dhamoon, A. S. (2019). Sepsis: The Evolution in Definition, Pathophysiology, and Management. *SAGE Open Medicine*, *7*. https://doi.org/10.1177/2050312119835043

Gyawali, R., Nwamaioha, N., Fiagbor, R., Zimmerman, T., Newman, R. H., & Ibrahim, S. A. (2019). The Role of Prebiotics in Disease Prevention and Health Promotion. In *Dietary Interventions in Gastrointestinal Diseases: Foods, Nutrients, and Dietary Supplements*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-814468-8.00012-0

Hallama, M., Pekrun, C., Lambers, H., & Kandeler, E. (2019). Hidden Miners – The Roles of Cover Crops and Soil Microorganisms in Phosphorus Cycling through Agroecosystems. *Plant and Soil*, *434*(1–2), 7–45. https://doi.org/10.1007/s11104-018-3810-7

Heger, M., Zens, G., Bangalore, M., & Heger, M. P. (2018). Does the Environment Matter for Poverty Reduction?

The Role of Soil Fertility and Vegetation Vigor in Poverty Reduction. *Does the Environment Matter for Poverty Reduction? The Role of Soil Fertility and Vegetation Vigor in Poverty Reduction*, *August*. https://doi.org/10.1596/1813-9450-8537

Hikouei, I. S., Kim, S. S., & Mishra, D. R. (2021). Machine-Learning Classification of Soil Bulk Density in Salt Marsh Environments. *Sensors*, *21*(13). https://doi.org/10.3390/s21134408

Hong, S., Piao, S., Chen, A., Liu, Y., Liu, L., Peng, S., Sardans, J., Sun, Y., Peñuelas, J., & Zeng, H. (2018). Afforestation Neutralizes Soil pH. *Nature Communications*, *9*(1), 1–7. https://doi.org/10.1038/s41467-018-02970-1

Huang, R., McGrath, S. P., Hirsch, P. R., Clark, I. M., Storkey, J., Wu, L., Zhou, J., & Liang, Y. (2019). Plant–microbe networks in soil are weakened by century-long use of inorganic fertilizers. *Microbial Biotechnology*, *12*(6), 1464–1475. https://doi.org/10.1111/1751-7915.13487

Igiehon, N. O., & Babalola, O. O. (2018). Rhizosphere microbiome modulators: contributions of nitrogen fixing bacteria towards sustainable agriculture. *International journal of environmental research and public health*, *15*(4), 574.

Jain, I., Kumar, V., & Satyanarayana, T. (2015). Xylooligosaccharides: an economical prebiotic from agroresidues and their health benefits.

Jang, J., Anderson, E. L., Venterea, R. T., Sadowsky, M. J., Rosen, C. J., Feyereisen, G. W., & Ishii, S. (2019). Denitrifying bacteria active in woodchip bioreactors at low-temperature conditions. Frontiers in Microbiology, 10, 635.

Jegadeesh, R., Lakshmanan, H., Kab-Yeul, J., Sabaratnam, V., & Raaman, N. (2018). Cultivation of Pink Oyster Mushroom Pleurotus djamor var. roseus on Various Agro-residues by Low Cost Technique. *Journal of Mycopathological Research*, *56*(3), 213–220.

Jiang, F., Du, C., Jiang, W., Wang, L., & Du, S. kui. (2020). The Preparation, Formation, Fermentability, and Applications of Resistant Starch. *International Journal of Biological Macromolecules*, *150*, 1155–1161. https://doi.org/10.1016/j.ijbiomac.2019.10.124

Jim, C. Y., & Ng, Y. Y. (2018). Porosity of Roadside Soil as Indicator of Edaphic Quality for Tree Planting. *Ecological Engineering*, *120*(June), 364–374. https://doi.org/10.1016/j.ecoleng.2018.06.016

Kang, S. M., Radhakrishnan, R., You, Y. H., Khan, A. L., Park, J. M., Lee, S. M., & Lee, I. J. (2015). Cucumber Performance is Improved by Inoculation with Plant Growth-Promoting Microorganisms. *Acta Agriculturae Scandinavica Section B: Soil and Plant Science*, *65*(1), 36–44. https://doi.org/10.1080/09064710.2014.960889

Kaur, A. P., Bhardwaj, S., Dhanjal, D. S., Nepovimova, E., Cruz-martins, N., Kuča, K., Chopra, C., Singh, R., Kumar, H., Șen, F., Kumar, V., Verma, R., & Kumar, D. (2021). Plant Prebiotics and Their Role in the Amelioration of Diseases. *Biomolecules*, *11*(3), 1–28. https://doi.org/10.3390/biom11030440

Khangwal, I., & Shukla, P. (2019). Prospecting prebiotics, innovative evaluation methods, and their health applications: a review. 3 Biotech, 9(5), 187.

Kim, H., Kim, J., Shin, S. G., Hwang, S., & Lee, C. (2016). Continuous fermentation of food waste leachate for the production of volatile fatty acids and potential as a denitrification carbon source. *Bioresource technology*, *207*, 440-445.

Kim, H. S., Titgemeyer, E. C., & Aldrich, C. G. (2023). Evaluation of Fermentability of Whole Soybeans and Soybean Oligosaccharides by a Canine In Vitro Fermentation Model. *Fermentation*, *9*(5), 1–13. https://doi.org/10.3390/fermentation9050414

Kome, G. K., Enang, R. K., Tabi, F. O., & Yerima, B. P. K. (2019). Influence of Clay Minerals on Some Soil Fertility Attributes: A Review. *Open Journal of Soil Science*, *09*(09), 155–188. https://doi.org/10.4236/ojss.2019.99010

Kong, Z., Glick, B. R., Duan, J., Ding, S., Tian, J., McConkey, B. J., & Wei, G. (2015). Effects of 1-aminocyclopropane-1-carboxylate (ACC) Deaminase-Overproducing Sinorhizobium Meliloti on Plant Growth and Copper Tolerance of *Medicago lupulina*. *Plant and Soil*, *391*(1–2), 383–398. https://doi.org/10.1007/s11104-015-2434-4

Krohn, C., Jin, J., Wood, J. L., Hayden, H. L., Kitching, M., Ryan, J., Fabijański, P., Franks, A. E., & Tang, C. (2021). Highly Decomposed Organic Carbon Mediates the Assembly of Soil Communities with Traits for the Biodegradation of Chlorinated Pollutants. *Journal of Hazardous Materials*, *404*(September 2020). https://doi.org/10.1016/j.jhazmat.2020.124077

Kumar, H., Bajpai, V. K., Dubey, R. C., Maheshwari, D. K., & Kang, S. C. (2010). Wilt Disease Management and Enhancement of Growth and Yield of *Cajanus Cajan* (L) Var. Manak by Bacterial Combinations Amended with Chemical Fertilizer. *Crop Protection*, *29*(6), 591–598. https://doi.org/10.1016/j.cropro.2010.01.002

Kumar, V., Kumar, M., Sharma, S., & Prasad, R. (2017). Probiotics and Plant Health. *Probiotics and Plant Health*, *May 2022*, 1–600. https://doi.org/10.1007/978-981-10-3473-2

Lastochkina, O., Garshina, D., Ivanov, S., Yuldashev, R., Khafizova, R., Allagulova, C., Fedorova, K., Avalbaev, A., Maslennikova, D., & Bosacchi, M. (2020). Seed Priming with Endophytic *Bacillus subtilis* Modulates Physiological Responses of Two Different *Triticum aestivum* L. Cultivars under Drought Stress. *Plants*, *9*(12), 1–20. https://doi.org/10.3390/plants9121810

Li, Y., Li, H., Han, X., Han, G., Xi, J., Liu, Y., ... & Lai, H. (2022). Actinobacterial Biofertilizer Improves the Yields of Different Plants and Alters the Assembly Processes of Rhizosphere Microbial Communities. *Applied Soil Ecology*, 171, 104345.

Lim, S. F., & Matu, S. U. (2015). Utilization of Agro-Wastes to Produce Biofertilizer. *International Journal of Energy and Environmental Engineering*, *6*(1), 31–35. https://doi.org/10.1007/s40095-014-0147-8

Lindström, K., & Mousavi, S. A. (2020). Effectiveness of Nitrogen Fixation in Rhizobia. *Microbial Biotechnology*, *13*(5), 1314–1335. https://doi.org/10.1111/1751-7915.13517

Liu, Y., Wang, Y., Zhang, L., Liu, L., Cai, T., Chang, C., Sa, D., Yin, Q., Jiang, X., Li, Y., & Lu, Q. (2023). The Effect of *Lactobacillus planturum* YQM48 Inoculation on the Quality and Microbial Community Structure of Alfalfa Silage Cultured in Saline-Alkali Soil. *Fermentation*, *9*(6). https://doi.org/10.3390/fermentation9060511

Lockyer, S., & Stanner, S. (2019). Prebiotics – An Added Benefit of Some Fibre Types. *Nutrition Bulletin*, *44*(1), 74–91. https://doi.org/10.1111/nbu.12366

Lou, Z., Sun, Y., Bian, S., Ali Baig, S., Hu, B., & Xu, X. (2017). Nutrient Conservation during Spent Mushroom Compost Application using Spent Mushroom Substrate Derived Biochar. *Chemosphere*, *169*, 23–31. https://doi.org/10.1016/j.chemosphere.2016.11.044

Lyng, M., & Kovács, Á. T. (2023). Frenemies of the Soil: *Bacillus* and *Pseudomonas* Interspecies Interactions. *Trends in Microbiology*, *31*(8), 845–857. https://doi.org/10.1016/j.tim.2023.02.003

Ma, K., Zhang, Y., Ruan, M., Guo, J., & Chai, T. (2019). Land Subsidence in a Coal Mining Area Reduced Soil Fertility and Led to Soil Degradation in Arid and Semi-Arid Regions. *International Journal of Environmental Research and Public Health*, *16*(20). https://doi.org/10.3390/ijerph16203929

Mahanty, T., Bhattacharjee, S., & Goswami, M. (2016). Biofertilizers: A Potential Approach for Sustainable Agriculture Development. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-016-8104-0

Mahmud, M. S., & Chong, K. P. (2021). Formulation of Biofertilizers from Oil Palm Empty Fruit Bunches and Plant Growth-Promoting Microbes: A Comprehensive and Novel Approach Towards Plant Health. *Journal of King Saud University-Science*, 33(8), 101647.

Martins, G. N., Ureta, M. M., Tymczyszyn, E. E., Castilho, P. C., & Gomez-Zavaglia, A. (2019). Technological Aspects of the Production of Fructo and Galacto-Oligosaccharides. Enzymatic Synthesis and Hydrolysis. *Frontiers in Nutrition*, *6*(May). https://doi.org/10.3389/fnut.2019.00078

Maximillian, J., Brusseau, M. L., Glenn, E. P., & Matthias, A. D. (2019). Pollution and Environmental Perturbations in the Global System. In *Environmental and Pollution Science* (3rd ed.). Elsevier Inc. https://doi.org/10.1016/b978-0-12-814719-1.00025-2

Mendoza-Arroyo, G. E., Chan-Bacab, M. J., Aguila-Ramírez, R. N., Ortega-Morales, B. O., Canche Solis, R. E., Chab-Ruiz, A. O., ... & Camacho-Chab, J. C. (2020). Inorganic phosphate solubilization by a novel isolated bacterial strain Enterobacter sp. ITCB-09 and its application potential as biofertilizer. *Agriculture*, *10*(9), 383.

Menendez, E., & Garcia-Fraile, P. (2017). Plant Probiotic Bacteria: Solutions to Feed the World. *AIMS Microbiology*, *3*(4), 747–748. https://doi.org/10.3934/microbiol.2017.4.747

Milić, S., Ninkov, J., Zeremski, T., Latković, D., Šeremešić, S., Radovanović, V., & Žarković, B. (2019). Soil Fertility and Phosphorus Fractions in a Calcareous Chernozem after a Long-Term Field Experiment. *Geoderma*, *339*(March 2018), 9–19. https://doi.org/10.1016/j.geoderma.2018.12.017

Moghana, A., & Sumathy, J. H. (2020). Production of Liquid Biofertilizers from Cotton Cheese Whey. International Journal of Current Research in Multidisciplinary, *5*(1), 28-34.

Msimbira, L. A., & Smith, D. L. (2020). The Roles of Plant Growth Promoting Microbes in Enhancing Plant Tolerance to Acidity and Alkalinity Stresses. *Frontiers in Sustainable Food Systems*, *4*(July), 1–14. https://doi.org/10.3389/fsufs.2020.00106

Muñoz-Rojas, M. (2018). Soil Quality Indicators: Critical Tools in Ecosystem Restoration. *Current Opinion in Environmental Science and Health*, *5*, 47–52. https://doi.org/10.1016/j.coesh.2018.04.007

Mushtaq, Z., Mushtaq, H., Faizan, S., & Parray, M. A. (2021). Microbial degradation of organic constituents for sustainable development. In *Microbiota and Biofertilizers, Vol 2: Ecofriendly Tools for Reclamation of Degraded Soil Environs* (Vol. 2). https://doi.org/10.1007/978-3-030-61010-4_5

Mutanda, T., Mokoena, M. P., Olaniran, A. O., Wilhelmi, B. S., & Whiteley, C. G. (2014). Microbial Enzymatic Production and Applications of Short-Chain Fructooligosaccharides and Inulooligosaccharides: Recent Advances and Current Perspectives. *Journal of Industrial Microbiology and Biotechnology*, *41*(6), 893–906. https://doi.org/10.1007/s10295-014-1452-1

Neina, D. (2019). The Role of Soil pH in Plant Nutrition and Soil Remediation. *Applied and Environmental Soil Science*, *2019*(3). https://doi.org/10.1155/2019/5794869

Nimnoi, P., Pongsilp, N., & Lumyong, S. (2014). Co-Inoculation of Soybean (Glycine Max) with *Actinomycetes* and *Bradyrhizobium Japonicum* Enhances Plant Growth, Nitrogenase Activity and Plant Nutrition. *Journal of Plant Nutrition*, *37*(3), 432–446. https://doi.org/10.1080/01904167.2013.864308

Nordberg Karlsson, E., Schmitz, E., Linares-Pastén, J. A., & Adlercreutz, P. (2018). Endo-xylanases as Tools for Production of Substituted Xylooligosaccharides with Prebiotic Properties. *Applied Microbiology and Biotechnology*, *102*(21), 9081–9088. https://doi.org/10.1007/s00253-018-9343-4

Palaniappan, A., Antony, U., & Emmambux, M. N. (2021). Current Status of Xylooligosaccharides: Production, Characterization, Health Benefits and Food Application. *Trends in Food Science and Technology*, *111*, 506–519. https://doi.org/10.1016/j.tifs.2021.02.047

Pandurang Gurav, P. (2018). A review on Soil Potassium Scenario in Vertisols of India. *Open Access Journal of Science*, *2*(1), 90–91. https://doi.org/10.15406/oajs.2018.02.00051

Pérez-López, E., Cela, D., Costabile, A., Mateos-Aparicio, I., & Rupérez, P. (2016). In Vitro Fermentability and Prebiotic Potential of Soyabean Okara by Human Faecal Microbiota. *British Journal of Nutrition*, *116*(6), 1116–1124. https://doi.org/10.1017/S0007114516002816

Prakamhang, J., Tittabutr, P., Boonkerd, N., Teamtisong, K., Uchiumi, T., Abe, M., & Teaumroong, N. (2015). Proposed Some Interactions at Molecular Level of PGPR Coinoculated with *Bradyrhizobium Diazoefficiens* USDA110 and *B. Japonicum* THA6 on Soybean Symbiosis and its Potential of Field Application. *Applied Soil Ecology*, *85*(did), 38–49. https://doi.org/10.1016/j.apsoil.2014.08.009

Rahimi, S., Modin, O., & Mijakovic, I. (2020). Technologies for biological removal and recovery of nitrogen from wastewater. *Biotechnology Advances*, *43*, 107570.

Rashid, A., Mir, M. R., & Hakeem, K. R. (2016). Biofertilizer use for sustainable agricultural production. Plant, Soil and Microbes: Volume 1: Implications in Crop Science, 163-180.

Redondo-Cuenca, A., García-Alonso, A., Rodríguez-Arcos, R., Castro, I., Alba, C., Miguel Rodríguez, J., & Goñi, I. (2023). Nutritional Composition of Green Asparagus (*Asparagus Officinalis* L.), Edible Part and By-Products, and Assessment of Their Effect on the Growth of Human Gut-Associated Bacteria. *Food Research International*, *163*(November 2022). https://doi.org/10.1016/j.foodres.2022.112284

Rinninella, E., Raoul, P., Cintoni, M., Franceschi, F., Miggiano, G. A. D., Gasbarrini, A., & Mele, M. C. (2019). What is the Healthy Gut Microbiota Composition? A Changing Ecosystem Across Age, Environment, Diet, and Diseases. *Microorganisms*, *7*(1). https://doi.org/10.3390/microorganisms7010014

Rosenblueth, M., Ormeño-Orrillo, E., López-López, A., Rogel, M. A., Reyes-Hernández, B. J., Martínez-Romero, J. C., Reddy, P. M., & Martínez-Romero, E. (2018). Nitrogen Fixation in Cereals. *Frontiers in Microbiology*, *9*(AUG), 1–13. https://doi.org/10.3389/fmicb.2018.01794

Sah, B. N. P., Vasiljevic, T., McKechnie, S., & Donkor, O. N. (2016). Effect of Pineapple Waste Powder on Probiotic Growth, Antioxidant and Antimutagenic Activities of Yogurt. *Journal of Food Science and Technology*, *53*(3), 1698–1708. https://doi.org/10.1007/s13197-015-2100-0

Santos, M. S., Nogueira, M. A., & Hungria, M. (2019). Microbial inoculants: reviewing the past, discussing the present and previewing an outstanding future for the use of beneficial bacteria in agriculture. *AMB Express*, *9*(1). https://doi.org/10.1186/s13568-019-0932-0

Sattar, A., Naveed, M., Ali, M., Zahir, Z. A., Nadeem, S. M., Yaseen, M., Meena, V. S., Farooq, M., Singh, R., Rahman, M., & Meena, H. N. (2019). Perspectives of Potassium Solubilizing Microbes in Sustainable Food Production System: A Review. *Applied Soil Ecology*, *133*(September), 146–159. https://doi.org/10.1016/j.apsoil.2018.09.012

Saxena, A. K., Kumar, M., Chakdar, H., Anuroopa, N., & Bagyaraj, D. J. (2020). Bacillus Species in Soil as a Natural Resource for Plant Health and Nutrition. *Journal of Applied Microbiology*, *128*(6), 1583–1594. https://doi.org/10.1111/jam.14506

Scott, K. P., Martin, J. C., Duncan, S. H., & Flint, H. J. (2014). Prebiotic Stimulation of Human Colonic Butyrate-Producing Bacteria and Bifidobacteria, In Vitro. *FEMS Microbiology Ecology*, *87*(1), 30–40. https://doi.org/10.1111/1574-6941.12186

Shie-Lih, T., Chen-Chung, K., & Ling, H. S. (2020). Recent Advance in Extraction of Prebiotics from Plants: A Review. *International Journal of Biomass and Renewables,* 9(2), 14-21.

Sneha, S., Anitha, B., Sahair, R. A., Raghu, N., Gopenath, T. S., Chandrashekrappa, G. K., & Basalingappa, M. K. (2018). Biofertilizer for crop production and soil fertility, 299-306.

Sofo, A., Ricciuti, P., Fausto, C., Mininni, A. N., Crecchio, C., Scagliola, M., Malerba, A. D., Xiloyannis, C., & Dichio, B. (2019). The Metabolic and Genetic Diversity of Soil Bacterial Communities Depends on the Soil Management System and C/N Dynamics: The Case of Sustainable and Conventional Olive Groves. *Applied Soil Ecology*, *137*(February), 21–28. https://doi.org/10.1016/j.apsoil.2018.12.022

Soua, L., Koubaa, M., Barba, F. J., Fakhfakh, J., Ghamgui, H. K., & Chaabouni, S. E. (2020). Water-Soluble Polysaccharides from Ephedra alata Stems: Structural Characterization, Functional Properties, and Antioxidant Activity. *Molecules*, *25*(9). https://doi.org/10.3390/MOLECULES25092210

Stewart, Z. P., Pierzynski, G. M., Middendorf, B. J., & Vara Prasad, P. V. (2020). Approaches to improve soil fertility in sub-Saharan Africa. *Journal of Experimental Botany*, *71*(2), 632–641. https://doi.org/10.1093/jxb/erz446

Strachel, R., Wyszkowska, J., & Baćmaga, M. (2017). The Role of Compost in Stabilizing the Microbiological and Biochemical Properties of Zinc-Stressed Soil. *Water, Air, and Soil Pollution*, *228*(9). https://doi.org/10.1007/s11270-017-3539-6

Sustr, M., Soukup, A., & Tylova, E. (2019). Potassium in Root Growth and Development. *Plants*, *8*(10). https://doi.org/10.3390/plants8100435

Tachon, S., Zhou, J., Keenan, M., Martin, R., & Marco, M. L. (2013). The Intestinal Microbiota in Aged Mice is Modulated by Dietary Resistant Starch and Correlated With Improvements in Host Responses. *FEMS Microbiology Ecology*, *83*(2), 299–309. https://doi.org/10.1111/j.1574-6941.2012.01475.x

Taiseer, M., Youssef, M. M., & Moharrm, H. A. (2014). Analysis, health benefits and applications of prebiotics: A review. Alexandria Journal of Food Science and Technology, 11(2), 25-37.

Tan, H., Chen, W., Liu, Q., Yang, G., & Li, K. (2018). Pectin Oligosaccharides Ameliorate Colon Cancer by Regulating Oxidative Stress- and Inflammation-Activated Signaling Pathways. *Frontiers in Immunology*, *9*(JUN), 1–13. https://doi.org/10.3389/fimmu.2018.01504

Teles, E. A. P., Xavier, J. F., Arcênio, F. S., Amaya, R. L., Gonçalves, J. V. S., Rouws, L. F. M., ... & Coelho, I. S. (2024). Characterization and evaluation of potential halotolerant phosphate solubilizing bacteria from Salicornia fruticosa rhizosphere. *Frontiers in Plant Science*, *14*, 1324056.

Thatoi, H., Singdevsachan, S. K., & Patra, J. K. (2018). Prebiotics and Their Production From Unconventional Raw Materials (Mushrooms). In *Therapeutic, Probiotic, and Unconventional Foods*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-814625-5.00005-4

Thomas, A., Barczak, A., & Zakhia-Rozis, N. (2022). *Sustainable food systems for food security: Need for combination of local and global approaches*. https://library.oapen.org/handle/20.500.12657/57580%0Ahttps://library.oapen.org/bitstream/handle/20.500.12657/57580/9782759235766.pdf?sequence=1

Tzounis, X., Rodriguez-Mateos, A., Vulevic, J., Gibson, G. R., Kwik-Uribe, C., & Spencer, J. P. E. (2011). Prebiotic Evaluation of Cocoa-Derived Flavanols in Healthy Humans by using a Randomized, Controlled, Double-Blind, Crossover Intervention Study. *American Journal of Clinical Nutrition*, *93*(1), 62–72. https://doi.org/10.3945/ajcn.110.000075

Vassileva, M., Flor-Peregrin, E., Malusá, E., & Vassilev, N. (2020). Towards Better Understanding of the Interactions and Efficient Application of Plant Beneficial Prebiotics, Probiotics, Postbiotics and Synbiotics. *Frontiers in Plant Science*, *11*(July), 1–5. https://doi.org/10.3389/fpls.2020.01068

Vassilev, N., & de Oliveira Mendes, G. (2018). Solid-State Fermentation and Plant-Beneficial Microorganisms. *Current Developments in Biotechnology and Bioengineering* (pp. 435-450). Elsevier.

Vazquez-Olivo, G., Gutiérrez-Grijalva, E. P., & Heredia, J. B. (2019). Prebiotic Compounds from Agro-Industrial By-Products. *Journal of Food Biochemistry*, *43*(6), 1–8. https://doi.org/10.1111/jfbc.12711

Vengadaramana, A., & Jashothan, P. T. J. (2012). Effect of Organic Fertilizers on the Water Holding Capacity of Soil in Different Terrains of Jaffna Peninsula in Sri Lanka. *Journal of Natural Product and Plant Resources,* *2012*(4), 500–503. http://scholarsresearchlibrary.com/archive.html

Wang, M., & Cheong, K. L. (2023). Preparation, structural characterisation, and bioactivities of fructans: A review. *Molecules*, *28*(4), 1613.

Wang, X., Huang, M., Yang, F., Sun, H., Zhou, X., Guo, Y., Wang, X., & Zhang, M. (2015). Rapeseed Polysaccharides as Prebiotics on Growth and Acidifying Activity of Probiotics In Vitro. *Carbohydrate Polymers*, *125*, 232–240. https://doi.org/10.1016/j.carbpol.2015.02.040

Wang, X. W., Cai, H., Liu, Y. L., Li, C. L., Wan, Y. S., Song, F. P., & Chen, W. F. (2019). Addition of organic fertilizer affects soil nitrogen availability in a salinized fluvo-aquic soil. *Environmental Pollutants and Bioavailability*, *31*(1), 331-338.

Wang, X., & Komatsu, S. (2022). The Role of Phytohormones in Plant Response to Flooding. *International Journal of Molecular Sciences*, *23*(12). https://doi.org/10.3390/ijms23126383

Wichienchot, S., Thammarutwasik, P., Jongjareonrak, A., Chansuwan, W., Hmadhlu, P., Hongpattarakere, T., ... & Ooraikul, B. (2011). Extraction and Analysis of Prebiotics from Selected Plants from Southern Thailand. Songklanakarin Journal of Science & Technology, 33(5).

Wiesmeier, M., Urbanski, L., Hobley, E., Lang, B., von Lützow, M., Marin-Spiotta, E., van Wesemael, B., Rabot, E., Ließ, M., Garcia-Franco, N., Wollschläger, U., Vogel, H. J., & Kögel-Knabner, I. (2019). Soil Organic Carbon Storage as a Key Function of Soils - A Review of Drivers and Indicators at Various Scales. *Geoderma*, *333*(November 2017), 149–162. https://doi.org/10.1016/j.geoderma.2018.07.026

Woo, S. L., & Pepe, O. (2018). Microbial consortia: Promising Probiotics as Plant Biostimulants for Sustainable Agriculture. *Frontiers in Plant Science*, *9*(2003), 7–12. https://doi.org/10.3389/fpls.2018.01801

World, T., & Group, B. (2018). *Food Security and Nutrition: Challenges for Agriculture and the Hidden Potential of Soil a Report to the G20 Agriculture Deputies Food and Agriculture Organization of the United Nations (FAO), and Organization of Economic Co-operation and Development (OEC*. www.fao.org/publications

Xavier, G. R., Jesus, E. de C., Dias, A., Coelho, M. R. R., Molina, Y. C., & Rumjanek, N. G. (2023). Contribution of Biofertilizers to Pulse Crops: From Single-Strain Inoculants to New Technologies Based on Microbiomes Strategies. *Plants*, *12*(4). https://doi.org/10.3390/plants12040954

Yi, J., Sheng, G., Suo, Z., Zhong, K., Qi, S., Dan, Z., Hui, Y., Li, P., & Lin, J. (2020). Biofertilizers with Beneficial Rhizobacteria Improved Plant Growth and Yield in Chili (*Capsicum annuum* L.). *World Journal of Microbiology and Biotechnology*, 1–12. https://doi.org/10.1007/s11274-020-02863-w

Yousfi, S., Marín, J., Parra, L., Lloret, J., & Mauri, P. V. (2021). A Rhizogenic Biostimulant Effect on Soil Fertility and Roots Growth of Turfgrass. *Agronomy*, *11*(3), 1–14. https://doi.org/10.3390/agronomy11030573

Yuan, G., Huan, W., Song, H., Lu, D., Chen, X., Wang, H., & Zhou, J. (2021). Effects of Straw Incorporation and Potassium Fertilizer on Crop Yields, Soil Organic Carbon, and Active Carbon in the Rice–Wheat System. *Soil and Tillage Research*, *209*(February), 104958. https://doi.org/10.1016/j.still.2021.104958

Zandi, P., & Schnug, E. (2022). Reactive Oxygen Species, Antioxidant Responses and Implications from a Microbial Modulation Perspective. *Biology*, *11*(2), 1–30. https://doi.org/10.3390/biology11020155

Zhang, M. Y., & Cai, J. (2023). Preparation of Branched RG-I-Rich Pectin from Red Dragon Fruit Peel and the Characterization of its Probiotic Properties. *Carbohydrate Polymers*, 299, 120144.

Zhao, Z., Mao, Y., Gao, S., Lu, C., Pan, C., & Li, X. (2023). Organic Carbon Accumulation and Aggregate Formation in Soils under Organic and Inorganic Fertilizer Management Practices in a Rice–Wheat Cropping System. *Scientific Reports*, *13*(1), 1–12. https://doi.org/10.1038/s41598-023-30541-y