JOURNAL OF SOILSCAPE AND AGRICULTURE

Volume 3, Number 2, 2025

E-ISSN: 2963-7961

Journal Homepage: http://journal.unej.ac.id/JSA

Potential Plant Growth-Promoting Microorganism (PGPM) as Biological Control Agents of Paddy in Indonesia

Mahindra Dewi Nur Aisyah[a], Trisnani Alif[b*]

[a,b] Jurusan Produksi Pertanian, Politeknik Negeri Jember, Indonesia

A R T I C L E I N F O

Article History:
Received: 13 - 01 - 2025
Accepted: 18 - 03 - 2025
Published: 17 - 05 - 2025

Keyword:
Biopesticides;
Pathogen;
Pest;
Rice;

Corresponding Author:
name author
[b]Jurusan Produksi Pertanian, Politeknik Negeri Jember
*email: trisnani@polije.ac.id

A B S T R A C T

Today, the main goal of agriculture is increasing crop yields to meet the ever-increasing human population. Climate change has increased the challenges associated with the cultivation of food crops, especially rice. It affects rice production due to the influence of biotic factors (Plant Pest Organisms) and an uncertain environment. To address this phenomenon, Plant Growth Promoting Microbial (PGPM) is considered a better alternative than using chemicals. It has been proven that Plant Growth Promoting Rhizobacteria (PGPR) and Fungi (PGPF) are effective in suppressing plant diseases and controlling pests by producing inhibitory chemicals and inducing immune responses in plants. Furthermore, PGPM increases growth and yields. As biofertilizers and biopesticides, PGPR and PGPF are considered attractive and economically viable approaches to the cultivation of rice in Indonesia. The potential for PGPM utilization is still high considering the diversity of microbes and the fact that these microbes can be found under a variety of environmental conditions. However, it is also a challenge to develop products, especially treatments to maintain the performance of the microbes that will be used

INTRODUCTION

The global human population is expected to reach 9.8 billion by 2050 and food demand for this growing population will also increase by 50% or even 56% (van Dijk et al., 2021). Based on this phenomenon, it is imperative to improve agricultural production to balance the social and economic challenges caused by population growth. The challenges become even greater when one-third of agricultural land is threatened by desertification and decreased soil fertility due to climate change factors and excessive use of high agricultural inputs (Adl, 2016). For example, decreasing rice production caused by extreme climate change conditions (uncertain rainy and dry seasons) and an increase in the attack and development of plant pest organisms (OPT) is a very serious problem in rice cultivation because it can result in failed harvests (Sudewi et al., 2020).

Plant production and protection systems using a biological approach are currently very developed (Philppot et al., 2013). This approach is based on natural practices and ecological balance to minimize the input of chemicals that have many disadvantages (Singh et al., 2016). Prospects for enriching soil with bioorganic inputs can through changing cultivation practices and manipulating plant rhizosphere using bio-inputs. Bio-inputs are biological products obtained from living organisms such as fungi, bacteria, plants, or their derivatives which can be used as biostimulants, biofertilizers, biocontrollers, biostabilizers, or inoculants for plant protection or to increase soil nutrition and fertility (de Salamone et al. al., 2019).

Microbial inoculants are becoming popularly used to improve plant health and soil fertility, to increase plant resistance to biotic and abiotic agents, and to reduce damage from pests and diseases (Singh et al., 2016). It has been proven to have an impact on plant growth and development, crop production, increasing intrinsic resistance/tolerance of plants to stress (biotic and abiotic), soil remediation. (Kazerooni, et al. 2021). Various studies also provide evidence regarding induced systemic resistance, plant innate immunity, root rhizosphere biology, antagonistic attributes of microbial communities, the impact of inoculated microbes on non-target organisms, and strengthen the facts about the benefits of microbial inoculation in soil and/or plants (Farrar et al., 2014; Reddy & Saravanan, 2013). In particular, Plant Growth Promoting Microorganisms (PGPM), including the Plant Growth Promoting Rhizobacteria (PGPR) and Fungi (PGPF) groups, can also act as an alternative for managing pests and diseases due to the harmful effects of chemical pesticides (Waghunde et al. 2016). Therefore, recently, more attention has been paid to plant growth-promoting rhizobacteria and fungi (PGPR and PGPF, respectively) to replace or supplement agricultural chemicals.

DISCUSSIONS

1. Plant Growth Promoting Microorganism (PGPM) Mechanism as Biological Control Agents

PGPM which is currently being developed consists of PGPR and PGPF. PGPR consists of a heterogeneous group of nonpathogenic bacteria colonizing roots and improving plant growth, generally found in the rhizosphere of plants. PGPRs are categorized based on their habitat into extracellular (e-PGPR-symbiotics) and intracellular (iPGPR-free-living) PGPRs (Gray and Smith 2005). ePGPR resides in the interspaces in root cortex, rhizosphere, and rhizoplane cells; whereas, iPGPR resides in the nodular structures of root cells (Figueiredo et al. 2010). ePGPR includes different bacterial genera such as Erwinia, Flavobacterium, Arthrobacter, Agrobacterium, Azotobacter, Azospirillum, Burkholderia, Bacillus, Caulobacter, Chromobacterium, Micrococcous, Pseudomonas, and Serratia (Ahemad and Kibret 2014). iPGPR includes members of the Rhizobiaceae family (such as Rhizobium, Bradyrhizobium, Allorhizobium, Mesorhizobium), Frankia species, and endophytes, and many other types of bacteria (Bhattacharyya and Jha 2012). Meanwhile, PPGF is a nonpathogenic saprophyte that has beneficial effects on plants. Currently, research on the interaction of PGPF and plants is also starting to be developed although it is not as much as PGPR. Well-known nonpathogenic fungal genera includes Aspergillus, Piriformospora, Fusarium, Penicillium, Phoma, Rhizoctonia, and Trichoderma and stimulates various beneficial plant traits for higher yields (Jaber and Enkerli 2017; Lopez and Sword 2015). Some examples of PGPFs with BCA activity include endophytes, ectomycorrhizae (EcM), arbuscular mycorrhizae (AMF), yeast, Trichoderma sp., and certain avirulent phytopathogenic strains such as Fusarium oxysporum, Cryphonectria parasitica, and Muscodor albus (Waghunde et al. 2017).

PGPM produces certain compounds that are useful as biocontrol or Biological Control Agents (BCAs) consisting of direct antagonist, indirect antagonist, and mixed mechanisms (Table 1), specifically in rice plants (Figure 1). PGP Bacteria and fungi through their respective mechanisms are able to encourage healthy plants so that several reports provide a trend of success in the production of cultivated plants. The interactions formed and the resulting benefits have been studied extensively in recent decades because these microorganisms can reduce the use of pesticides. PGPR and PGPF also protect plants from phytopathogenic microorganisms and pests (Etesami and Maheshwari 2018).

Table 1 Antagonism exhibited by biological control agents

No	Type	Mechanism
1	Direct antagonism	Parasitism (Symbiotic interaction between two phylogenetically unrelated organisms)
		Hyperparasitism (Parasites using other parasites as their host
		Commensalism (one partner benefits while other is neither benefited nor harmed)
2	Indirect antagonism	Competition (interaction harmful to both the partners)
		SAR (systemic acquired resistance)
		ISR (Induced systemic resistance)
3	Mixed path antagonism	Antibiosis, lytic enzymes production, siderophore production, organic and anorganic volatile substances

Source: Hussain et al. (2022)

Several reports have explained that the direct antagonism was carried out by PGPM in controlling pests and diseases of cultivated plants. Parasitism is a type of interaction between two organisms that are phylogenetically unrelated. For example, Trichoderma spp., has parasitic activity against various phytopathogens such as Botrytis cinerea, Rhizoctonia solani, Pythium spp., Sclerotium rolfsii, Sclerotinia sclerotiorum, and Fusarium spp. (Waghunde et al. 2016). As it is generally known, Rhizoctonia solani causes several plant diseases such as rice blight and black scab disease in potatoes, so Trichoderma spp. can potentially be used as a BCA for all these diseases (Jia et al. 2013; Rahman et al. 2014). Some other examples related to hyperparasites and mycoparasites are powdery mildew pathogens parasitized by several hyperparasites such as *Ampelomyces quisqualis*, *Acrodontium kawahiforme*, *A. alternatum*, *Cladosporium oxysporum*, and *Gliocladium virens*, and viruses causing hypovirulence in

Cryphonectria parasitica, an ascomycete causing chestnut blight. (Heydari and Pessarakli 2010; Tjamos et al. 2010).

Dominantly, BCA has a more competent nutrient uptake system than phytopathogens. One is controlling Fusarium wilt as the result of carbon competition between pathogenic and nonpathogenic F. oxysporum strains (Alabouvette et al. 2009). Fire blight, a disease transmitted by Erwinia amylovora, can be suppressed by a closely related saprophytic species, E. herbicola, which competes for nutrients on the leaf surface. PGPM producing chemical stimuli can induce persistent variations in plants thereby increasing their capacity to tolerate pathogen infection and induce systemic defense against various pathogens, known as induced resistance, which consists of 2 forms, SAR and ISR. SAR is the innate resistance capacity of plants activated upon exposure to chemical elicitors from nonpathogenic, virulent, or avirulent microbes or artificial chemical stimuli (Gozzo and Faoro 2013). Induction of SAR mediated by the accumulation of chemical stimuli such as salicylic acid (SA) is commonly released after pathogen attack. SA is the first chemical signal induceing the production of pathogenesis-related (PR) proteins, for example chitinase, β-1,3 glucanse. The PR gene encodes chitinase and β-1,3-glucanase which play an important role in reducing or preventing pathogen colonization (Sudisha et al. 2012). SAR has been proven to be able to fight several pathogens and pests. Promising results on tomato plants using several strains of B. firmus against the root-knot nematode Meloidogyne incognita (Kofold and White) (Chitwood) (Tylenchida: Heteroderidae). A serine protease (Sep1) with nematicidal activity was found to be produced by B. firmus strains (geng et al. 2016). On the other hand, experimental application of B. subtilis decreased intestinal enzyme activity and caused changes in peritrophic membranes and epithelial cells *in Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae)(Chandrasekaran et al., 2014)

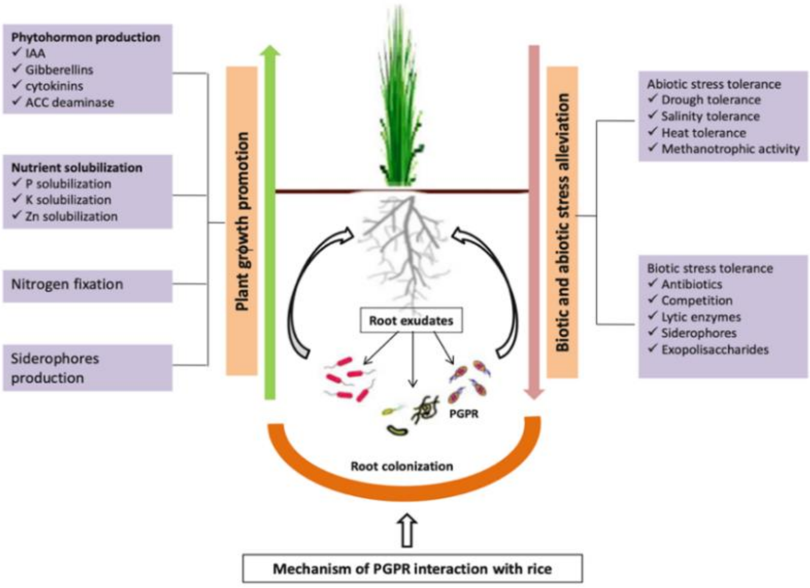

Figure 1. Mechanism of PGP interaction with rice (Hussain et al. 2022)

Meanwhile, ISR naturally exists in plants and is generally associated with stimulation by non-pathogenic rhizobacteria originating from plants (Pieterse and Van Wees 2015). ISR does not depend on the SA-mediated pathway and PR proteins are not involved. The mechanism of ISR is plant specific and depends on the plant genotype. Application of nonpathogenic PGP induces ISR facilitated by the production of phytohormones (i.e., jasmonic acid and ethylene). PGP induces ISR in several plant organs used to combat various environmental stressors. The plant defense system produces a large nhoumber of enzymes involved in plant defense, such as polyphenol oxidase, β-1, 3-glucanase, chitinase, phenylalanine ammonia lyase, peroxidase, etc. Although ISR does not directly fight specific pathogens, it plays an important role in plant defense. So the mechanism can be used to control various diseases in plants (Kamal et al. 2014). For example, ISR activity induced by the use of three bacteria as *Bacillus halotolerans*, *Massilia alkalitolerans*, and *Bacillus aryabhattai* was shown to be effective reduced the growth of *P. ultimum* and *R. solani* in tomato and maize (Abdelaziz *et al*, 2023).

This mixed mechanism, sometimes almost similar to PGPR and PGPF, induces resistance to insect pests through the synthesis of phytohormones, increases uptake of phosphorus and nitrogen, and increases solubility of iron and minerals through chelation growth. Systemic Resistance by rhizobacteria resembles systemic acquired resistance induced in pathogens including nematodes, insects, bacteria, fungi and viral pathogens (Hossain et al., 2016; Rashid and Chung, 2017)). PGPR against pest with various mode of action, such as degradation of gut epithelium gut, tissue, antimicrobial activity and toxicity, action on neuro-system, antifeeding, pathogenesis, septicaemia and cellular immunity suppression (Ruiu, 2020). Rhizobacterial inoculation also induces phytohormonal signals or regulators such as, jasmonic acid, ethylene, indole-3-acetic acid (IAA), gibberellic acid, cytokinin and 1-amino-cyclopropane-1-carboxylate (ACC) deaminase (Pieterse et al., 2014; Vejan et al., 2016; Gouda et al., 2018) that regulates plant secondary metabolite concentrations. Several strains of Bacillus and Pseudomonas are used as biofertilizer inoculants which have direct and indirect effects on insect pest resistance. And suppresses soil-borne pathogens through the production of siderophores and antimicrobial metabolites (Kennedy et al. 2014; Hussain et al, 2016). Aisyah et al. (2015) stated that plants given PGPR increased phenol content and affected instar development, feeding activity and egg laying locations of *P. xylostella.* Microbial induction in strawberry plants increases polyphenol oxidase, flavonoids and anthocyanins having a negative impact on *T. urticae* reproduction (Mouden et al. 2021).

PGPR also inhibits plant pests through the release of various volatile and diffuse metabolites (e.g., pyoluteorin and pyrrolnitrin) that are toxic to insect pests thereby reducing their populations as observed (Naaem et al. 2018). Direct mechanisms include the production of plant hormones, solubilization of phosphates, and increased uptake of iron. Indirect effects include antibiotics production, nutritional competition, parasitism, pathogen toxin inhibition, and induced resistance (Elnahal et al., 2022). In addition, PGPR helps increase phosphorus and nitrogen uptake and increases the activity of indole acetic acid which helps wheat plants absorb. In addition, PGPR can compete with other bacteria by colonizing quickly and accumulating a greater supply of nutrients, thereby preventing the growth of other organisms such as pathogens

(Salomon et al., 2017; Abd El-Mageed et al., 2020). Bacteriocins, antibacterial proteins, and enzymes are examples of antimicrobial peptides produced by PGPM that can inhibit metabolic processes or growth activities of pathogens, most of which are specific to certain strains, can target ribosomal RNA (rRNA), change membrane structure, and damage pathogen cell walls (Nazari and Smith, 2020). Furthermore, the siderophores produced by PGPM are special iron-chelating agents that inhibit phytopathogens from gaining access to iron and are also able to maintain plant health, especially in iron-deficient environments (Shen et al., 2013; Radzki et al., 2013).

2. Opportunities and Challenges in Utilizing Plant Growth Promoting Microorganism (PGPM) as Biological Control Agents for Paddy in Indonesia

In recent decades, interest in beneficial microorganisms in rice has increased due to their potential use as plant growth regulators and various pest and disease control measures (Jha and Subramanian, 2012). The results showed that all PGPRs promoted rice growth (grain yield increased by 10.50-51.30% in greenhouse conditions and 4.83-9.16% in paddy fields) and reduced As damage to rice. In particular, S10 reduced As accumulation in brown rice under greenhouse (3.50-26.01%) and paddy field (9.26-10.50%) conditions by significantly reducing the available As concentration in the rhizosphere soil, especially in Dabaoshan-B land (34.00%). In contrast, under greenhouse conditions, strains S6 and S7 increased As concentrations by 6.10-20.10% and 2.14-14.60%, respectively. Our results show that PGPR inoculation can be used to reduce As accumulation and promote rice growth in As-contaminated rice fields. However, because the impact of PGPR varies by strain and depends on environmental factors, careful selection of strains and environmental conditions as well as initial testing will be essential before applying PGPR to As-contaminated rice fields. PGPR in rice increased grain yield by 51.3% and 9.16% in greenhouse and paddy fields respectively, in arsenic-accumulating soils in China (Aw et al., 2020). The highest grain yield in both wheat varieties due to the application of PGPR may be due to better grain per stalk and productive tillers. It is well known that productive tillering and grain per stalk are important traits contributing to the outcomes resulting in better grain yield in this study.

Various PGPM research has been carried out in Indonesia, especially on rice plants (table 2) showing a positive trend. The use of PGPM needs to be massively socialized to farmers, so that farmers slowly switch to environmentally friendly cultivation. Apart from that, farmers need to be given evidence that in the long term the use of PGPM will reduce the chemical inputs currently used. Alawiyah and Cahyono (2018) stated that farmers understand that the use of biological agents will reduce the use of fertilizers and pesticides, but many farmers do not understand in detail how to apply the use of biological agents on land. Demonstration plots and FFD (Farmer Field Day) are methods that can be used to introduce the use of PGPM in plant cultivation. Rachmawatie et al. (2022) carried out sharing, direct practice, and on-farm monitoring of farmer groups that utilize *Trichoderma* sp. Continuous recognition efforts accompanied by assistance and concrete evidence in the field will change farmers' paradigm in sustainable cultivation practices.

Biological control through the use of PGPM is the most promising effort for sustainable agriculture because the agricultural pest control approach is proven to be environmentally friendly. The use of live microorganisms to reduce pest and disease populations in a conservative, reliable, and ecologically friendly manner. In developed countries, biological control is considered a sustainable, cheaper and safer way of managing pest control; thus, it benefits farmers as producers and consumers compared to synthetic (chemical) pest management (El-Saadony et al. 2022). Considering that Indonesia has high microbial biodiversity, of course, this opportunity needs to be optimized to support environmentally friendly cultivation practices, especially paddy.

Table 2. PGPM research on paddy in Indonesia

Kind of Paddy	PGPM	Treatment	Reference
Bacteria			
Beras merah	*Serratia marcencens*	Seed treatment can increase can increase chlorophyll, panicles number, tillers number, weight of 1000 seeds, yield of dry seeds harvested and reduce the intensity of leaf spot disease	Nurmala et al, 2021
Inpari Unsoed 79 Agritan	Bakteri diazotrof	Seed treatment can reduce disease intensity by up to 70%.	Isnaeni et al. 2021
IR 64, Cisantana, Inpari Unsoed 79 Agritan	Rizobakter	Seed treatment was able to induce resistance to *Xanthomonas oryzae* pv. Oryzae and can increase growth and crop yields	Khaeruni et al. 2014
LokaL Kamba	*Bacillus* sp	Seed treatment can increase the number of productive tillers, the number of grains per panicle, and the total number of grains.	Sudewi, 2020.
Inpari 42	*Bacillus amyloliquefaciens*		
Ciherang	*Kombinasi Pseodomonas aruginosa* dan *Bacillus cereus*	Spraying plants every afternoon can increase grain weight and resistance to blast disease (*Pyricularia grisea*) attacks	Jannah, 2016
IPB 3S	*Bacillus polumixa* dan *Pseudomonas fluorescens*	Soaking seeds for 12 hours can reduce fungal infections and increase rice seed germination	Andini dan Tondok, 2020
Fungi			

Inpari 13	Mikoriza	Applied to planting media, it can increase plant height, number of panicles, and plant carbohydrate levels.	Mustaqimah, et al. 2019
-	*Trichoderma* sp.	Soaking seeds and spraying can reduce the severity of blast disease in rice, increase plant height, number of tillers and grain weight.	Hidayat, et al. 2014 Yanti, et al. 2021,
Kuriak Kusuik	*Trichoderma spp*	Soaking seeds can increase the seed vigor index.	Aldo dan Anhar, 2021
Ciherang	*Nigrospora* sp	Soaking seeds and spraying plants can reduce the severity of leaf blast disease	Hariyanti, et al. 2022
Ciherang	*Aspergillus niger, Penicillium sp,* dan *Trichoderma viridae*	Mycelium mixed into the planting medium can increase the growth of rice plants in saline soil	Subowo, 2015
Beras merah	*Aspergillus niger* dan *Aspergillus oruzae*	Can increase germination capacity, resist water stress and increase production.	Yustisia, 2020
PAK-TIWI 1	*Monosporium* sp, *Curvularia sp* dan *Nigrospora* sp	Soaking seeds can increase the physiological activity of plants and can increase the production of the hormone IAA.	Rachmawati, 2022
Padi	*Bauveria bassiana*	Increases mortality of brown planthoppers	Aristyawan et. al. 2020

Apart from that, there are various challenges in applying PGPM as a pest and disease control agent. Successful colonization of root tissue and/or rhizosphere is an important component for PGPM to become an effective BCA. However, the performance of inoculated PGPM can vary, depending on survival rates in the soil, plant compatibility, interactions with other local microbial species, and environmental factors (Vejan et al., 2016). PGPR performance is generally assessed based on geographic region, soil type, species host plants, and various environmental conditions (El-Saadony et al. 2022). In addition, in vitro PGPM testing is important to carry out before trials in the greenhouse and/or field (Bashan et al., 2014). This testing stage will guarantee the suitability of PGPM for increasing production, managing pests, diseases, and resilience to climate change conditions.

Furthermore, PGPM stability is also influenced by various technical factors such as method, formulation, transportation, and storage conditions. To achieve the survival rate of PGPM as

BCA, it is necessary to have the formulation technology used and the shelf life of the microbes measured and optimize the production of the targeted microbial types, and if it has already been in the large-scale production stage, the costs required are not too expensive (Lobo et al., 2019; Carrasco-Espinosa et al., 2015; Zhang et al., 2019) (Kang et al., 2017). Due to the variety of factors influencing PGPM performance, time and academic-industry collaboration is needed to ensure its usefulness.

CONCLUSIONS

Plant Growth Promoting Microbial (PGPM) is considered capable of increasing rice production amidst uncertain climate conditions and excessive use of pesticides. Plant Growth Promoting Rhizobacteria (PGPR) and Fungi (PGPF) have been proven effective in suppressing plant diseases and controlling pests and pathogens with various mechanisms and inducing immune responses in plants. As biofertilizers and biopesticides, PGPR and PGPF are considered an attractive and economically viable approach to support sustainable agriculture.

ACKNOWLEDGEMENTS

Thank you to Yam Saroh, P.hD who was the Proofread on our article

REFERENCES

Abdelaziz, S., Belal, E.E., Al-Quwaie, D.A., Ashkan, M.F., Alqahtani, F.S.,· Khaled El-Tarabily, A., El-Mageed,. T.A., Shami, A., Nader, M.M., and Hemeda, N.F. 2023. Extremophilic bacterial strains as plant growth promoters and biocontrol agents against *Pythium ultimum* and *Rhizocotnia solani*. *Journal of Plant Pathology*. 105(4): 1347 – 1369

Abd El-Mageed, T. A., Rady, M. M., Taha, R. S., Abd El Azeam, S., Simpson, C. R., and Semida, W. M. (2020). Effects of integrated use of residual sulfur-enhanced biochar with effective microorganisms on soil properties, plant growth and short- term productivity of *Capsicum annuum* under salt stress. *Sci. Hortic.* 261:108930. doi: 10.1016/j.scienta.2019.108930

Adl, S., M. (2016). Rhizosphere, Food Security, and Climate Change: A Critical Role for Plant-Soil Research. Rhizosphere 1(1), 1–3. DOI. 10.1016/j.rhisph.2016.08.005

Aisyah, M., D., N. HagusTarno, B., T. Rahardjo. (2015). Respon Ulat Kubis *Plutella xylostella* Linn (Lepidoptera: Plutellidae) Setelah Aplikasi Plant Growth Promoting Rhizobacteria (PGPR) pada Tanaman Kailan (*Brassica Oleracea* Var. Alboglabra L). Jurnal Hama dan Penyakit Tumbuhan, 3 (3): 96-105. [Indonesian]

Ahemad M. and M. Kibret. (2014). Mechanisms and Applications of Plant Growth Promoting Rhizobacteria: Current Perspective. J King Saud Univ-Sci, 26(1):1–20

Alabouvette,C., Raaijmakers, J. M, Paulitz, T. C, Steinberg, C, Moënne-Loccoz Y .2009. The rhizosphere: a playground and battlefield for soilborne pathogens and beneficial microorganisms. Plant Soil. 5 (21) :56-88.

Alawiyah F., M. dan E. D., Cahyono. (2018). Persepsi Petani Terhadap Introduksi Inovasi Agen Hayati Melalui Kombinasi Media Demplot dan FFD. Jurnal Ekonomi Pertanian dan Agribisnis (JEPA), 2 91): 19-28 [Indonesian]

Aldo, W. and A. Anhar. (2021). The response of Isolates *Trichoderma* spp. on vigor index of local rice seeds varities Kuriak kusuik. *In Proceedings of the national conference on Biology*, Padang, 14 December, pp. 1547-1551

Andini, D., and E. T., Tondok. (2020). Perlakuan Air Panas dan *Plant Growt Promoting Rhizobacteria* untuk menekan Cendawan Terbawa Benih pada Padi Varietas IPB-3S. Jurnal Fitopatologi Indonesia, 16(6):235-242. [Indonesian]

Anggraeni, F., Isnaeni, dan A. T. Poernomo. 2016. Pengaruh konsentrasi molase terhadap aktivitas enzim fibrinolitik dari Bacillus subtilis ATCC 6633. Berskala Ilmiah Kimia Farmasi. 5(1): 18-24. [Indonesian]

Aristyawan T, Muchtar R, Meidiantie D. 2020. Pengaruh agen hayati terhadap wereng batang cokelat (*Nillavarpata lugens Stall*) Pada tanaman padi. Jurnal Ilmiah Respati. 11:69-79

Arystiawan, T., R. Muchtar, and D. Meidiantie. (2020). Pengaruh Agen Hayati terhadap Wereng Batang Cokelat (*Nillavarpata lugens* Stall) pada Tanaman Padi. Jurnal Ilmiah Respati, 11 (1). [Indonesian]

Bashan Y, L. E., de Bashan., S. R., Prabhu and J. P., Hernandez. (2014). Advances in plant Growth-Promoting Bacterial Inoculant Technology: Formulations and Practical Perspectives (1998–2013). Plant Soil, 378: 1–33. DOI: 10.1007/s11104-013-1956-x

Bhattacharyya P. N., D. K., Jha. (2012). Plant Growth-Promoting Rhizobacteria (PGPR): Emergence in Agriculture. World J Microbiol Biotechnol, 28(4):1327–1350

Bowen G. D, A. D., Rovira. (1999). The rhizosphere and its management to improve plant growth. Adv Agron, 66:1–102.

Zhang -Espinosa K., R. I., García-Cabrera, A. Bedoya-López, M. A., Trujillo-Roldán, and N. A., Valdez-Cruz. (2015). Positive Effect of Reduced Aeration Rate on Growth and Stereospecificity Of Dl-Malic Acid Consumption by *Azospirillum brasilense*: improving The Shelf Life Of A Liquid Inoculant Formulation. J. Biotechnol, 195: 74–81. DOI: 10.1016/j.jbiotec.2014.12.020

Chandrasekaran, R.; Revathi, K.; Thanigaivel, A.; Kirubakaran, S.A.; Senthil-Nathan, S. 2014. *Bacillus subtilis* chitinase identified by matrix-assisted laser desorption/ionization time-of flight/time of flight mass spectrometry has insecticidal activity against *Spodoptera litura* Fab. Pestic. Biochem. Physiol, 116: 1–12.

de Salamone I. E. G., R. Esquivel-Cote, D. J Hernández-Melchor, A. Alarcón, D. P Singh, V. K Gupta, and R. Prabha. (2019). Manufacturing and Quality Control 2 of Inoculants from the paradigm of circular agriculture. In *Microbial Interventions in Agriculture and Environment: Vol. 2: Rhizosphere, Microbiome, and Agro-ecology* (pp. 37–74). Springer.

Farrar K., D. Bryant, and N. Cope-Selby. (2014). Understanding and Engineering Beneficial Plant-Microbe Interactions: Plant Growth Promotion in Energy Crops. Plant Biotechnol J, 12(9): 1193–1206. DOI: 10.1111/pbi.12279

El-Saadony M.T, A. M Saad, S. M Soliman, H. M Salem, A. I Ahmed, M. Mahmood, A. M El-Tahan, A. A., M Ebrahim, T. A Abd El-Mageed, S. H Negm, S. Selim, A. O Babalghith, A. S Elrys, K. A El-Tarabily and S. F AbuQamar. (2022). Plant Growth- Promoting Microorganisms as Biocontrol Agents of Plant Diseases: Mechanisms, Challenges and Future Perspectives. Front Plant Sci, 13: 923880. DOI: 10.3389/fpls.2022.923880

Elnahal, A. S., El-Saadony, M. T., Saad, A. M., Desoky, E. S. M., El-Tahan, A. M., Rady, M. M., et al. (2022). The Use of Microbial Inoculants For Biological Control, Plant Growth Promotion, And Sustainable Agriculture: A Review. Eur. *J. Plant Pathol*. 162: 759–792. doi: 10.1007/s10658-021-02393-7

Etesami H., D. K Maheshwari. (2018). Use Of Plant Growth Promoting Rhizobacteria (PGPRs) With Multiple Plant Growth Promoting Traits In Stress Agriculture: Action Mechanisms And Future Pros- Pects. *Ecotoxicol Environ Saf*, 156:225–246

Figueiredo MDVB, Seldin L, de Araujo FF et al. 2010. Plant growth promoting rhizobacteria: fundamentals and applications. In: Maheshwari DK (ed) Plant growth and health promoting bacteria. Springer, Berlin/Heidelberg, pp 21–43

Gozzo, F. and Faoro, F. 2013. Systemic acquired resistance (50 years after discovery): moving from the lab to the field. *J Agric Food Chem*, 26;61(51):12473-91

Geng, C.; Nie, X.; Tang, Z.; Zhang, Y.; Lin, J.; Sun, M.; Peng, D. (2016). A novel serine protease, Sep1, from Bacillus firmus DS-1 has nematicidal activity and degrades multiple intestinal-associated nematode proteins. *Sci. Re*p. 6, 25012

Gouda S., Kerry R. G., Das G., Paramithiotis S., Shin H. -S., Patra J. K. (2018). Revitalization of plant growth promoting rhizobacteria for sustainable development in agriculture. *Microbiol. Res.* 206, 131–140. DOI: 10.1016/j.micres.2017.08.016

Gray E.J, D. L Smith. (2005). Intracellular and Extracellular PGPR: commonalities And Distinctions in The Plant-Bacterium Signaling Processes. Soil Biol Biochem, 37(3):395–412

Hariyanti D. P, Giyanto, S. Wiyono, and Widodo. (2022). Penekanan Penyakit Blas Pada Tanaman Padi melalui Perlakuan Cendawan Endofit *Nigrospora* sp. Jurnal Fitopatologi Indonesia, 18(5):195-204. [Indonesian]

Heydari, A. and M. Pessarakli. 2010. A Review on Biological Control of Fungal Plant Pathogens using Microbial Antagonists. Journal of Biological Sciences 10: 273-290.

Hidayat, Y.S., M Nurdin, and R. D Suskandini. (2014). Penggunaan *Trichoderma* sp. sebagai Agensia Pengendalian *Pyricularia oryzae* Cav. Penyebab Blas Padi. J Agrotek Tropika, 2(3):414-419. [Indonesian].

Hussain M., A. Zsgher, M. Tahir, et al. (2016). Bacteria in Combination With Fertilizers Improve Growth, Productivity and Net Returns of Wheat (*Triticum aestivum* L.). Pak J Agric Sci, 53:633–645.

Hossain MT, Khan A, Chung EJ, Rashid MH, Chung YR (2016) Biological control of rice bakanae by an endophytic *Bacillus oryzicola* YC7007. Plant Pathol J 32:228–241. DOI: 10.5423/PPJ.OA.10.2015.0218

Jaber L. R., and S. E Araj. (2017). Interactions among Endophytic Fungal Entomopathogens (Ascomycota: Hypocreales), the Green Peach Aphid *Myzus persicae* Sulzer (Homoptera: Aphididae), and the Aphid Endoparasitoid *Aphidius colemani* Viereck (Hymenoptera: Braconidae). Biol Control, 116:53–61

Jannah, R. (2016). Pengaruh Aplikasi Bakteri *Bacillus cereus* dan *Pseudomonas aeruginosa* terhadap Produktivitas Tanaman Padi Yang Terinfeksi Penyakit Blas Sebagai Referensi Mata Kuliah Mikrobiologi. P.hD. Universitas Islam Negeri Ar-Raniry, Aceh. [Indonesian

Jha, Y and Subramanian, R.B. 2012. PGPR regulate caspase-like activity, programmed cell death, and antioxidant enzyme activity in paddy under salinity. Physiol Mol Biol Plants. 20(2): 201–207.

Kang S.W., M. S Rahman, A. N Kim, K. Y Lee, C. Y Park, W. L Kerr, et al. (2017). Comparative study of The Quality Characteristics of Defatted Soy Flour Treated by Supercritical Carbon Dioxide and Organic Solvent. J. Food Sci Technol, 54, 2485–2493. DOI: 10.1007/s13197-017-2691-8

Kamal R, Y. S Gusain, V. Kumar. (2014). Interaction and Symbiosis of AM Fungi, actinomycetes And Plant Growth Promoting Rhizobacteria with Plants: Strategies for The Improvement of Plants Health and Defense System. Int J Curr Microbiol Appl Sci , 3: 564–585

Kazeeroni, E.A, Sajeewa, S.N.M., Arjun, A., Abdullah M.A., Sang-Mo K., Lee-Rang K., and In-Jung L. 2021. Rhizospheric *Bacillus amyloliquefaciens* Protects *Capsicum annuum* cv. *Geumsugangsan* From Multiple Abiotic Stresses via Multifarious Plant Growth-Promoting Attributes. Front Plant Sci. DOI: 10.3389/fpls.2021.669693.

Kennedy I. R., A. Choudhury, M. L Kecskés. (2014). Non-symbiotic Bacterial Diazotrophs in Crop-Farming Systems: Can Their Potential for Plant Growth Promotion Be Better Exploited?. Soil Biol Biochem, 36:1229–1244.

Lobo C. B., M. S Juárez Tomás, E Viruel, M. A Ferrero, and M. E Lucca. (2019). Development of Low-Cost Formulations of Plant Growth-Promoting Bacteria To Be Used As Inoculants In Beneficial Agricultural Technologies. Microbiol Res, 219: 12–25. DOI 10.1016/j.micres.2018.10.012

Lopez, D. C., Sword GA. (2015). The endophytic fungal entomopathogens *Beauveria bassiana* and *Purpureocillium lilacinum* enhance the growth of cultivated cotton (*Gossypium hirsutum*) and negatively affect survival of the cotton bollworm (*Helicoverpa zea*). Biol Control 89:53–60

Mouden S, J. A Bac-Molenaar, I. F Kappers, E. A. M Beerling, and K. A Leiss. (2021). Elicitor application In Strawberry Results in Long-Term Increase of Plant Resilience Without Yield Loss. Front Plant Sci, 12:1321. DOI: 10.3389/fpls.2021. 695908

Mustqimah N. M., S. Nurhartika, and A. Muhibuddin. (2019). Pengaruh Waktu inokulasi Mikoriza Arbuskular Pada Campuran Media Tanam AMB-07 dan Pasir pantai terhadap Pertumbuhan Dan Karbohidrat Padi (*Oryza sativa* L.) Var. Inpari 13. Jurnal Sains dan Seni, 8(2):49-53. [Indonesian]

Nazari, M., and Smith, L.Donald. 2020. A PGPR-Produced Bacteriocin for Sustainable Agriculture: A Review Thuricin 17 Characteristic and Applications. *Frontiers in Plant Science*. 11:1-7

Nurmala C. S., I. M Sudana, and I. D. P Singarsa. (2021). Pengaruh Jenis Bakteri PGPR dalam beberapa Jenis Media Pembawa untuk Meningkakan Pertumbuhan dan Ketahanan Tanaman Padi Beras Merah Lokal Jatiluwih terhadap Penyakit. Jurnal Agroekoteknologi Tropika, 10(1):233-243. [Indonesian]

Pieterse C. M. J., and S. C. M Van Wees. (2015). Induced Disease Resistance. In: Lugtenberg B (ed) Principles of plant-Microbe Interactions: Microbes for Sustainable Agriculture. Springer, Cham, pp 123–134

Pieterse C. M. J., C. Zamioudis, R. L Berendsen, D. M Weller, S. C. M. V Wees, andP. A. H. M Bakker. (2014). Induced Systemic Resistance by Beneficial Microbes. Annu Rev Phytopathol, 52: 347–375. DOI: 10.1146/annurev-phyto- 082712-102340

Philppot L, J. M Raaijmakers, P. Lemanceau, and W. H van der Putten. (2013). Going back to the roots: The microbial ecology of the rhizosphere. Nat Rev Microbiol, 11: 789–799. DOI: 10.1038/nrmicro3109

Rachmawati, F. (2022). Efektivitas Cendawan Endofit Penginduksi Ketahanan padi terhadap Alelopati. P.hD. Jember, Universitas Negeri Jember. [Indonesian]

Rashid MH, Khan A, Hossain MT, Chung YR (2017) Induction of systemic resistance against aphids by endophytic *Bacillus velezensis* YC7010 via expressing PHYTOALEXIN DEFICIENT4 in *Arabidopsis.* Front Plant Sci. 8:211. DOI: 10.3389/fpls.2017.00211

Radzki, W., Gutierrez Mañero, F., Algar, E., Lucas, J., García, J. A., García-Villaraco, A., et al. (2013). Bacterial siderophores efficiently provide iron to iron-starved tomato plants in hydroponics culture. Antonie Van Leeuwenhoe*k*, 104: 321–330. doi: 10.1007/s10482-013-9954-9

Reddy C. A., and R. Saravanan. 2013. Polymicrobial Multi-Functional Approach For Enhance-Ment Of Crop Productivity. Adv Appl Microbiol, 82: 53–113. DOI: 10.1016/B978-0-12-407679-2.00003-X

Ruiu, L. (2020). Plant-Growth-Promoting Bacteria (PGPB) against Insects and Other Agricultural Pests. Agronomy, 10, 861; DOI:10.3390/agronomy10060861

Singh J. S., A. N Kumar, A. Rai, and D. P Singh. (2016). Cyanobacteria: A Precious Bio-Resource In Agriculture, Ecosystem, And Environmental Sustainability. Frontiers in Microbiol, 7(529): 1–19. DOI: 10.3389/fmicb.2016.00529

Sudewi S., A. Ala, Baharuddin, and M. Farid. (2020). Keragaman Organisme Pengganggu Tanaman (OPT) pada Tanaman Padi Varietas Unggul Baru (VUB) dan varietas lokal pada percobaan semi lapangan. Jurnal Agrikultura, 31(1): 15–24. [Indonesian]

van Dijk M., T. Morley, M. L Rau, and Yashar. (2021). A meta-Analysis of Projected Global Food Demand and Population at Risk Of Hunger For The Period 2010–2050.

Subowo Y. B,. (2015). Penambahan pupk hayati jamur sebgai pendukung pertumbuhan tanaman padi (*Oryza sativa*) pada tanah salin. In Proceedings of the national conference on Biodiversitas Indonesian, pp.150-154.

Sudewi, S. (2020). PGPR (Plant Growth Promotion Rhizobacteria) Asal Padi Lokal Aromatik Sulawesi Tengah: Karakterisasi dan potensinya untuk memacu pertumbuhan dan produktivitas padi. M. Sc. Makassar: Universitas Hasanuddin [Indonesian]

Salomon, M. V., Funes Pinter, I., Piccoli, P., and Bottini, R. (2017). “Use of plant growth-promoting rhizobacteria as biocontrol agents: induced systemic resistance against biotic stress in plants,” in *Microbial applications: Biomedicine, agriculture and industry*. ed. V. C. Kalia (Cham: Springer International Publishing), 133–152. DOI: 10.1007/978-3-319-52669-0_7

Shen, X., Hu, H., Peng, H., Wang, W., and Zhang, X. (2013). Comparative genomic analysis of four representative plant growth-promoting rhizobacteria in *Pseudomonas*. BMC Genomics 14:271. DOI: 10.1186/1471-2164-14-271

Tjamos, S. E, Flemetakis, E, Paplomatas, E. J, Katinakis, P. 2010. Induction of resistance to Verticillium dahliae in Arabidopsis thaliana by the biocontrol agent K-165 and pathogenesis-related proteins gene expression. Molecular Plant-Microbe Interactions, 18(6), 555-561.

Vejan P., R. Abdullah, T. Khadiran, S. Ismail, and B. A Nasrulhaq. (2016). Role of Plant Growth Promoting Rhizobacteria in Agricultural Sustainability: A Review. Molecules , 21:573. DOI: 10.3390/molecules21050573

Waghunde R. R., R. M Shelake, A. N Sabalpara. (2016). *Trichoderma*: A Significant Fungus For Agriculture and Environment. Afr J Agric Res, 11:1952–1965

Yanti Y, H. Hamid, N. Hermeria, and M. P Tanjung. (2021). Penggunaan *Trichoderma* Spp. untuk Pengendalian Penyakit dan Peningkatan Pertumbuhan Tanaman Cabai Di Nagari Taeh Baruah Kecamatan Payakumbuh Kabupaten Limapuluh Kota. Jurnal Hilirisasi Ipteks, 4(4):187-196. [Indonesian]

Yogaswaea, Y., R. Suharjo, R. Suskandini, and C. Ginting. (2020). Kemampuan Isolat jamur *Trichoderma* spp. sebagai antagonis. J Agrotek Tropika, 8(2): 235-246

Yustisia, D. (2020). Eksplorasi Cendawan Endofit Padi Lokal Sinjai Dan Potensinya Sebagai Pemacu Pertumbuhan Tanaman Padi (*Oryza sativa* L.). P.hD. Universitas Hasanuddin, Makasar. [Indonesian]

Zhang H., Y. Liu, and G. Wang. (2019). Integrated Use Of Maize Bran Residue For One-Step Phosphate Bio-Fertilizer Production. Appl Biochem Biotechnol, 187: 1475–1487. DOI: 10.1007/s12010-018-2874-4

Yanti, Y., Hamid, H., Nurbailis, Hermeria, N., and Tanjung, M.T. 2021. Utolization of Trichoderma sp as Disease Control and Increasing Production of Rice Plaant in Nagari Simabur, Pariangan,Tanah datar. *Jurnal Hilirisasi* IPTEKS. 4(4). 187-196