

Rrhizobacterial Novel Approach for Waste Rice Bran Management in Farmers' Fields

Aashish Kashyap¹, Dr. Vijay Kumar²

¹Student, University Institute of Biotechnology, Chandigarh University, Gharuan (Punjab), India

²Assistant professor, University Institute of Biotechnology, Chandigarh University, Gharuan (Punjab), India

Abstract: *The primary challenge in sustainable agriculture is the management of rice bran, a significant by-product of rice cultivation. Rice bran, which contains high concentrations of proteins, lipids, and fibers, presents both an opportunity and challenge for agricultural waste management. Conventional disposal and utilization methods do not adequately address the environmental and economic requirements of rice bran. In this review, we propose the application of rhizobacterial agents as a novel approach to their management in rice fields. Since the emergence of soil-grown plants, rhizobacteria have been demonstrated to be valuable components of beneficial interactions between these microorganisms and plant roots, rendering them promising tools for improving waste management practices. These bacteria actively contribute to the maintenance of soil fertility through nitrogen fixation, plant growth promotion, and the biocontrol of plant pathogens. Their role in the decomposition of agricultural waste may offer distinct advantages for rice bran management. The composition, behavior in soil, and limitations of traditional waste management methods, such as landfill disposal and direct incineration of rice bran, were examined.*

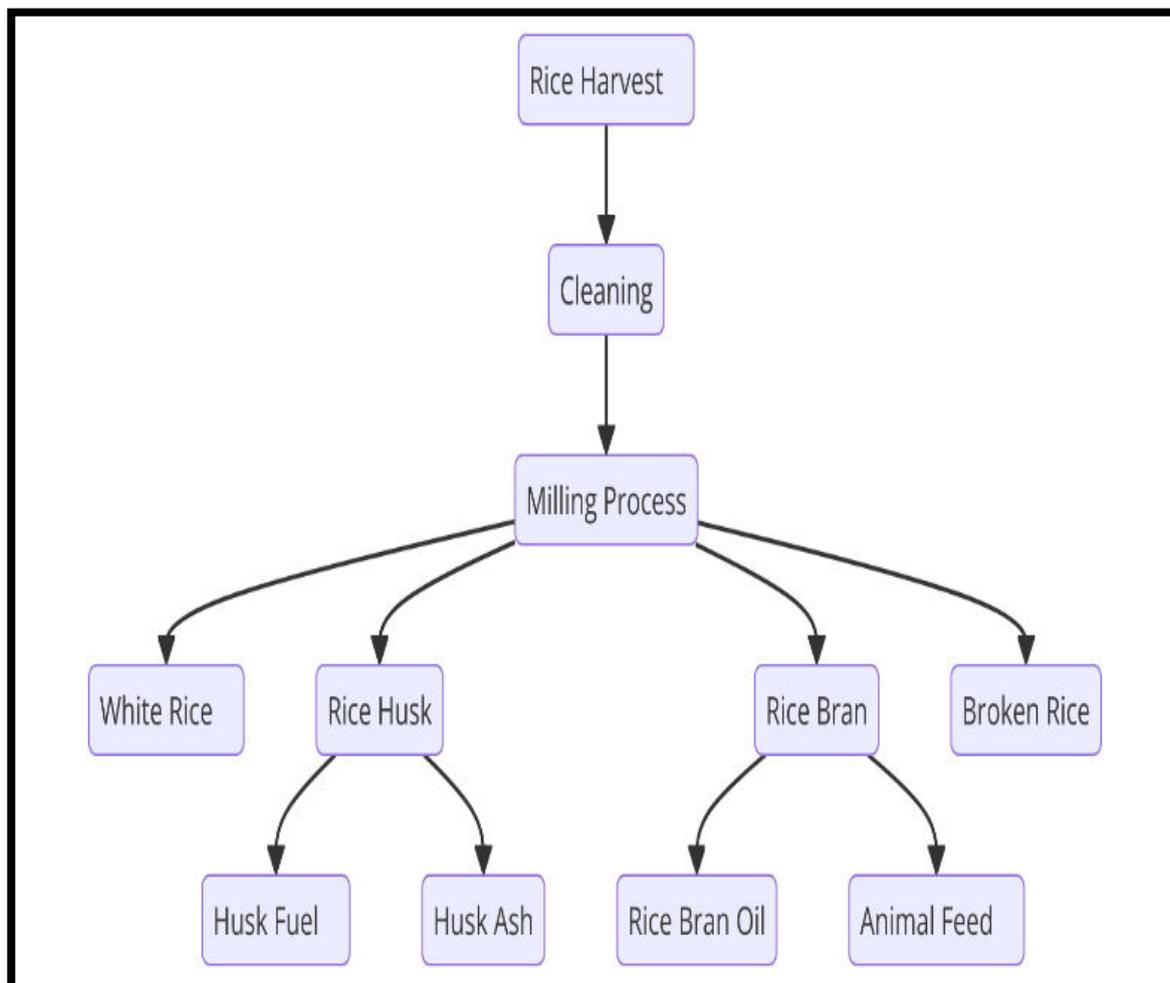
Keywords: *Rhizobacteria, Rice Bran Management, Sustainable Agriculture, Plant Growth Promotion, Waste Management*

1. Introduction

Rice is the second most widely grown crop in the world and is a staple food for more than half of the global population (Samal et al., 2022). Rice Bran is one of the most important byproducts of rice production (Tan et al., 2020). Rice bran, which accounts for approximately 10% of the total excess fat mass of brown rice in regular milling techniques, is the outer layer of the brown rice kernel (Sharif et al., 2014). It is also packed with protein, fat, and dietary fiber (not to forget antioxidants and vitamins in the case of seafood and free-ranging insects) (Ryan, 2011). Rice bran is often considered a waste owing to its short shelf life after milling, mainly due to lipase enzyme activity, which leads to rancidity (Houston, 1972). Rice bran is commonly wasted or underused in the agricultural systems of several developing nations, which indicates poor

management of this resource. In addition, cultivation practices involve the disposal of rice bran as manure in fields and lead to environmental problems such as soil acidification (and references therein) and high greenhouse gas emissions, including methane (Chauhan and Johnson, 2010). However, in recent years, interest in developing sustainable solutions for rice bran waste management has increased. The environmental and economic advantages of valorization of rice bran are known (Sharif et al., 2014), and several studies have been conducted in these fields. (Vejan et al., 2016).

The disposal and utilization of rice bran poses many challenges for farmers. One of the major challenges is the rapid deterioration of rice bran because it contains a relatively high fat content, which causes liberation through hydrolysis to form free fatty acids that could result only in rancidity (Ramezanzadeh et al., 1999). This makes rice bran unsuitable for long-term use and limits its application in animal feed (Oliveira et al., 2011). Additionally, rice bran is dumped in fields or allowed to decompose, causing environmental problems, including soil deterioration and greenhouse gas release (Nidhishree et al., 2024). These environmental consequences are mostly in rice-producing areas, where significant amounts of rice bran are generated annually.

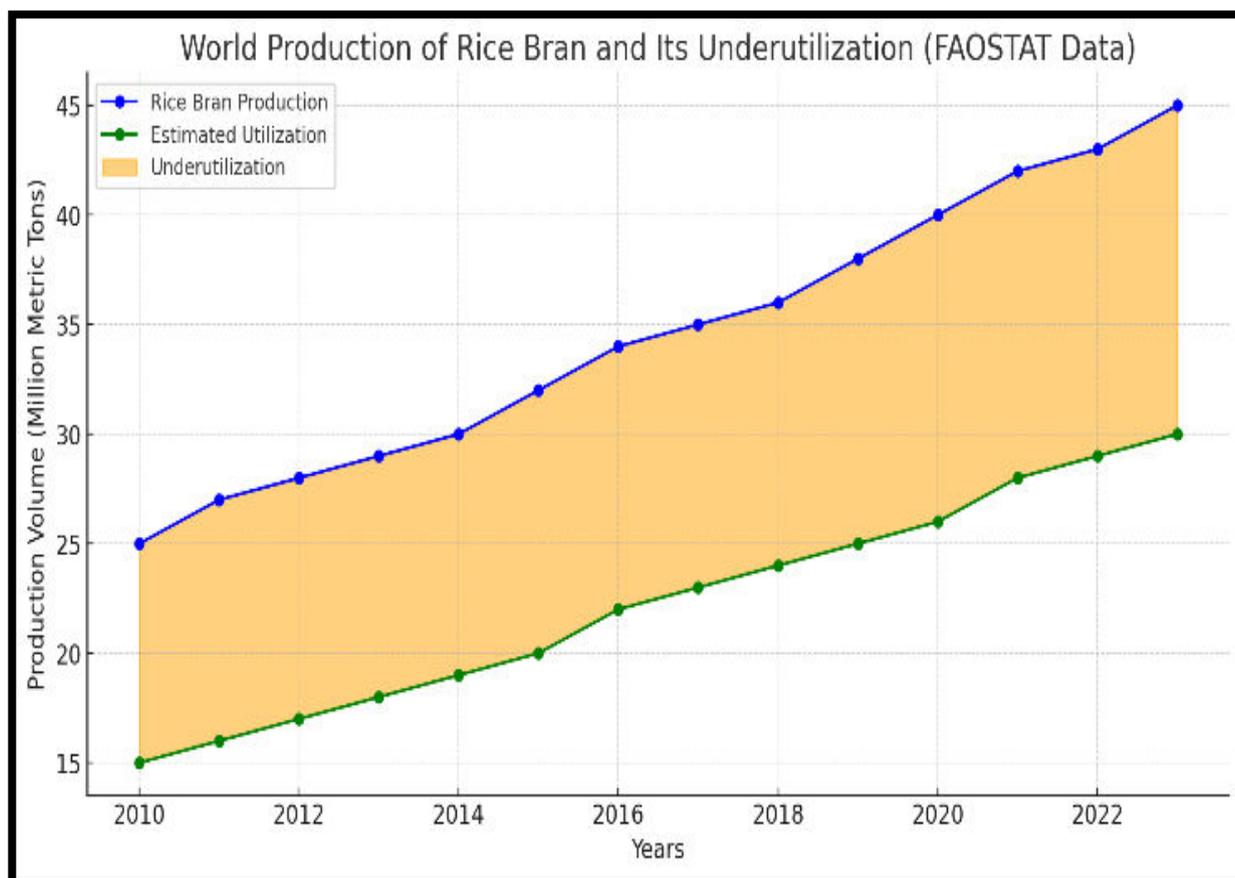


(Fig 1). Manufacturing rice and its derivatives.

The purpose of this review is to discuss innovative rhizobacterial strategies for waste rice bran management in agricultural fields (Vessey, 2003). These microorganisms have been used in different agricultural applications to enhance nutrient cycling, reduce soil

pathogens, and enhance crop yields (Lugtenberg and Kamilova, 2009). Interestingly, the use of rhizobacteria in rice bran waste management is a novel concept. Preliminary research suggests that a few rhizobacterial lines can degrade rice bran and hence can convert it to nutritionally beneficial soil, while also reducing the negative environmental aspects of the material.

Plant growth-promoting bacteria (PGPB) are rhizobacteria discovered within the rhizosphere that have been used as a contemporary approach to natural waste management in agriculture (Singh et al., 2011). They are interacting with the roots of plants and have crucial features in nutrient biking, natural count range decomposition, and improving soil fertility (Richardson and Simpson, 2011). Some rhizobacteria strains are known to degrade complex organic substances such as rice bran into simple compounds that can be more easily assimilated by plants (Singh and Jha, 2016). The use of rhizobacteria to handle rice bran waste is primarily based on their enzymatic potential to degrade the natural content of rice bran, including lipids, proteins, and carbohydrates (Ahmad et al., 2008). Bacteria also reduce waste from rice bran, serving as decomposers that convert it into valuable nutrients, which in turn can increase soil health and support plant growth (Saharan and Nehra, 2011). These microorganisms are especially good in liberating essential nutrients along with nitrogen, phosphorus, and potassium from organic waste, therefore decreasing the requirement for chemical fertilizers (Adesemoye et al., 2009). Studies have known that rhizobacterial can enhance the biodegradation of rice bran and inhibitory its hazardous environmental affects & make it secure vitamins deliver for crops (Nevita et al., 2018). Additionally, Wonderful strains of rhizobacteria have been observed to suppress the inhabitants of pathogenic organisms in soil thereby lowering up-coming outbreaks of disorder in vegetation. The dual effects of rhizobacterial waste degradation and pathogen suppression render them suitable for inclusion in sustainable agricultural practices (Riaz et al., 2021).



(Fig 2). Graph showing the global production of rice bran and its underutilization according to FAOSTAT data. The blue line represents rice bran production, the green line shows estimated utilization, and the orange-shaded area highlights the gap between production and utilization, emphasizing underutilization.

2. Rice bran: composition and characteristics

During the processing of rice, one of the nutritious by-products that emerge is called rice bran and it contains nutrition (Saunders, 1990). Rice bran is a highly nutritive content that supplies, proteins, lipids, fibers, vitamins and minerals in rice grain representing approximately 10% of the weight; it could become surprisingly valuable for both human intakes as well agricultural purposes (Saunders, 1985).

Its weight part of protein is 12– 15%, and it contains vital amino acids such as lysine, methionine (Saunders, 1990). Rice bran contains proteins that can be valuable in animal feed and as a dietary supplement in human diets. Rice bran proteins are not digestible and feature been located to have antioxidant properties, in addition to enhancing their fee in purposeful food programs (Fabian and Ju, 2011). Lipids are one of the major components of rice bran, with lipid content ranging from 15-20% depending on the variety and milling method (Gul et al., 2015). It is rich in unsaturated fatty acid lipids (oleic and linoleic acids) and has health benefits such as cardiovascular protection (Lerma-García et al., 2009). However, the high fat content also makes rice bran susceptible to rapid rancidity due to enzymatic activity, especially lipase enzymes, which break down fats into free fatty acids, causing rice bran to spoil rapidly after milling (Ramezanzadeh et al., 1999).

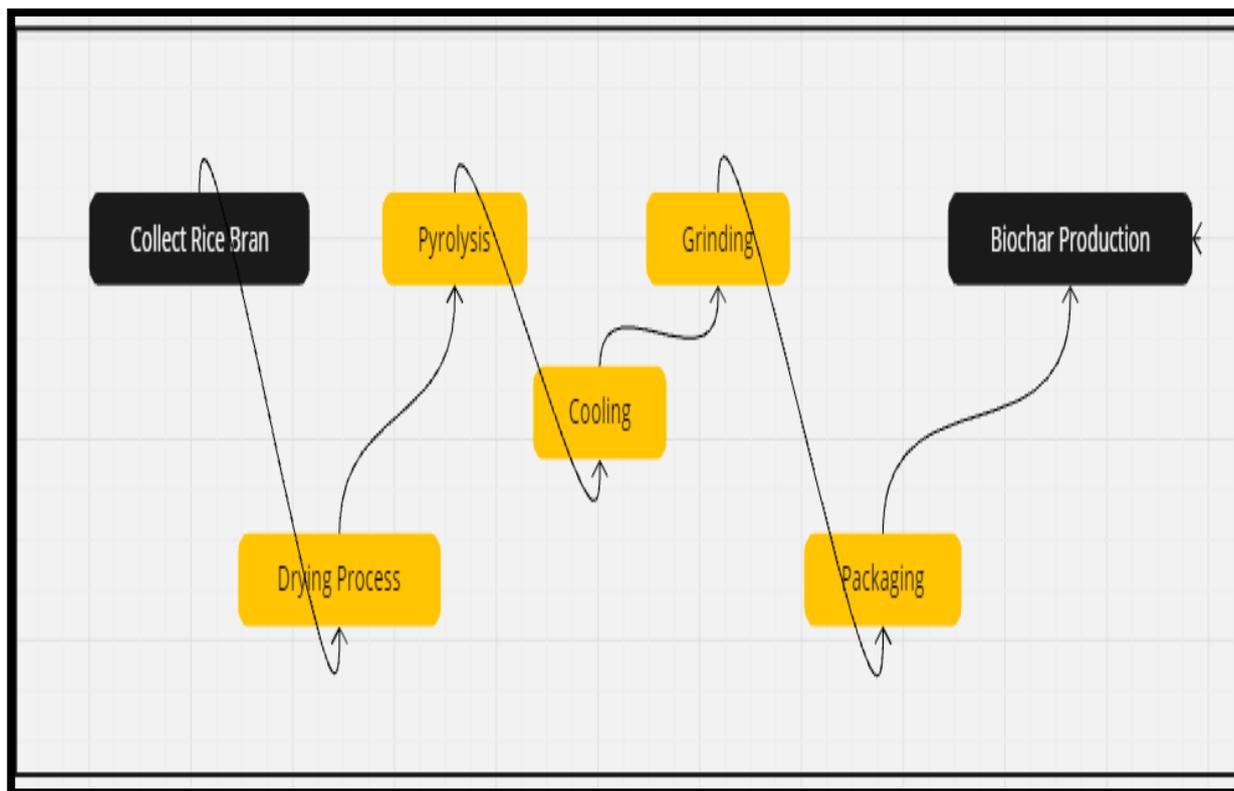
Rice bran is a very good source of micronutrients, in addition to B-nutrients (other than

thiamine, niacin, and riboflavin) and diet E in the form of tocopherols and tocotrienols, which are sturdy antioxidants (Iqbal, Bhanger, and Anwar, 2005). Rice bran also contains essential minerals including phosphorus, potassium, magnesium and small quantities of zinc, iron and manganese all of which play a role in its overall nutrition (Saunders, 1990).

3. Current methods of rice bran waste management

Composting is one of the most common traditional strategies used for rice bran waste management. Composting is the aerobic decomposition of organic materials, such as rice bran, by microorganism movement (Bernal et al., 2009). This method involves mixing of rice bran with media comprising natural wastes, e.g., crop residue, manure and kitchen waste in certain proportions to form feed material for various worms [*Eisenia fetida* (Savigny)] which finally converts the feed to a nutrient-rich compost that can be applied on agricultural fields as soil conditioner (Liang et al., 2003). Although composting is a low-cost and green technique, there are a few problems with it. Because of this, rice bran has a gradual decomposition system due to its excessive fat content, which leads to less effectiveness compared to other agricultural residues (Hsu and Lo, 1999).

Biochar production from Rice Bran Biochar manufacturing is an innovative technique that utilizes rice bran waste through pyrolysis (thermal degradation, without oxygen) of this rich agro-waste to produce biochar (Jindo et al., 2014). Biochar is a carbon-rich material that is widely investigated for its potential use as a soil amendment and carbon sequestration agent (Lehmann et al., 2006). During pyrolysis, rice bran is heated to 400–600°C, which converts the organic count number into a solid carbon system (Demirbas, 2004). Rice bran-based biochar has numerous blessings when carried out to the soil. This supports soil structure, contributes to water retention, and can aid in nutrient supply by serving as a storage pool for nutrients, such as nitrogen and phosphorus (Glaser et al., 2002). Additionally, biochar has been shown to increase soil microbial activity, promoting microorganisms that improve plant growth and fitness (Graber et al., 2010). Farmers can reduce their dependence on synthetic fertilizers and increase crop yields with biochar, the supported application of rice bran waste (Jeffery et al., 2011). However, the production of biochar from rice bran entails a comparatively system and electricity requirements that are expensive for small-scale farmers (Roberts et al., 2010). In addition, biochar emits unstable compounds and gases that must be managed correctly to prevent air pollution (Brown et al., 2006). Despite these problems, biochar production is an attractive way to add value to rice bran waste and improve soil fertility.



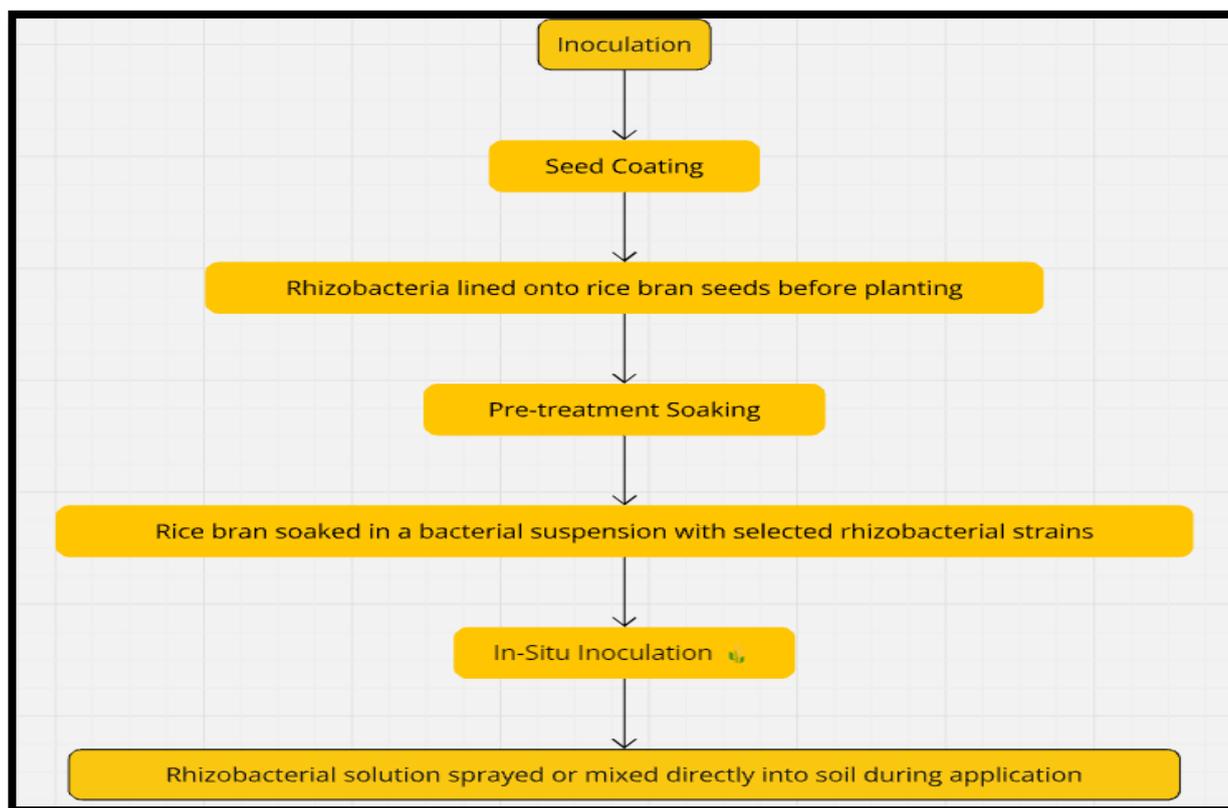
(Fig.3) Flowchart illustrating the biochar production process from Rice Bran.

Anaerobic digestion is a good method for rice bran waste management and biogas production (Weiland, 2010). Anaerobic digestion is a process in which microorganisms break down organic material in the absence of oxygen, ensuing within the commercial biogas (a combination of methane and carbon dioxide) (Mata-Alvarez et al., 2000). Due to its high lipid and carbohydrate content, rice bran is an excellent substrate for anaerobic digestion, providing a high richness of organic matter for biogas production. Biogas produced through anaerobic digestion can be employed as a renewable electric power source for electrical power production, heating, and cooking, and it also results in a reduction in greenhouse gases (Bond and Templeton, 2011). Moreover, the digestate (the scarf left with after the establishment of anaerobic digestion) can also be used as a nutrient-rich supply to enhance soil health and fertility (Möller and Müller, 2012). This makes anaerobic digestion a very sustainable process for the disposal of rice bran waste, particularly where energy assets are restricted.

4. Novel approaches using rhizobacteria for rice bran management

The current method describes a novel approach of inoculating rice bran with beneficial rhizobacteria to expedite its decomposition and improve its application as a soil amendment. In this method, milled rhizobacteria are part of the rice bran earlier than software to the soil aids spoil down natural matter longer bacterial activity (Carlson et al., 2015). There are several methods to inoculate rice bran seeds: 1) Seed Coating: Application of rhizobacteria to rice bran seeds before planting. This technique ensures that the 'beneficial microorganism added to the soil milieu with the proximal of the rice bran wherein they can initiate decompose organic count within no time (Reddy, 2017). 2) One-way-soaked pre-treatment of rice bran in a bacterial suspension with selected

rhizobacterial strains. This approach allows the microorganism to colonize the rice bran and start the enzymatic degradation earlier than it is carried out to the field (Wang et al., 2020). 3) In situ inoculation: Throughout the application of rice bran to the soil, a rhizobacterial resolution may be sprayed or combined simultaneously into the soil (Vessey, 2003). This method simultaneously introduces beneficial organisms to the soil environment, where they can interact with rice bran and enhance its decomposition. Treatment of rice bran with rhizobacteria has also been shown to significantly enhance the decomposition rate.



(Fig4.) Flowchart diagram showing all the inoculation techniques

Some of these produce enzymes like cellulase, hemicellulose and lipases which breakdown the complex forms of rice bran to a simpler and more available form (Singh et al., 2016). The fast digestion of this natural matter helps to break it down into smaller, microorganism-friendly pieces, making nutrients more available to live flowers (Geisseler and Scow, 2014). Rhizobacteria promote the activity of decomposer microorganisms, which in turn accelerates the decomposition of rice bran. Studies have shown that rice bran inoculated with certain rhizobacterial strains decomposes more rapidly than non-inoculated rice bran (Kannan and Sureendar, 2009). Rapid decomposition is desirable for soil health because it causes an immediate release of nutrients such as nitrogen, phosphorous, and potassium (Marschner et al., 2003). Additionally, faster microbial activity as a result of inoculation enhances nutrient dynamics in the soil. Beneficial rhizobacteria not only hasten decomposition but also ameliorate the mineralization process, converting organic forms of nutrients into inorganic forms which are very easily accessible to plants (Richardson et al., 2009).

Rhizobacteria-inoculated rice bran applied to the soil has a significant effect on soil microbial diversity and activity. Here's why you need useful rhizobacteria over and above supplying more resource, it stimulates the boom (growth) of numerous microorganisms by helping to create a favourable condition that enhances diversity in microbial community, field where it has been demonstrated (Mendes et al., 2013). This increased microbial diversity is also associated with improved soil fitness and resilience, as more complex communities are better prepared for environmental challenges and support plant growth (van der Heijden et al., 2008). Rhizobacteria also enhance the activity of soil microbes involved in nutrient cycling e.g. rhizobacteria decorating nitrogen-fixing bacteria (resulting in high levels of N input to be supplied by the soil, (Richardson and Simpson, 2011). This increased microbial interest helps maintain a healthy soil atmosphere to sell better nutrients by means of flowers and assist in unusual soil fertility (Friesen et al., 2011). Rice bran applied with rhizobacteria resulted in superior root system development, and it also contributed significantly to nutrient availability as well as illness and pest resistance in rhizobacteria-primed plants (Jetiyanon and Kloepper, 2002). In addition to growth blessings, the advanced soil structure and moisture retention associated with rice bran application also contributed to improved plant fitness. Rice bran contains organic matter, which helps in the aeration and water-holding capacity of the soil medium, making it environmentally friendly for plant roots (Tejada and Gonzalez, 2007).

For example, a research project carried out in India demonstrated that inoculating rice bran with Bacillus and Pseudomonas strains significantly increased the decomposition rate and improved soil nutrient availability compared with non-inoculated rice bran (Sivasakthi et al., 2014). The results revealed better plant growth and higher yields in fields treated with inoculated rice bran, demonstrating that this technique can support sustainable waste disposal and soil improvement (Zandi and Basu, 2016). Another study in Thailand tested the effects of rhizobacteria-inoculated rice bran on soil fitness and crop productivity. A study found that inoculated rice bran promoted soil microbial diversity and activity, leading to increased nutrient availability and better plant growth. The trial results showed that rhizobacteria-inoculated rice bran used as a soil amendment can be a powerful example of making rice bran waste beneficial, as well as enhancing crop yield and soil fitness (Pathak et al., 2010). Examples of Successful Implementation in Different Agricultural Settings: This technique has been successfully applied to rhizobacteria-inoculated rice bran in all types of agriculture. In Vietnam, farmers have used this method to deal with rice bran waste and improve soil fertility in rice paddy systems. The application of rhizobacteria-inoculated rice bran led to increased soil nutrient levels, better plant growth, and improved rice yields, demonstrating the practical benefits of this approach in local farming systems (Ha et al., 2015). In Kenya, a project focused on smallholder farmers showed that the addition of rhizobacteria-inoculated rice bran improves soil health and crop productivity. The farmers reported achieving higher maize yields and other increased plant growth, as well as improved soil quality (whose particular methods or means), which suggests the potential for scaling this approach to benefit other farmers in various regions.

By all accounts, the above example of a disease case study and controlled experiment shows that inoculating rhizobacteria in rice bran can control disease-causing organism

populations with great mind effect regardless of whether it is in a rural setting without technical equipment or methods of urbanization/computerizing percolation performance functions. Many experiments have been successful in changing the natural environment of soil human fields and food sources for rice production because these insects or bad plants are removed. Some perennial trees that grow objects of higher ecological value, as well as tall fruit species for reclaiming wetlands and boosting bird populations and land use breadth, can also be replanted. Most importantly, the repeated success of this method in many different environments demonstrates its potential as a sustainable solution for waste management and improvement of soils in agricultural systems.

5. Challenges and limitations

Ensuring the successful inoculation of beneficial microorganisms is a major technical challenge in the application of rhizobacteria to control rice bran (Bashan et al., 2014).

The agricultural use of rhizobacteria depends on their survival rate during inoculation and, hence, maintenance in the indigenous habitat to exert their beneficial effects. Factors, such as storage conditions, application methods, and the natural microbiome present in the soil, can determine bacterial survival and competence. For instance, when the inoculants are exposed to severe temperatures or they experience improper care during handling, this could affect their viability and thus reduce the quality of decomposition that they will be producing and plant boom would be sufficient (Schütz et al., 2018).

Differences in soils, such as pH, moisture, and nutrient levels, may affect how well introduced microorganisms compete with those living naturally on a site. A few times, the introduced rhizobia may also find it difficult to create a niche in soil that already harbors various kinds of competing or complementing microorganisms (Litchman and Klausmeier, 2008). The persistence of rhizobacteria in the soil is another venture. Weather events or battle for means with other small microorganisms in the soil might weaken the effectiveness of rhizobacteria (Fierer et al., 2007). Therefore, they want normal observation and upkeep to ensure that their vigor and effectiveness remain as good as when they were first released into the ground (Hart and Trevors, 2005). This challenge is frequently encountered by farmers with various types of agricultural activities in different soil environments (Bhardwaj et al., 2014). Soil type (e.g., sandy, loamy, or clayey) can affect the location of rhizobacteria move within it (Chenu and Stotzky, 2002). Even within the soil, unfavorable physical structures and excessive compaction may hinder bacterial colonization and activity (Bengough et al., 2011). Variations in soil porosity can affect oxygen availability required for the survival and activity of aerobic rhizobacteria (Young and Ritz, 2000). The soil pH and nutrient levels also have a critical impact on the in vivo efficacy of rhizobacteria. Most rhizobacteria have specific pH ranges in which they grow and reproduce, and deviating from these conditions reduces their effectiveness (Meena et al., 2014). Furthermore, an imbalance within the soil's nutrient status or deficiency of certain nutrients may affect how well inoculated rhizobacteria perform, and consequently, how much they enhance plant growth (Babalola, 2010). Soil moisture and air temperature are important factors influencing rhizobacterial activity. Extreme moisture conditions, either too wet or too

dry, can affect the survival and function of the rhizobacteria. Temperature fluctuations cause changes in bacterial metabolism and activity, potentially reducing them or their effectiveness in promoting rice bran composting and plant growth.

The manufacturing and application of rhizobacterial inoculants are expensive. Factors such as costs for isolating and culturing effective strains, preparing inoculants, and spreading them in the field all increase (Herrmann and Lesueur, 2013). For small-scale peasants or those next to the poor, the cost of adopting rhizobacterial technology may be a burden. Evaluating the cost-effectiveness of using rhizobacteria requires a thorough cost-benefit analysis (Giller et al., 2009). However, while rhizobacteria can promote soil health and increase yields, the benefits should clearly outweigh the costs of producing and applying their inoculants (Bhattacharyya and Jha, 2012). This includes estimating potential savings on synthetic fertilizers and increased crop yields versus the costs of implementing and maintaining the technology (Adesemoye et al., 2009)

Farmers have to sense the benefits of rhizobacterial application first and know how to use it before they will try to practice. The importance of teaching faculty and extension facilities for popularizing information about how good these little beings are is also telling practical techniques to adopt them. Without proper training or incentives, farmers might not be ready to take on the new technology market (Feder and Umali, 1993).

To succeed, a rhizobacterial project needs suitable infrastructure, including centers for producing and distributing inoculants. A project such as that inherent in rhizobia is difficult to accommodate when a region has only limited infrastructure. Moreover, our task now is to provide ongoing support and technical aid - help in the field - so as not only to resolve any problems that arise, but also to ensure efficient utilization of this technology (Bashan and Holguin, 2002).

Incorporating rhizosphere microecosystems into existing agronomic practices might require adjustments or buy-ins by market participants. Farmers and agricultural organizations should be convinced of the advantages and practicality of rhizobacterial control of rice bran. This involves demonstrating successful case studies, providing monetary incentives, and addressing fears associated with technology adoption and integration (Feder et al., 1985).

In summary, managing rice bran soil health issues by means of rhizo-bacterial techniques may involve complex exercises that involve not only many concomitant technical problems, such as structure, but also an excessive expenditure on time and money, and also that the technology is virtually unproven. Addressing these problems through research, education, and facility building is essential to make full use of the rhizosphere as a tool to realize sustainable agriculture.

6. Conclusion

Rhizobacterial techniques are a viable way forward for sustainable agriculture in the management of rice bran. To improve soil fertility and reduce environmental effects, rice bran can be effectively broken down into nutrient-rich organic matter by utilizing the enzymatic powers of rhizobacteria (Ahmad et al., 2008). Studies conducted in the field have shown how well bacteria such as *Bacillus* and *Pseudomonas* improve nutrient availability and speed up decomposition (Sivasakthi et al., 2014). It is possible to reduce the need for chemical fertilizers and enhance soil health by combining this strategy with

existing sustainable practices, such as organic farming. However, to guarantee widespread acceptance, issues such as maximizing bacterial survival, controlling expenses, and adjusting to various soil conditions must be resolved (Herrmann and Lesueur, 2013).

Investments in infrastructure, education, and farmer training can increase the uptake of rhizobacterial technology with the support of policymakers (G. and Feder 1993). In addition to facilitating effective waste management, this approach supports international initiatives to advance sustainable and profitable farming methods. Rhizobacterial techniques can be crucial in turning agricultural waste into a useful resource for sustainable farming systems with more study and development (Lehmann et al., 2006).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgement

I express my heartfelt gratitude to Chandigarh University and the Department of Biotechnology for providing the resources, support, and guidance necessary to complete this review.

I extend my sincere thanks to the faculty members and mentors of the Department of Biotechnology for their invaluable advice and encouragement throughout this research process. Their expertise and insights have been instrumental in enhancing my understanding of the complexities of this topic.

I would also like to acknowledge the unwavering support of my family, friends, and colleagues who motivated me to persevere and remain dedicated to my academic endeavour's.

Finally, I am grateful to all the authors, researchers, and scholars whose work has formed the foundation of my review, enabling me to broaden my perspective and contribute to this field of study.

I appreciate your contributions and inspiration, which made this study possible.

This study did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

1. References

2. Adesemoye, A. O., Torbert, H. A., & Kloepper, J. W. 2009. *Plant growth-promoting rhizobacteria allow reduced application rates of chemical fertilizers. Microbial Ecology, 58(4), 921–929.*
3. Ahmad, F., Ahmad, I., and Khan, M. S. 2008. *Screening of free-living rhizobacteria for their multiple plant growth-promoting activities. Microbiological Research, 163(2), 173–181.*
4. Babalola, O. O. 2010. *Beneficial bacteria of agricultural importance. Biotechnology*

- Letters*, 32(11), 1559–1570.
5. Bashan, Y., and Holguin, G. 2002. *Plant growth-promoting bacteria: A potential tool for arid mangrove reforestation*. *Trees*, 16, 159–166.
 6. Bashan, Y., de-Bashan, L. E., Prabhu, S. R., and Hernandez, J.-P. 2014. "Advances in plant growth-promoting bacterial inoculant technology: Formulations and practical perspectives (1998–2013)." *Plant and Soil*, 378(1-2), 1-33.
 7. Bengough, A. G., McKenzie, B. M., Hallett, P. D., and Valentine, T. A. 2011. *Root elongation, water stress, and mechanical impedance: A review of limiting stresses and beneficial root tip traits*. *Journal of Experimental Botany*, 62(1), 59–68.
 8. Bernal, M. P., Alburquerque, J. A., and Moral, R. 2009. *Composting of animal manures and chemical criteria for compost maturity assessment: A review*. *Bioresource Technology*, 100(22), 5444–5453.
 9. Bhardwaj, D., Ansari, M. W., Sahoo, R. K., and Tuteja, N. 2014. *Biofertilizers function as key players in sustainable agriculture by improving soil fertility, plant tolerance, and crop productivity*. *Microbial Cell Factories*, 13(1), 66.
 10. Bhattacharyya, P. N., and Jha, D. K. 2012. *Plant growth-promoting rhizobacteria (PGPR): Emergence in agriculture*. *World Journal of Microbiology and Biotechnology*, 28(4), 1327-1350.
 11. Bond, T., and Templeton, M. R. 2011. *History and future of domestic biogas plants in the developing world*. *Energy for Sustainable Development*, 15(4), 347-354.
 12. Brown, R. A., Kercher, A. K., Nguyen, T. H., Nagle, D. C., and Ball, W. P. 2006. *Production and characterization of synthetic wood chars for use as surrogates for natural sorbents*. *Organic Geochemistry*, 37(3), 321-333.
 13. Carlson, J., Saxena, J., Basta, N., Hundal, L., Busalacchi, D., and Dick, R. P. 2015. *Application of organic amendments to restore degraded soil: Effects on soil microbial properties*. *Environmental Monitoring and Assessment*, 187, 1-15.
 14. Chauhan, B. S., and Johnson, D. E. 2010. *The role of seed ecology in improving weed management strategies in the tropics*. *Advances in Agronomy*, 105, 221-262.
 15. Chenu, C., & Stotzky, G. 2002. *Interactions between microorganisms and soil particles: An overview*. *Soil Science Society of America Journal*, 66(3), 953-961.
 16. Demirbas, A. 2004. *Effects of temperature and particle size on bio-char yield from pyrolysis of agricultural residues*. *Journal of Analytical and Applied Pyrolysis*, 72(2), 243-248.
 17. Fabian, C., and Ju, Y. H. 2011. *A review on rice bran protein: Its properties and extraction methods*. *Critical Reviews in Food Science and Nutrition*, 51(9), 816-827.
 18. Feder, G., and Umali, D. L. 1993. *The adoption of agricultural innovations: A review*. *Technological Forecasting and Social Change*, 43(3-4), 215-239.
 19. Feder, G., Just, R. E., and Zilberman, D. 1985. *Adoption of agricultural innovations in developing countries: A survey*. *Economic Development and Cultural Change*, 33(2), 255-298.
 20. Fierer, N., Bradford, M. A., and Jackson, R. B. 2007. *Toward an ecological classification of soil bacteria*. *Ecology*, 88(6), 1354-1364.
 21. Friesen, M. L., Porter, S. S., Stark, S. C., von Wettberg, E. J., Sachs, J. L., and Martinez-Romero, E. 2011. *Microbially mediated plant functional traits*. *Annual Review of Ecology, Evolution, and Systematics*, 42, 23-46.

22. Geisseler, D., and Scow, K. M. 2014. Long-term effects of mineral fertilizers on soil microorganisms – A review. *Soil Biology and Biochemistry*, 75, 54-63.
23. Giller, K. E., Witter, E., Corbeels, M., and Tittonell, P. 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, 114(1), 23-34.
24. Glaser, B., Lehmann, J., and Zech, W. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal: A review. *Biology and Fertility of Soils*, 35(4), 219-230.
25. Graber, E. R., Harel, Y. M., Koltun, M., Cytryn, E., Silber, A., David, D. R., Tsechansky, L., Borenshtein, M., and Elad, Y. 2010. Biochar impact on development and productivity of pepper and tomato grown in fertigated soilless media. *Plant and Soil*, 337(1-2), 481-496.
26. Gul, K., Yousuf, B., Singh, A. K., Singh, P., and Wani, A. A. 2015. Rice bran: Nutritional values and its emerging potential for development of functional food—A review. *Bioactive Carbohydrates and Dietary Fibre*, 6(1), 24-30.
27. Hart, M. M., and Trevors, J. T. 2005. Microbe management: application of mycorrhizal fungi in sustainable agriculture. *Frontiers in Ecology and the Environment*, 3(10), 533-539.
28. Herrmann, L., and Lesueur, D. 2013. Challenges of formulation and quality of biofertilizers for successful inoculation. *Applied microbiology and biotechnology*, 97(20), 8859-8873.
29. Df, H. 1972. Rice bran and polish. *Rice: Chemistry and Technology*, 272-300.
30. Hsu, J. H., and Lo, S. L. 1999. Chemical and spectroscopic analysis of organic matter transformations during composting of pig manure. *Environmental pollution*, 104(2), 189-196.
31. Html, S. T., Wang, Z., Liu, Z., Zhang, Y., and Si, B. 2020. The role of biochar to enhance anaerobic digestion: a review. *Journal of Renewable Materials*, 8(9), 1033-1052.
32. Iqbal, S., Bhangar, M. I., and Anwar, F. 2005. Antioxidant properties and components of some commercially available varieties of rice bran in Pakistan. *Food chemistry*, 93(2), 265-272.
33. Jeffery, S., Verheijen, F. G., van der Velde, M., and Bastos, A. C. 2011. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, ecosystems & environment*, 144(1), 175-187.
34. Jetiyanon, K., and Kloepper, J. W. 2002. Mixtures of plant growth-promoting rhizobacteria for induction of systemic resistance against multiple plant diseases. *Biological control*, 24(3), 285-291.
35. Jindo, K., Mizumoto, H., Sawada, Y., Sanchez-Monedero, M. A., and Sonoki, T. 2014. Physical and chemical characterization of biochars derived from different agricultural residues. *Biogeosciences*, 11(23), 6613-6621.
36. Kannan, V., and Sureendar, R. 2009. Synergistic effect of beneficial rhizosphere microflora in biocontrol and plant growth promotion. *Journal of Basic Microbiology*, 49(2), 158-164.
37. Lehmann, J., Gaunt, J., and Rondon, M. 2006. Bio-char sequestration in terrestrial ecosystems—a review. *Mitigation and adaptation strategies for global change*, 11, 403-427.

38. Lerma-García, M. J., Herrero-Martínez, J. M., Simó-Alfonso, E. F., Mendonça, C. R., and Ramis-Ramos, G. 2009. Composition, industrial processing and applications of rice bran γ -oryzanol. *Food Chemistry*, 115(2), 389-404.
39. Liang, C., Das, K. C., and McClendon, R. W. 2003. The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend. *Bioresource technology*, 86(2), 131-137.
40. Litchman, E., and Klausmeier, C. A. 2008. Trait-based community ecology of phytoplankton. *Annual review of ecology, evolution, and systematics*, 39(1), 615-639.
41. Lugtenberg, B., and Kamilova, F. 2009. Plant-growth-promoting rhizobacteria. *Annual review of microbiology*, 63(1), 541-556.
42. Marschner, P., Kandeler, E., and Marschner, B. 2003. Structure and function of the soil microbial community in a long-term fertilizer experiment. *Soil Biology and Biochemistry*, 35(3), 453-461.
43. Mata-Alvarez, J., Macé, S., and Llabrés, P. 2000. Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. *Bioresource technology*, 74(1), 3-16.
44. Meena, V. S., Maurya, B. R., and Verma, J. P. 2014. Does a rhizospheric microorganism enhance K^+ availability in agricultural soils?. *Microbiological research*, 169(5-6), 337-347.
45. Mendes, R., Garbeva, P., and Raaijmakers, J. M. 2013. The rhizosphere microbiome: significance of plant beneficial, plant pathogenic, and human pathogenic microorganisms. *FEMS microbiology reviews*, 37(5), 634-663.
46. Möller, K., and Müller, T. 2012. Effects of anaerobic digestion on digestate nutrient availability and crop growth: A review. *Engineering in life sciences*, 12(3), 242-257.
47. Nevita, T., Sharma, G. D., and Pandey, P. 2018. Composting of rice-residues using lignocellulolytic plant-probiotic *Stenotrophomonas maltophilia*, and its evaluation for growth enhancement of *Oryza sativa* L. *Environmental Sustainability*, 1, 185-196.
48. Nidhishree, A. S., Menezes, R. A., Venkatachalam, H., and Bhat, K. S. 2024. Rice bran as a sustainable source for value added materials: An overview. *Discover Materials*, 4(1), 93.
49. dos Santos Oliveira, M., Feddern, V., Kupski, L., Cipolatti, E. P., Badiale-Furlong, E., and de Souza-Soares, L. A. 2011. Changes in lipid, fatty acids and phospholipids composition of whole rice bran after solid-state fungal fermentation. *Bioresource Technology*, 102(17), 8335-8338.
50. Ramezanzadeh, F. M., Rao, R. M., Windhauser, M., Prinyawiwatkul, W., Tulley, R., and Marshall, W. E. 1999. Prevention of hydrolytic rancidity in rice bran during storage. *Journal of Agricultural and Food Chemistry*, 47(8), 3050-3052.
51. Riaz, U., Murtaza, G., Anum, W., Samreen, T., Sarfraz, M., and Nazir, M. Z. 2021. Plant growth-promoting rhizobacteria (PGPR) as biofertilizers and biopesticides. *Microbiota and biofertilizers: a sustainable continuum for plant and soil health*, 181-196.
52. Richardson, A. E., and Simpson, R. J. 2011. Soil microorganisms mediating phosphorus availability update on microbial phosphorus. *Plant physiology*, 156(3), 989-996.
53. Richardson, A. E., Barea, J. M., McNeill, A. M., and Prigent-Combaret, C. 2009. Acquisition of phosphorus and nitrogen in the rhizosphere and plant growth promotion by microorganisms.

54. Roberts, K. G., Gloy, B. A., Joseph, S., Scott, N. R., and Lehmann, J. 2010. Life cycle assessment of biochar systems: estimating the energetic, economic, and climate change potential. *Environmental science & technology*, 44(2), 827-833.
55. Rocha, I., Ma, Y., Souza-Alonso, P., Vosátka, M., Freitas, H., and Oliveira, R. S. 2019. Seed coating: a tool for delivering beneficial microbes to agricultural crops. *Frontiers in plant science*, 10, 1357.
56. Ryan, E. P. 2011. Bioactive food components and health properties of rice bran. *Journal of the American Veterinary Medical Association*, 238(5), 593-600.
57. Saharan, B. S., and Nehra, V. 2011. Plant growth promoting rhizobacteria: a critical review. *Life Sci Med Res*, 21(1), 30. Retrived from: www.researchgate.net.
58. Samal, P., Babu, S. C., Mondal, B., and Mishra, S. N. 2022. The global rice agriculture towards 2050: An inter-continental perspective. *Outlook on Agriculture*, 51(2), 164-172.
59. Saunders, R. M. 1985. Rice bran: Composition and potential food uses. *Food Reviews International*, 1(3), 465-495.
60. Saunders, R. M. 1990. The properties of rice bran as a foodstuff.
61. Schütz, L., Gattinger, A., Meier, M., Müller, A., Boller, T., Mäder, P., and Mathimaran, N. 2018. Improving crop yield and nutrient use efficiency via biofertilization—A global meta-analysis. *Frontiers in plant science*, 8, 2204.
62. Sharif, M. K., Butt, M. S., Anjum, F. M., and Khan, S. H. 2014. Rice bran: a novel functional ingredient. *Critical reviews in food science and nutrition*, 54(6), 807-816.
63. Sharma, B., Vaish, B., Monika, Singh, U. K., Singh, P., and Singh, R. P. 2019. Recycling of organic wastes in agriculture: an environmental perspective. *International journal of environmental research*, 13, 409-429.
64. Singh, J. S., Pandey, V. C., and Singh, D. P. 2011. Efficient soil microorganisms: a new dimension for sustainable agriculture and environmental development. *Agriculture, ecosystems & environment*, 140(3-4), 339-353.
65. Singh, R. P., and Jha, P. N. 2016. The multifarious PGPR *Serratia marcescens* CDP-13 augments induced systemic resistance and enhanced salinity tolerance of wheat (*Triticum aestivum* L.). *PLoS one*, 11(6), e0155026.
66. Sivasakthi, S., Usharani, G., and Saranraj, P. 2014. Biocontrol potentiality of plant growth promoting bacteria (PGPR)-*Pseudomonas fluorescens* and *Bacillus subtilis*: A review. *Afr. J. Agric. Res*, 9(16), 1265-1277.
67. Tan, B. L., Norhaizan, M. E., Tan, B. L., and Norhaizan, M. E. 2020. Phytonutrients and antioxidant properties of rice by-products. *Rice by-products: Phytochemicals and food products application*, 41-68.
68. Tejada, M., and Gonzalez, J. L. 2007. Influence of organic amendments on soil structure and soil loss under simulated rain. *Soil and Tillage Research*, 93(1), 197-205.
69. Van Der Heijden, M. G., Bardgett, R. D., and Van Straalen, N. M. 2008. The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. *Ecology letters*, 11(3), 296-310.
70. Vejan, P., Abdullah, R., Khadiran, T., Ismail, S., and Nasrulhaq Boyce, A. 2016. Role of plant growth promoting rhizobacteria in agricultural sustainability—a review. *Molecules*, 21(5), 573.
71. Vessey, J. K. 2003. Plant growth promoting rhizobacteria as biofertilizers. *Plant and soil*, 255, 571-586.

72. Weiland, P. 2010. *Biogas production: current state and perspectives. Applied microbiology and biotechnology*, 85, 849-860.
73. Young, I. M., and Ritz, K. 2000. *Tillage, habitat space and function of soil microbes. Soil and Tillage Research*, 53(3-4), 201-213.
74. Zandi, P., and Basu, S. K. 2016. *Role of plant growth-promoting rhizobacteria (PGPR) as biofertilizers in stabilizing agricultural ecosystems. Organic farming for sustainable agriculture*, 71-87.