



Arid Zone Journal of Basic and Applied Research

Faculty of Science, Kashim Ibrahim University
Maiduguri, Nigeria

Journal homepage: <https://www.azjournalbar.com>



Research Article

Isolation and Identification of Rhizobacteria with Biofertilizer Potential from Irrigated Rice Fields in Damaturu, Yobe State, Nigeria

Sheriff Wakil¹, Haruna Yahaya Ismail², Ibrahim Alkali Allamin² and Adam Lawan Ngala³

¹Department of Microbiology, Yobe State University, Damaturu, Nigeria

²Department of Microbiology, University of Maiduguri, Borno State, Nigeria

³Department of Soil Science, University of Maiduguri, Borno State, Nigeria

*Corresponding author's Email: wakilsheriff028@gmail.com, doi.org/10.55639/607.special.002

ARTICLE INFO:

ABSTRACT

Keywords:

Rhizosphere,
Biofertilizer,
PGPR,
Bacillus sp.

The rhizosphere microbiome plays a key role in plant productivity and soil fertility, particularly in intensive systems such as irrigated rice cultivation. Although rice rhizosphere microbial communities have been widely studied, information from semi-arid regions of Nigeria remains limited. Biofertilizers offer an environmentally friendly alternative to chemical fertilizers, whose prolonged use negatively affects soil structure and fertility. This study examined the cultivable rhizobacterial community and physicochemical properties of irrigated rice fields in Damaturu, Yobe State, Nigeria. Ten rhizosphere soil samples (10 g each) were randomly collected at a depth of 0-15 cm. Physicochemical analyses were performed using standard methods, while microbiological assessment involved serial dilution (10^{-1} - 10^{-7}), pour plate culturing, and incubation at 30°C for 24-48 h. Isolates were characterized using Gram staining, biochemical tests, and plant growth-promoting trait assays. The soils were clay-loamy, slightly acidic to neutral (pH 6.1–7.1), and moderately fertile. Total bacterial counts ranged from 1.02×10^{12} to 3.18×10^{12} CFU/g, with the highest count recorded in sample S9. Seven rhizobacterial isolates were identified, dominated by *Bacillus* spp. (40%), followed by *Pseudomonas* spp. (20%) and *Azotobacter* spp. (10%). The predominance of *Bacillus* spp. reflects their spore-forming capacity, while the presence of all three genera indicates potential plant growth-promoting traits, including indole acetic acid production, ammonia production, and phosphate solubilization. These findings suggest that *Bacillus* sp. (S9) has potential as a biofertilizer for sustainable rice (*Oryza sativa* L. FARO) production and reduced reliance on chemical fertilizers in Damaturu, Yobe State.

Corresponding author: Sheriff Wakil, USMAN, **Email:** wakilsheriff028@gmail.com
Department of Microbiology, Yobe State University, Damaturu, Nigeria

INTRODUCTION

The rhizosphere microbiome is a critical driver of plant health and soil fertility, especially in intensive agricultural systems like irrigated rice farming (Ukwai *et al.*, 2024). The rhizosphere bacteria in soil can play pivotal roles in nutrient cycling, phosphate solubilization, nitrogen fixation, phytohormone production, and pathogen suppression, collectively enhancing plant growth and stress tolerance (Fahad *et al.*, 2021). Genera such as *Bacillus* spp., *Pseudomonas* spp., *Azotobacter* spp. And other rhizobacteria isolates are well-documented plant growth-promoting rhizobacteria (PGPR) (Glick, 2005; Adesemoye & Kloepper, 2009). Bacteria are the major class of microorganisms that keep soils healthy and productive with several functions to the soil; they supply nutrients to the crops, it helps in plant growth, it controls the activities of plant pathogens and it improves the soil structure. Bacteria can be used for biofertilizer, bioremediation in polluted soils (Hayat *et al.*, 2010). Bacteria are tiny and one-celled organisms. A ton of microscopic bacteria may be active in each acre of land. Bacteria are similar to clay soil particles in size (Fahad *et al.*, 2021). Bacteria grow and live in thin water films around soil particles and near roots in an area called the rhizosphere. Because bacteria are small in size, this enables them to grow and adapt more rapidly in most soils. Bacteria population can multiply easily in double within 30minutes thereby flourishing microbial populations increase soil productivity and crop yields over time. The oxygen levels of the soils determine the activities of soil bacteria. Most bacteria in the soils prefer oxygenated soils and make use of the oxygen to decompose most carbon compound in the soil (Lowenfels and Lewis, 2006; Adesemoye & Kloepper, 2009).

The development and use of microbial-based fertilizers has recently gained significance due to the recognition of the deleterious effects on the environment generated by the excessive and improper application of chemical fertilizers (Bar-On *et al.*, 2018). This was a result of the improved knowledge about the relationships occurring in the rhizosphere, between the plant and all soil microorganisms, as well as due to the immense efforts in isolating and selecting microbial strains showing plant growth

promoting capabilities (Parmar and Sindhu, 2013; Serri *et al.* 2022). Biofertilizers have been identified as an alternative to chemical fertilizers to increase soil fertility and crop production in sustainable farming. It has emerged as an important component of the integrated nutrient supply system and hold a great promise to improve crop yields through environmentally better nutrient supplies (Sakariyawo *et al.*, 2013). Biofertilizers improve root proliferation due to the release of growth promoting hormones. Microorganism converts complex nutrients into simple nutrients for the availability of the plants. Biofertilizers are products of one or more species of microorganisms which have the ability to mobilize nutritionally important elements from non-useable to useable form through biological processes such as nitrogen fixation, phosphate solubilization, excretion of plant growth promoting substances and biodegradation in soil (Agu *et al.*, 2021).

The rice (*Oryza sativa* L.) has become the most popular and the most important cereal crop consumed by the almost 250 million of worldwide population while conserving environmental condition without destroying the forest for rice land extension (Nikmatul *et al.*, 2020; Rahmah *et al.*, 2017). The need of this commodity is going to increase year by year due to the population growth (Somchit *et al.*, 2017). The increase of rice demand cannot be supplied if there is no improvement in rice production. There are several strategies to improve rice production. High yielding varieties have given significant rice production increase (Long-ping, 2014). Rice (*Oryza sativa* L. FARO 44) is a staple food for a significant portion of the Nigerian population, its demand continues to rise, and understanding its associated rhizobacteria can enhance agricultural productivity (Sakariyawo *et al.*, 2013; Grema *et al.*, 2022). The use of rhizobacteria (biofertilizer) accelerates mineralization of organic residues in soil, therefore makes the nutrients more available to crops (Agu *et al.*, 2021). However, the aim of this study was to isolate, identified and evaluate the effect of PGP traits; indole acetic acid, ammonia production and phosphate solubilization on rhizobacteria from irrigated rice fields in Damaturu, Yobe State, Nigeria, to explore their biofertilizer

potential for sustainable rice and other crops production.

MATERIAL AND METHOD

Study area and sample collection

The study was conducted in irrigated rice fields in Damaturu, Yobe State, Nigeria (geographical coordinates 12°00'N 11°30'E). Ten (10) rhizosphere soil samples (approximately 10g each) were aseptically collected from the root zone (0-15 cm depth) of rice plants using sterile polyethylene bags between January and April 2025. Samples were transported to the Chemistry and Microbiology Laboratories of Yobe State University, for physicochemical analysis and isolation of rhizobacteria isolates using standard methods.

Soil physicochemical analysis

The soil texture, pH, organic carbon, soil nitrogen, water holding capacity, exchangeable bases and cation exchange capacity were conducted using standard laboratory procedures (Machido, 2010; Ukwai *et al.*, 2024; Ofori, 2016) at Chemistry Laboratory, Yobe State University, Damaturu-Nigeria.

Microbiological analysis of bacterial isolate and plant growth promoting traits

One (1) gram of each soil sample was serially diluted (10^{-1} to 10^{-7}) in sterile distilled water. 0.1 mL aliquot from appropriate dilutions was spread-plated onto yeast extract mannitol agar medium (YEMA) and nutrient agar for total rhizobium bacterial. The YEMA plates were incubated at 37°C for three days, while the nutrient agar plates were incubated at 37°C for 24 hours. The resulting colonies were counted using colony counter. The isolated rhizobacteria were sub-cultured incubated at 37°C for 24 hours, the morphological characteristics of the

isolates, gram stain and biochemical characteristics were observed (Vimala *et al.*, 2018; Oyeleke and Manga, 2008). The identified isolate was subculture on peptone water, nutrient broth and Pikovskaya's at for plant growth promoting characteristics includes indole acetic acid (IAA), ammonia production and phosphate solubilization activities of rhizobacteria isolates (Cheesbrough, 2006; Sarker *et al.*, 2014, Olayemi *et al.*, 2007; Justin *et al.*, 2020, Joseph *et al.*, 2007, Mahboubia *et al.*).

RESULTS

The physicochemical analysis revealed a clay-loamy soil texture which is known for good water and nutrient retention. The soil pH ranged from slightly acidic to neutral (6.1 to 7.1). Other parameters (Fig. 1) indicated moderately fertile conditions conducive for microbial activity and rice growth.

The bacterial population count varied across samples, with the highest count observed in sample S9 (3.18×10^{12} CFU/mL) and the lowest in S3 (1.02×10^{12} CFU/mL) (Fig. 2).

Based on morphological, Gram staining and biochemical characteristics (Table 1), the isolates were identified as *Bacillus* spp. (40%), *Pseudomonas* spp. (20%), and *Azotobacter* spp. (10%). All isolates were positive for catalase and oxidase tests.

Potential plant growth-promoting (PGP) traits such as indole acetic acid, ammonia production and phosphate solubilization were show in (table 2) S9 *Bacillus* sp. had the multiple PGP trait indicate potential to serve as biofertilizers, contributing to sustainable rice (*Oryza sativa* L. FARO) growth and other crops cultivation as well as reducing the use of chemical fertilizer.

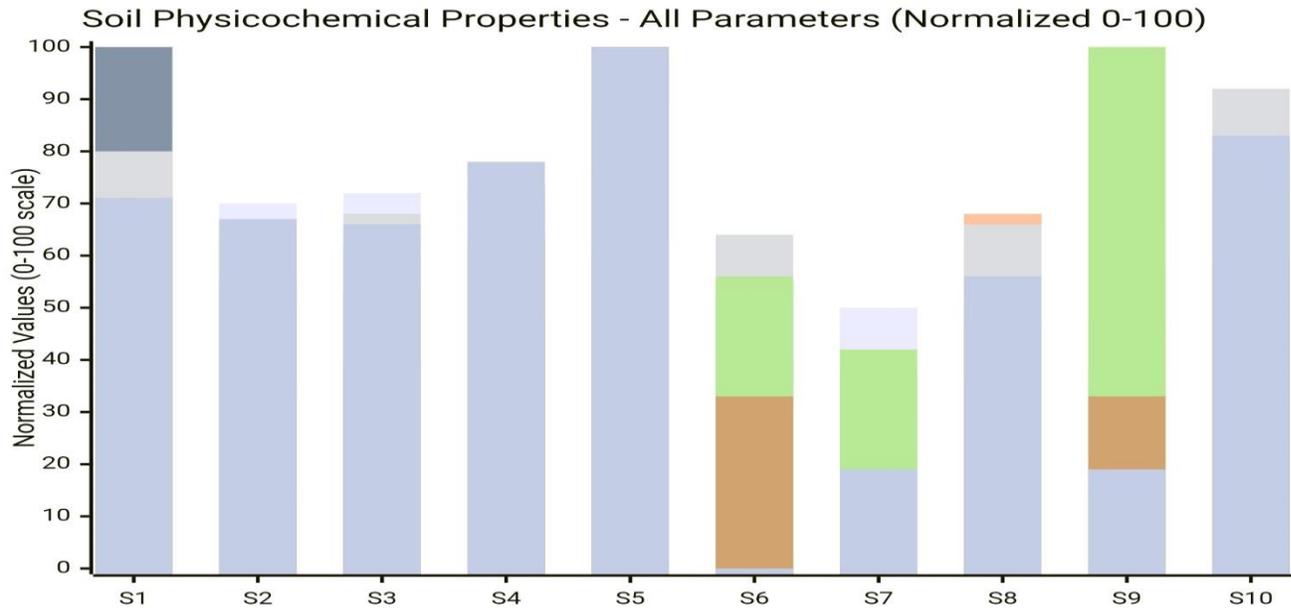


Fig. 1: Shows physicochemical properties of rhizosphere soil samples (● Blue pH neutral-optimal, ● Green: Electrical Conductivity EC (mS/cm) lower is better, ● Yellow: Organic Carbon OC (%), ● Orange: Nitrogen -N (mg/kg), ● Purple: Water Holding Capacity WHC (%), ● Red: Sodium Na (cmol/kg) lower is better, ● Brown: Cation Exchange Capacity CEC (cmol/kg)

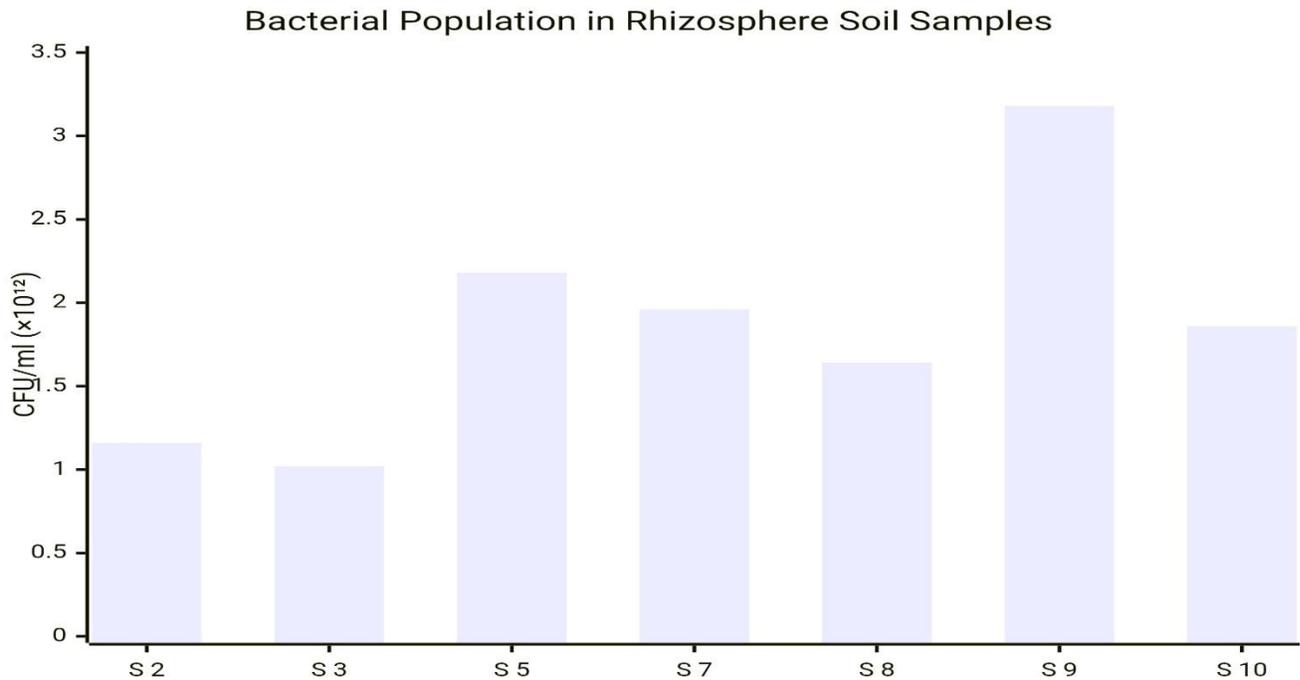


Fig. 2: Shows population of rhizobacteria in Rhizosphere soil sample (S = Sample Rhizosphere Isolate, CFU = Colony Forming Unit)

Table 1: Shows gram stain, morphological appearance and biochemical tests of suspected isolates

Isolate code	GS	MPA	Biochemical Test						Suspected isolate
			Ind	MR	Ox	Cat	Cit	VP	
S2	+	Milky white, irregular shape	-	+	+	+	+	-	<i>Bacillus</i> sp.
S3	-	Pale yellow/green	-	-	+	+	+	-	<i>Pseudomonas</i> sp.
S5	+	Creamy white, round	-	+	+	+	+	-	<i>Bacillus</i> sp.
S7	-	Brownish mucoid	-	-	+	+	+	-	<i>Azotobacter</i> sp.
S8	+	Creamy white	-	+	+	+	+	-	<i>Bacillus</i> sp.
S9	+	Milky white	-	+	+	+	+	+	<i>Bacillus</i> sp.
S10	-	Greenish	-	-	+	-	+	+	<i>Pseudomonas</i> sp.

S= Soil samples, GS= Gram stain, MPA= Morphological appearance, Ind= Indole test, MR= Methyl red, Ox= Oxidase, Cat= Catalase, Cit= Citrate, VP= Voges-Proskauer, -= negative, += positive

Table 2: Shows plant growth promoting traits of rhizobacterial isolates

Isolate Codes	Indole Acetic Acid (IAA)	Ammonia Production	Phosphate Solubilization
S2	+	-	+
S3	-	-	-
S5	+	-	+
S7	-	-	-
S8	-	+	-
S9	+	+	+
S10	-	-	-

S2A= *Bacillus* sp., S3C= *Pseudomonas* sp., S5A= *Bacillus* sp., S7B= *Azotobacter* sp., S8A= *Bacillus* sp., S9A= *Bacillus* sp., S10C= *Pseudomonas* sp., += Positive, -= Negative

**Fig 3:** Shows some of the plates of rhizobacteria isolates from rhizosphere soil samples.



Fig 4a: Show gram positive isolate

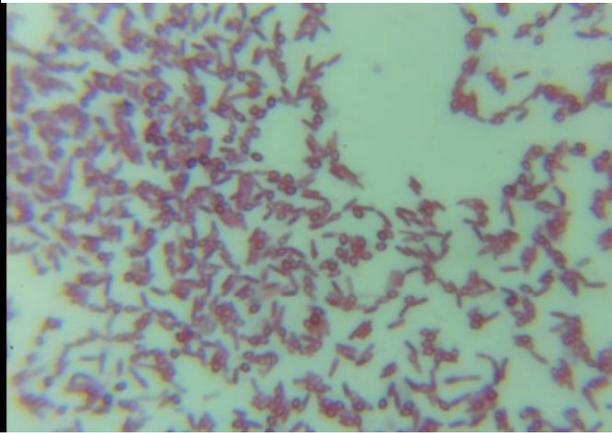


Fig 4b: Show the gram-negative isolate



Fig. 5: Show some of the biochemical tests for rhizobacteria isolates



Fig 4a: Show IAA on PGPB



Fig 4b: Show Phosphate Solubilization on PGPB



Fig 5: Show Ammonia Production on PGPB

DISCUSSION

This study provides a foundational characterization of the cultivable rhizobacterial community in the irrigated rice fields of Damaturu, Yobe State- Nigeria. The predominance of *Bacillus* spp. Is consistent with global studies on rice rhizospheres (Smalla *et al.*, 2001; Agu *et al.*, 2021; Xun *et al.*, 2022; Oledede *et al.*, 2014) and can be attributed to their ability to form endospores, allowing them to withstand the fluctuating moisture and temperature conditions typical of irrigated soils in semi-arid climates.

The observed soil properties create a favourable environment for these bacteria. The near-neutral pH (6.1-7.1) is optimal for the activity of many PGPR, including *Bacillus*, *Pseudomonas* and *Azotobacter* spp. (Kumar *et al.*, 2020). The moderate levels of organic carbon (1.15-1.85%) provide a critical energy source for microbial metabolism. The correlation between higher bacterial counts (S9 *Bacillus* sp.) and specific soil parameters like organic carbon, while preliminary, suggests that soil fertility management could directly influence the size of the beneficial microbial pool.

The isolation of rhizobacteria were presented in fig. 2 which shows the total population of the isolates in collected rhizosphere soil samples and presented in colony forming units, among S9 had large number of colonies 3.18×10^{11} and the lest is S3 1.02×10^{11} CFU/ml, while the S1, S4

and S6 were no colonies after the culture, the finding was to findings of Kloepper, 2009; Perez-Jaramillo *et al.*, 2018; Agu *et al.*, 2021.

The gram staining, morphological and biochemical characteristics (Table 1), the isolates were identified as *Bacillus* spp. (40%), *Pseudomonas* spp. (20%), and *Azotobacter* spp. (10%). All isolates were positive for catalase and oxidase tests. The Previous and recent findings had indicated that *Bacillus* species formed the dominant populations in the rhizospheres of soil samples (Smalla *et al.*, 2001; Xun *et al.*, 2022). Previous study by Ismail *et al.*, 2023 shows the abundance of rhizobacteria *Bacillus* spp. (32.29%) and *Pseudomonas* spp. (17.64%) which is similar to finding of this study. Research finding of Shao *et al.*, 2021 and Zhang *et al.*, 2012; indicated that among many bacterial species in the rhizosphere soils, the population of *Bacillus*, *Pseudomonas*, *Azotobacter* and other species dominated the rhizosphere and showed a high capability to be used as a biofertilizer.

The potential plant growth-promoting (PGP) traits such as indole acetic acid, ammonia production and phosphate solubilization were show in table 2 (S9 *Bacillus* sp.) had a multiple PGP trait indicate potential to serve as biofertilizers, contributing to sustainable rice (*Oryza sativa* L. FARO 44) growth and other crops cultivation as well as reducing the use of chemical fertilizer which agreed with study by

Ajmal *et al.*, 2021 showed that diverse groups of bacteria thrive in environments which may have PGPB ability even under myriad stress conditions. Another study by Agu, Ejigbo and Ezaka, 2021 shows potentials of rhizobacteria isolates from Agricultural farms in Ibadan, to produce most PGP traits phosphate solubilizations, IAA production, ammonia production. Similarly, Farah Ahmad *et al.*, 2008, isolated a total of 19 rhizobacteria belonging to *Bacillus*, *Azotobacter* and *Pseudomonas* species were from different rhizospheric soil determined the production of IAA and observed that more than 70% of the isolates of *Bacillus* spp., produced IAA, whereas only 20% of *Pseudomonas* and 10% *Azotobacter* isolates was IAA producer. Studies by Tang *et al.*, 2020 have shown that IAA can be produced by bacteria and also a diverse group of bacterial species have been reported by Khatoon *et al.*, 2020 to produce IAA including some species reported in this study, which therefore supports the findings of this study. The findings of this study are consistent with global studies identifying these genera as dominant and highly effective PGPR (Backer *et al.*, 2018). Systematically reviewed that the most successful PGPR inoculants often possess multiple growth-promoting mechanisms. The combination of traits in this study for plant growth promoting traits obtained from the rhizobacteria *Bacillus* sp. (S9A) includes IAA which promotes root growth, directly linked to your observed increase in root length., ammonia production provides a readily available nitrogen source and phosphate solubilization crucial in neutral to alkaline soils where P is mostly insoluble. This finding aligned study by Sharma *et al.*, 2011; Kumar *et al.*, 2021.

CONCLUSION

In conclusion, it was observed that the rhizobacteria isolated (S9 *Bacillus* sp.) can serve as biofertilizers were capable of improving the rice (*Oryza sativa* L. FARO) growth due to its potential for biofertilizer production-based on PGP traits, IAA production, ammonia production and phosphate solubilizations. The moderately fertile, clay-loamy soils provide a conducive environment for these microbes. Since rhizobacteria can serve as biofertilizers which are capable of improving the soil fertility

and rice growth, it is now recommended that the use of biofertilizers should be encouraged in applying to rice and other cereal crops for best production and as well as reducing the use of chemical fertilizer usage. There should be better awareness among all the stake holders and farmers on the need to utilize the rhizobacterial isolates as biofertilizers. The primary contribution of this work is the provision of a characterized, locally sourced pool of rhizobacterial isolate from rice irrigation site in Damaturu, Yobe State-Nigeria.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCE

- Adesemoye, A. O., & Kloepper, J. W. (2009). Plant-microbe's interactions in enhanced fertilizer-use efficiency. *Applied Microbiology and Biotechnology*, 85(1), 1–12.
- Agu, E. A. Ejigbo, Olabisi D.O and E. Ezaka (2021): Isolation and characterization of bacteria with biofertilizer potential. *ournal*, www.ftstjournal.com 348 e-ISSN: 24085162; p-ISSN: 20485170; August, 2021: Vol. 6 No. 2 pp. 348 – 351. Supported by Institute of Agricultural Research & Training Moor-Plantation, Ibadan, Olabisi Onabanjo University, Ago Iwoye, Nigeria
- Ajmal AW, Saroosh S, Mulk S, Hassan MN, Yasmin H, Jabeen Z, Nosheen (2021): Bacteria Isolated from Wastewater Irrigated Agricultural Soils Adapt to Heavy Metal Toxicity While Maintaining Their Plant Growth Promoting Traits. *Sustainability*, 2021:13:7792. <https://doi.org/10.3390/su13147792>.
- Backer Rachel, J. Stefan Rokem, Gayathri Ilangumaran, John Lamont, Dana Praslickova, Emily Ricci, Sowmyalakshmi Subramanian & Donald L. Smith. 2018. Review of PGPR (plant growth-promoting rhizobacteria): contexts, mechanisms, commercialization roadmap. *Journal: Frontiers in Plant Science*. Year: 2018; Volume 9: Article 1473. DOI: 10.3389/fpls.2018.01473 [Frontiers+1](https://doi.org/10.3389/fpls.2018.01473)

- Bar-On, Y. M., Phillips, R., & Milo, R. (2018). The biomass distribution on Earth. *Proceedings of the National Academy of Sciences, 115(25), 6506–6511.
- Cheesbrough M (2006) District Laboratory Practice in Tropical Countries Part 2, Second Edition, Cambridge University Press.
- Fahad, Q., Xiukang, W., Haider, F. U., Kučerik, J., Mumtaz, M. Z., Holatko, J., and Mustafa, A. (2021). Rhizosphere bacteria in plant growth promotion, biocontrol, and bioremediation of contaminated sites: A comprehensive review of effects and mechanisms. *International Journal of Molecular Sciences, 22(19), 10529.*
- Farah Ahmad, Iqbal Ahmad, M.S. Khan (2008): Screening of free-living rhizospheric bacteria for their multiple plant growth promoting activities; *Microbiological Research* 163; 173-181.
- Glick, B. R. (1995). The enhancement of plant growth by free-living bacteria. *Canadian Journal of Microbiology, 41(2), 109–117.
- Grema. M. N., Ismail, H. Y. and Muhammad, S (2022). Effect of Biofertilizer, Organic and Inorganic Fertilizers on the Growth Parameters and Root Colonization of *Pennisetum Typhoides* (Burm F.) under Greenhouse Conditions. *Arid Zone Journal of Basic and Applied Research. 1(2): 93-103*
- Haruna Yahaya Ismail, Babangida Isa, Junaidu Sanusi, Bashir Aliyu (2023): In vitro detection of plant growth-promoting traits in bacteria isolated from the rhizosphere of *Vigna unguiculata* (L.) walp. *International Journal of Biology Research* www.biologyjournal.in ISSN: 2455-6548 Received: 20-01-2023, Accepted: 04-02-2023, Published: 23-02-2023 Volume 8, Issue 1, 2023, Page No. 9-15
- Hayat R, Ali S, Amara U, Khalid R, Ahmed I (2010): Soil Beneficial Bacteria and their Role in Plant Growth Promotion: A Review. *Microbiology, 2010:60(4):579-598.* doi:10.1007/s13213-010-0117-1.
- Ibrahim UB, Ismail HY, Farouq AA, Rabah AB, Muhammad AB, Allamin IA. (2021): Microbe-Assisted Phytoremediation of Petroleum Hydrocarbons. In: J. A. Malik (Ed.). *Handbook of Research on Microbial Remediation and Microbial Biotechnology for Sustainable Soil.* IGI Global, USA, 2021.
- J. N. Ukwa1, O. M. C. Uda, N. P. Nweze1, O. C. Okafor, C. N. Ochere, F. A. Ezech (2024): Isolation and Characterization of Biofertilizer Microbes within Rice Rhizosphere of Soil Samples Collected from Different Agroecological Zones of Ebonyi State, Nigeria, for Enhanced Plant Growth. *International Scientific Journal.* Available online at www.worldnewsnaturalsciences.com WNOFNS 57 (2024) 329-353 EISSN 2543-5426
- Joseph B, Ranjan Patra R, Lawrence R (2007). Characterization of plant growth promoting rhizobacteria associated with chickpea (*Cicer arietinum* L.). *International Journal of Plant Production* 1(2):141-152.
- Justin Ganava, Doloum Gomoung, Laurette Ngo Nkot, Steve Takoukam Toukam and Albert Kandarkar, K., Palaniappan, V., Gupta, P. C., Rajasekaran, R., Prabhakaran, J., Sevugapperumal, N., and Gupta, S. K. (2023). Identification of Promising Three-Way Hybrids of Pearl Millet for Drought-Prone Environments of North-Western India. *Agronomy, 13(11), 2813.*
- Kloepper, J.W., Lifshitz, R., Zablutowicz, R.M., Free-living bacterial inocula for enhancing crop productivity. *Trends Biotechnol. (2009) 7, 39-43.*
- Kumar, A., Singh, S., Mukherjee, A., Rastogi, R. P., & Verma, J. P. (2022): Salt-tolerant plant growth-promoting *Bacillus pumilus* strain JPVS11 to enhance plant growth attributes of rice and improve soil health under salinity stress. *Microbiological Research, 242, 126616.*
- Kumar, R., Swapnil, P., Meena, M., Selpair, S., and Yadav, B. G. (2021). Plant growth-promoting rhizobacteria (PGPR):

- Approaches to alleviate abiotic stresses for enhancement of growth and development of medicinal plants. *Sustainability*, 14(23), 15514.
- Long-ping, Y. (2014): Development of hybrid rice to ensure food security. – *Rice Sci.*
- Machido, D.A. (2010). Effects of fungicides on population size and activities of nitrifying and nitrogen fixing bacteria under screen house conditions. Department of Microbiology. Ahmadu Bello University Zaria: A PhD Thesis.
- Mahbouba B, Nadir B, Nadia Y, Abdelhamid D (2013). Phenotypic and molecular characterization of plant growth promoting rhizobacteria isolated from the rhizosphere of wheat (*Triticum durum* Desf.) in Algeria. *African Journal of Microbiology Research* 7(23):2893-2904.
- Marianus Evarist Ngui and Maya Melati (2023): Effects of Bacillus Species Biofertilizer Alone and in Combination with Chemical Fertilizers on the Growth and Development of Rice (*Oryza sativa* L.). *Journal of Agriculture and Environmental Sciences* December 2023, Vol. 12, No. 2, pp. 18-25 ISSN: 2334-2404 (Print), 2334-2412. Published by American Research Institute for Policy Development DOI: 10.15640/jaes.v12n2a2 URL: <https://doi.org/10.15640/jaes.v12n2a2>
- Nikmatul, K., Ratya, A., Nuhfil, H., Wahib, M. A. (2020): The analysis demand for animal source food in Indonesia: using quadratic almost ideal demand system. – *Business: Theory and Practice* 21(1): 427-43.
- Ofori, P. (2016). Yield response of soybean and cowpea to rock phosphate fertilizer blend and rhizobial inoculation on two benchmark soils of Northern Ghana. A thesis: College of agriculture and natural resources, Kwame Nkrumah University of science and technology, Kumasi, Ghana.
- Oladele, S and M. Awodun (2014): Response of lowland rice to biofertilizers inoculation and their effects on growth and yield in Southwestern Nigeria. *Journal of Agriculture and Environmental Sciences*, 3, 371-390.
- Olayemi OP, Odedara OO (2007): Screening of Endophytic Plant Growth-Promoting Bacteria Isolated from Two Nigerian Rice Varieties. *Biotechnology*, 2007:33(1):1-9. doi:10.4314/njb.v33i1.1.
- Oyeleke and Manga SB (2008). *Essential Laboratory Practical in Microbiology.*
- Perez-Jaramillo, J. E., (2018): Ecology and evolution of rhizobacteria. *Annual Review of Phytopathology*, 56, 6.1-6.22.
- Rahmah, D. M., Rizal, F., Bunyamin, A. (2017): Dynamic model of corn production in Indonesia. – *J. Teknotan* 11: 30-40.
- Sakariyawo, O. S., Okeleye, K. A., & Ojo, O. T. (2013). Growth and yield responses of lowland rice (*Oryza sativa* L.) to integrated nutrient management in the humid forest zone of Nigeria. *Journal of Agricultural Science*, 5(9), 1.
- Sarker M, Matsuka A, Komura T, Kanazawa S (2014): Application of a new PCR primer for terminal restriction fragment length polymorphism analysis of the bacterial communities in plant root. *J. Microbiol. Methods*. 59: 81-89.
- Serri, D. L., Pérez-Brandan, C., Meriles, J. M., Salvagiotti, F., Bacigaluppo, S., Malmantile, A., & Vargas-Gil, S. (2022). Development of a soil quality index for sequences with different levels of land occupation using soil chemical, physical and microbiological properties. **Applied Soil Ecology*, 180*, 104621.
- Shao J, Miao Y, Liu K, Ren Y, Xu Z, Zhang N, Xun W. (2021): Rhizosphere microbiome assembly involves seed-borne bacteria in compensatory phosphate solubilization. *Soil Biology and Biochemistry*, 2021:159:108273.
- Sharma S, Kumar V & Tripathi RB (2011): Isolation of phosphate solubilizing microorganism (PSMs) from soil. *J. Microbio. and Biotech. Res.*, 1(2): 90-95.
- Smalla K, Wieland G, Buchner A, Zock A, Parzy J, Kaiser S, Berg G. (2001): Bulk and rhizosphere soil bacterial

- communities studied by denaturing gradient gel electrophoresis: plant-dependent enrichment and seasonal shifts revealed. *Applied and environmental microbiology*,2001:67(10):4742-4751.
- Somchit, P., Sreewongchai, T., Sripichitt, P., Matthayathaworn, W., Uckarach, S., Keawsaard, Y., Worede, F. (2017): Genetic relationships of rice yield and yield components in RILs population derived from a cross between KDML105 and CH1 rice varieties. – *Walailak Journal of Science and Technology (WJST)* 14(12): 997-1004.
- Tang A, Haruna AO, Majid NMA, Jalloh MB (2020): Potential PGPR Properties of Cellulolytic, Nitrogen-Fixing, Phosphate-Solubilizing Bacteria in Rehabilitated Tropical Forest Soil. *Microorganisms*2020:8(3):442- 450.
- Xun W, Ren Y, Yan H, Ma A, Liu Z, Wang L. (2022): Sustained Inhibition of Maize Seed-Borne Fusarium Using a Bacillus-Dominated Rhizospheric Stable Core Microbiota with Unique Cooperative Patterns. *Advanced Science*, 2022, 2205215.
- Zhang J, Ma Y, Yu H. (2012): *Bacillus, Arthrobacter cupressi* sp. nov., an actinomycete isolated from the rhizosphere soil of *Cupressus sempervirens*. *International journal of systematic and environmental microbiology*,2012:62(11):2731-2736.