



Assessing the Growth Promoting and Yield Enhancing Potential of *Bacillus* sp. Based Biofertilizer in Rice *Oryza sativa* L. FARO 44 in a Microcosm in Damaturu, Yobe State, Nigeria

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Abstract

The chemical fertilizer dependency poses economic and environmental challenges in Nigerian rice cultivation. *Bacillus* species are group of rhizobacteria which serve as plant growth promoting bacteria (PGPR) inhabit the rhizosphere and aid root development. These rhizobacteria bacteria are vital to the growth and developments of rice *Oryza sativa* L. FARO 44 and can serve as bio-fertilizer and can enhance food security through green agricultural practices in Nigeria. This study accesses growth promoting and yield of rice using *Bacillus* specie S9A (3.18×10^{11} CFU/g) as biofertilizer in pot experiment in Screen House of Green City Garden Damaturu, Yobe State, Nigeria. Two types of soil samples were used (sterilized and unsterilized soil) and a completely randomized design with four treatments T1: Control (No biofertilizer), T2: 10mg/ml, T3: 15 mg/ml and T4: 20 mg/ml biofertilizer in triplicates. Rice plant height and number of leaves were measured in two weeks interval while root length as well as the weight of grain at harvest were measured at post-harvest 16 weeks after sowing (WAS) and analysed statistically. Soil physicochemical properties and microbial load were analysed pre- and post-harvest. The findings revealed that rice plants height, number leaves, root length and grain weight with 20mg/ml *Bacillus* specie biofertilizer showed high yield followed by 15 and 10mg/ml. The pots with unsterilized soil showed high yield compared to sterile/control pot across the treatments due native microbes likely contributed to nutrient cycling and plant health, creating a more robust plant-growth-promoting system. The study concludes that the *Bacillus* sp. based biofertilizer can effectively promotes rice growth and enhances yield while improving soil health as well as reducing the use of chemical fertilizer. It represents a sustainable strategy for rice production in the semi-arid agro-ecological zone of Damaturu, Yobe State.

Keywords: *Bacillus* sp. S9A, Biofertilizer; *Oryza sativa* L. (FARO 44); PGPR; Physicochemical; Rhizosphere; Semi-Arid Agro-Ecological Zone; Sustainable Agriculture

Introduction

Rice *Oryza sativa* L. is a paramount staple food and prioritized crop, since annual consumption is around 72 kg per capita, it is one of highest in Africa (FAO, 2019). The consumption of rice provides 20% of daily calories to more than 3.5 billion people. In the last years, world cereal production increased by up to 130%, but this is not enough to satisfy the increasing demand (Marianus and Maya, 2023). In Nigeria, food security is threatened by a rapidly growing population and declining agricultural productivity (Munir *et al.*, 2025). Yobe State, in the semi-arid northeastern region, faces significant

agricultural constraints including inherently low soil fertility, erratic rainfall, and high costs of synthetic fertilizers, which hinder optimal rice productivity. Excessive use of chemical fertilizers further leads to soil degradation, groundwater pollution, and increased production costs (Bais *et al.*, 2020; Grema *et al.*, 2022, Munir *et al.*, 2025).

The Nigerian rice has become the most popular and the most important cereal crop consumed by the almost 250 million of Nigerian population (Nikmatul *et al.*, 2020; Rahmah *et al.*, 2017; Munir *et al.*, 2025). The need for this commodity is going to increase year by year due to the population growth (Somchit *et al.*, 2017; Grema *et al.*, 2022). The increase of rice demand cannot be supplied if there is no improvement in rice production. There are several strategies to improve rice production. The high yielding varieties have given significant rice production increase (Linguist *et al.*, 2015). Rice breeding programmes to obtain a new variety with a high grain yield have been reported by previous studies (Hayat *et al.*, 2010; Hasan *et al.*, 2011; Akhtar *et al.*, 2011; Khamwichit *et al.*, 2006; Khatoon *et al.*, 2020). To meet this demand, production has historically relied on chemical fertilizers. However, their intensive use poses severe environmental threats, including soil degradation, water pollution, and greenhouse gas emissions (Alkahtani *et al.*, 2020; Daniel *et al.*, 2022). The high cost and import dependency of these fertilizers further exacerbate the problem for Nigerian farmers (Grema *et al.*, 2022, Munir *et al.*, 2025).

The drastic use of chemical fertilizers in present agriculture has become a key source for high crop yields. The injudicious use of fertilizers is however, polluting the soil and environment at a faster rate. The sole reliance on chemical fertilizers is about 195.4 million metric tonnes annually worldwide is not a sustainable and viable strategy because of the costs, both in domestic resource and foreign exchange involved in setting up fertilizer plants and sustaining the production. Thus, there is an acute need to have some cheaper way to exploit the intrinsic resources of the production system, which may be ecological and human friendly (Saeed *et al.*, 2021).

Biofertilizers containing Plant Growth-Promoting Rhizobacteria (PGPR), such as *Bacillus* species, offer a promising sustainable alternative. *Bacillus* spp. enhances plant growth through multiple mechanisms such as biological nitrogen fixation, phosphate and potassium solubilization, production of indole acetic acid and ammonia, and biocontrol against pathogens (Ngu and Melati, 2023). While studies in southern and northern Nigeria have shown the potential of biofertilizers, region-specific validation is crucial due to the unique edaphic and climatic conditions of the semi-arid Sahel (Grema *et al.*, 2022, Munir *et al.*, 2025). The used of biofertilizers as alternative to chemical fertilizers present a sustainable alternative for integrated nutrient management. They are cost-effective, eco-friendly, and can enhance soil health (Vessey, 2003, Bashan *et al.*, 2014, Agu *et al.*, 2021; Khatoon *et al.*, 2020).

The production and application of biofertilizers for rice growth and other crops are now common in developed world while in developing world it is now gaining pace. The benefits of individual effects of growth promoting bacteria as biofertilizer are well established (Oo *et al.*, 2022; Munir *et al.*, 2025). This study, therefore, aimed to assess the growth-promoting and yield-enhancing potential of a locally formulated *Bacillus* sp. based biofertilizer on rice under microcosm (controlled pot) conditions in Damaturu, Yobe State.

Material and Methods

Materials

The seed of rice *Oryza sativa* L. (FARO-44) was obtained from Institute for Agricultural Research Samaru, Zaria Kaduna State, Nigeria, strain of PGPR *Bacillus* sp. S9A with total population of 3.18×10^{11} colony-forming unit (CFU/ml), 2 litres capacity pot size.

Experimental Duration and Site

The study was conducted from January to April, 2025 at (geographical coordinates on latitude 11.7292899°00'N and longitude 11.9575316°N) at Screen House Green City Garden Damaturu, Yobe State, Nigeria.

Experimental Design/Procedure

The experiment was carried out using two types of soil samples (sterile/control and unsterilized soil) and a completely randomized design (CRD) were used. The physicochemical analysis of the soil samples was conducted before and after harvest (Shi *et al.*, 2011). 2 kg sterilized (control) and unsterilized soil were weighted into a labelled 2 litres capacity pot size for each treatment in three (3) replicates (sterilized soil n = 12 and unsterilized soil n = 12), four (4) different treatments of PGPR *Bacillus* sp. biofertilizer (T1 = 0 mg/ml, T2 = 10 mg/ml, T3 = 15 mg/ml and T4 = 20 mg/ml) were used. The pots were watered for 2 days prior to sowing of rice seed *Oryza sativa* L. (FARO-44), 5-10 seeds were sowed in each container in pot at depth (1-2 cm) randomly with uniform watering across the pot (Zahir *et al.*, 2011). The germination of seed was observed for 7-10 days, followed by seedling, tillering, panicle initiation and flowering (Danladi *et al.*, 2021; Grema *et al.*, 2022, Ukwa *et al.*, 2024, Munir *et al.*, 2025). The prepared PGPR *Bacillus* sp. biofertilizers concentrations (0, 10, 15 and 20 mg/ml) were applied in soil drench at interval of 2 weeks after sowing (2 WAS). The matured rice at pot were harvested after 3-4 months as well as the height and number of leaves were recorded. The rice grain yield weight with husk and without husk and root length were recorded at post-harvest 16 Weeks After Sowing (WAS) and analyzed statistically at $p < 0.05$ Duncan's Multiple Range Test (DMRT) (Marianus & Maya, 2023, Rekha *et al.*, 2018, Danladi *et al.*, 2021, Ngui & Melati, 2023).

Results

This study reveals physicochemical parameters; Soil texture is clay-loam which are good for water and nutrient retention, pH, E.C, TDS, OC, N, WHC, Na and CEC in control/sterile were a bit normal and favorable while for unsterilized soil in pots were normal and more favorable for lowland rice cultivation.

Table 1 shows the growth (number of leaves) of rice treated with different concentrations of a *Bacillus* sp. S9A biofertilizer in a sterilized pot experiment over 16 weeks. The highest concentration of biofertilizer 20 mg/ml, consistently produced the most leaves from week 6 onwards and resulted in a statistically significant higher final leaf count at 16 weeks after sowing (WAS).

Table 1: Number of Leaves Treated with Different Concentrations of Biofertilizer (*Bacillus* sp.S9A) at Pot Experiment (Sterilized Soil) In Damaturu, Nigeria

T (mg/ml)	Number of Leaves Per Plant (WAS)							
	2	4	6	8	10	12	14	16
0	1.7±0.6 ^o	3.3±0.6 ^{mno}	5.7±1.5 ^{kl}	10.0±1.0 ^l	12.7±1.5 ⁱ	16.3±0.6 ^h	18.7±0.6 ^{fg}	24.3±0.6 ^{de}
10	2.3±0.6 ^{no}	4.3±0.6 ^{lmn}	8.7±0.6 ^j	15.0±1.0 ^h	16.0±1.0 ^h	18.7±0.6 ^{fg}	20.0±1.0 ^{fg}	25.7±0.6 ^{cd}
15	3.0±0.0 ^{no}	5.3±0.6 ^{klm}	10.0±1.0 ^j	15.3±1.5 ^h	16.3±0.6 ^h	18.7±0.6 ^{fg}	23.3±0.6 ^e	28.3±0.6 ^b
20	3.7±0.6 ^{lmno}	6.7±0.6 ^k	15.7±0.6 ^h	18.3±0.6 ^g	20.7±1.2 ^f	23.3±0.6 ^e	27.0±1.0 ^{bc}	32.0±4.6 ^a

T= Treatment, T1= Control 0mg/ml, T2= 10 mg/ml, T3= 15mg/ml, T4= 20 mg/ml, WAS= week after sowing, alphabets in means with the same superscript in the same column are not significantly different at $p < 0.05$ Duncan's multiple range test (DMRT). Values are presented as mean ± SD

Table 2 shows the plant height of rice treated with different concentrations in a sterilized pot experiment over 16 weeks. The highest biofertilizer concentration, 20 mg/ml, resulted in significantly plants height from week 6 onwards, which show a strong growth-promoting effect on the rice. The control group (0mg/ml) consistently showed the least growth throughout the experiment.

Table 2: Plant Height Treated with Different Concentrations of Biofertilizer (*Bacillus* sp. S9A) At Pot Experiment (Sterilized Soil) In Damaturu, Nigeria

T (mg/ml)	Plant Height (WAS)							
	2	4	6	8	10	12	14	16
0	3.3±0.6 ^q	5.7±0.6 ^{pq}	10.7±1.5 ⁿ	16.7±1.5 ^l	19.7±0.6 ^k	26.3±2.1 ^{hi}	30.0±1.0 ^{fg}	36.7±2.5 ^{de}
10	4.3±0.6 ^q	8.3±0.6 ^o	15.3±0.6 ^l	21.0±1.0 ^k	24.7±0.6 ^{ji}	28.3±0.6 ^{gh}	32.0±1.0 ^f	38.0±1.0 ^d
15	5.3±0.6 ^{pq}	10.7±0.6 ⁿ	17.3±0.6 ^l	23.7±0.6 ^j	27.7±0.6 ^h	31.0±1.0 ^f	37.0±2.0 ^{de}	41.0±1.0 ^c
20	7.3±0.6 ^{op}	13.0±1.0 ^m	21.0±1.0 ^k	30.7±1.5 ^f	35.0±1.0 ^e	39.0±1.0 ^{cd}	45.3±2.1 ^b	50.3±4.2 ^a

T= Treatment, T1= Control 0mg/ml, T2= 10 mg/ml, T3= 15mg/ml, T4= 20 mg/ml, WAS= week after sowing, alphabets in means with the same superscript in the same column are not significantly different at $p < 0.05$ Duncan's multiple range test (DMRT). Values are presented as mean \pm SD

Table 3 shows the number of leaves of rice treated with different concentrations of a *Bacillus* sp. S9A biofertilizer in an unsterilized soil in pot over 16 weeks. Unlike in sterilized experiment, the control (0mg/ml) started with a high leaf count and later change to other treatments due to the complex interactions in the unsterilized soil with present microbiome. The highest biofertilizer concentration, 20 mg/ml, had produced the most leaves from week 4 onwards and resulted in a significantly higher final leaf count at 16 (WAS) compared to all other treatments.

Table 3: Number of Leaves Treated with Different Concentrations of Biofertilizer (*Bacillus* sp. S9A) At Pot Experiment (Unsterilized Soil) In Damaturu, Nigeria

T (mg/ml)	Number of Leaves Per Plant (WAS)							
	2	4	6	8	10	12	14	16
0	12.3±0.6 ^q	6.0±0.0 ^p	10.7±1.5 ^{no}	13.7±0.6 ^m	18.3±0.6 ^k	22.7±1.2 ^{hi}	25.3±0.6 ^{fg}	29.7±1.2 ^e
10	3.3±0.6 ^q	6.0±1.0 ^p	11.7±1.5 ⁿ	15.7±0.6 ^l	21.0±1.0 ^{ji}	24.3±1.5 ^{gh}	27.0±1.0 ^f	34.3±1.2 ^{cd}
15	3.7±0.6 ^q	7.7±0.6 ^p	13.7±0.6 ^m	17.3±0.6 ^{kl}	21.0±1.0 ^{ji}	26.0±1.0 ^{fg}	33.0±2.0 ^d	39.0±1.0 ^b
20	4.0±0.0 ^q	9.7±0.6 ^o	15.7±0.6 ^l	20.3±1.5 ⁱ	22.3±0.6 ^j	29.7±0.6 ^e	35.3±0.6 ^c	45.3±3.2 ^a

T= Treatment, T1= Control 0mg/ml, T2= 10 mg/ml, T3= 15mg/ml, T4= 20 mg/ml, WAS= week after sowing, alphabets in means with the same superscript in the same column are not significantly different at $p < 0.05$ Duncan's multiple range test (DMRT). Values are presented as mean \pm SD.

Table 4 shows the plant height (in cm) of rice treated with different concentrations of a *Bacillus* sp. S9A biofertilizer in an unsterilized pot over 16 weeks. The highest biofertilizer concentration, 20 mg/ml, resulted in significantly plants height from week 2 onwards, which show a strong growth-promoting effect on the rice. Therefore, unsterilized soil shows a wide plant height compared to unsterilized soil, the application of 20mg/ml biofertilizer had significantly enhanced plant height.

Table 4: Plant Height Treated with Different Concentrations of Biofertilizer (*Bacillus* sp.S9A) At Pot Experiment (Unsterilized Soil) In Damaturu, Nigeria

T(mg/ml)	Plant Height (WAS)							
	2	4	6	8	10	12	14	16
0	4.3±0.6 ^p	11.7±1.5 ⁿ	8.0±1.0 ^l	23.0±1.0 ^j	27.7±0.6 ^h	32.0±1.0 ^g	36.3±1.5 ^e	41.7±1.5 ^d
10	5.3±0.6 ^p	12.7±0.6 ^{mn}	20.7±0.6 ^k	27.3±1.5 ^h	34.0±1.0 ^f	37.0±1.0 ^e	41.0±1.0 ^d	49.7±2.5 ^c
15	6.3±0.6 ^{op}	14.3±0.6 ^m	21.7±1.5 ^{lk}	30.7±0.6 ^g	36.7±0.6 ^e	42.0±1.0 ^d	49.3±2.5 ^c	58.0±1.0 ^b
20	7.7±0.6 ^o	16.7±0.6 ^l	25.0±1.0 ^j	35.0±1.0 ^{ef}	40.0±1.0 ^d	48.0±1.0 ^c	57.0±2.0 ^b	66.0±2.0 ^a

T= Treatment, T1= Control 0mg/ml, T2= 10 mg/ml, T3= 15mg/ml, T4= 20 mg/ml, WAS= week after sowing, alphabets in means with the same superscript in the same column are not significantly different at $p < 0.05$ Duncan's multiple range test (DMRT). Values are presented as mean \pm SD

Table 5 shows final root length of rice *Oryza sativa* L. (FARO-44) plants after 16 weeks, biofertilizer concentrations (0, 10, 15 and 20mg/ml) were used. 20mg/ml concentrations show significantly longer roots in unsterilized soil type compared to sterilized soil. The *Bacillus* sp. biofertilizer is highly effective in promoting root growth of rice with its benefits shows in unsterilized soil which shows a synergy between the applied biofertilizer and the native soil microbiome.

Table 5: Plant Root Length at Post-Harvest Treated with Different Concentrations of Biofertilizer (*Bacillus* Sp.S9A) At Pot Experiment (Sterilized and Unsterilized Soil) In Damaturu, Nigeria

T(mg/ml)	Root Length Per Plant (Cm) 16WAS	
	Sterilized Soil	Unsterilized Soil
0	11.7±1.5 ^d	15.0±1.0 ^d
10	16.6±1.0 ^c	22.0±1.0 ^c
15	19.3±0.6 ^b	26.0±1.0 ^b
20	26.0±1.0 ^a	34.0±1.0 ^a

T= Treatment, T1= Control 0mg/ml, T2= 10 mg/ml, T3= 15mg/ml, T4= 20 mg/ml, WAS= week after sowing, alphabets in means with the same superscript in the same column are not significantly different at p< 0.05 Duncan's multiple range test (DMRT). Values are presented as mean ± SD

Figure 1 presents bar chart on the rice grain yield after 16 weeks post-harvest, showing the weight of rice grains with and without husks after treatment with different *Bacillus* sp.S9A biofertilizer concentrations in both sterilized and unsterilized soil types in pot. 20 mg/ml show more grain yield in both soil type, but best and higher grain yield shows in unsterilized soil across the treatment, which is likely due a synergistic effect between the biofertilizer and the native soil microbiome, 20mg/ml concentration, had great ability to increase rice grain yield.

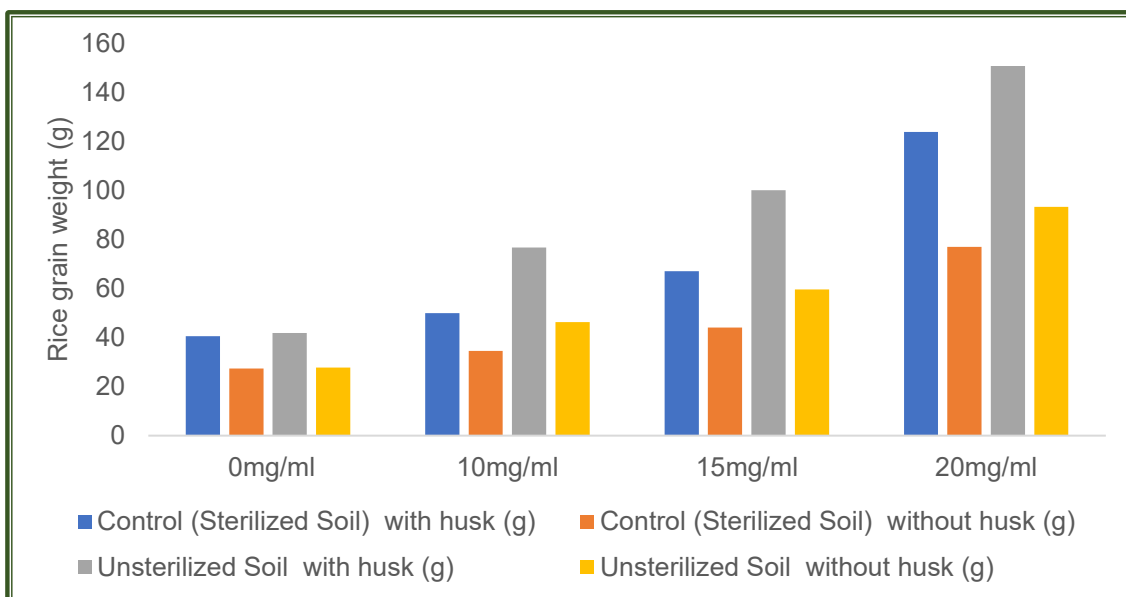


Figure 1: Rice yield (grain weight) at post-harvest (16WAS) treated with different concentrations of biofertilizer (*Bacillus* sp.S9A) at pot.

Figure 2 presents bar chart on the nutritional composition (proximate analysis) of rice grains harvested from plants grown in sterilized/control soil with different concentrations of *Bacillus* sp.S9A biofertilizer. The carbohydrates contents in control 0mg/ml (38.2%) whereas treatments 10mg/ml, 15mg/ml, and 20mg/ml show higher carbohydrate content over 47%. The moisture and ash contents show a significant decrease, while other variable components such as fat, protein, and fibre content showed some variation. The highest biofertilizer treatment 20mg/ml provided the most consistent and desirable results compared to 0, 10 and 15mg/ml. The biofertilizer treatments used across improved the nutritional quality of rice grains by increasing carbohydrate content and reducing moisture and ash.

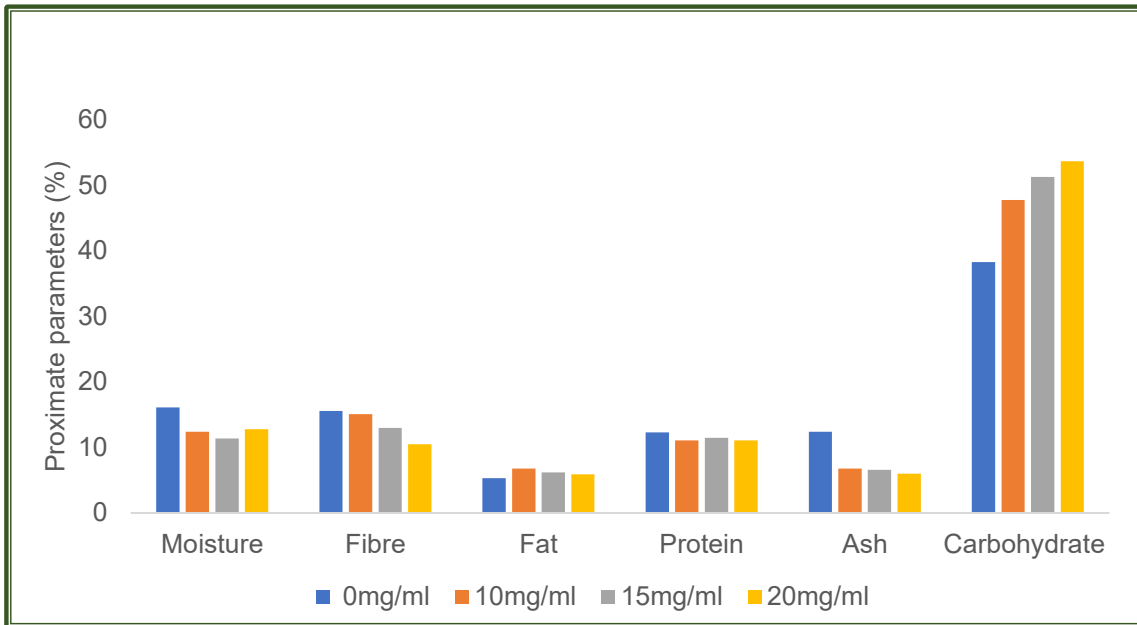


Figure 2: Proximate compositions of rice *Oryza sativa* L. grain yield at 16 weeks treated with different concentrations of biofertilizer (*Bacillus* sp.S9A) at pot experiment (Sterilized/control soil)

Figure 3 presents bar chart on the nutritional composition (proximate analysis) of rice grains harvested from plants grown in unsterilized soil with different concentrations of *Bacillus* sp.S9A biofertilizer. Unlike the sterilized soil, the effect in unsterilized soil shows better content which is due to interactions between the biofertilizer and the native soil microbiome. The carbohydrates and protein contents in 15 mg/ml were higher (57.7%) and average protein content in 10mg/ml (14.4%) and 20mg/ml (13.0%). The moisture and ash content were generally lower across all treatments. The highest concentration 15 and 20mg/ml provided the most consistent and balanced nutritional profile.

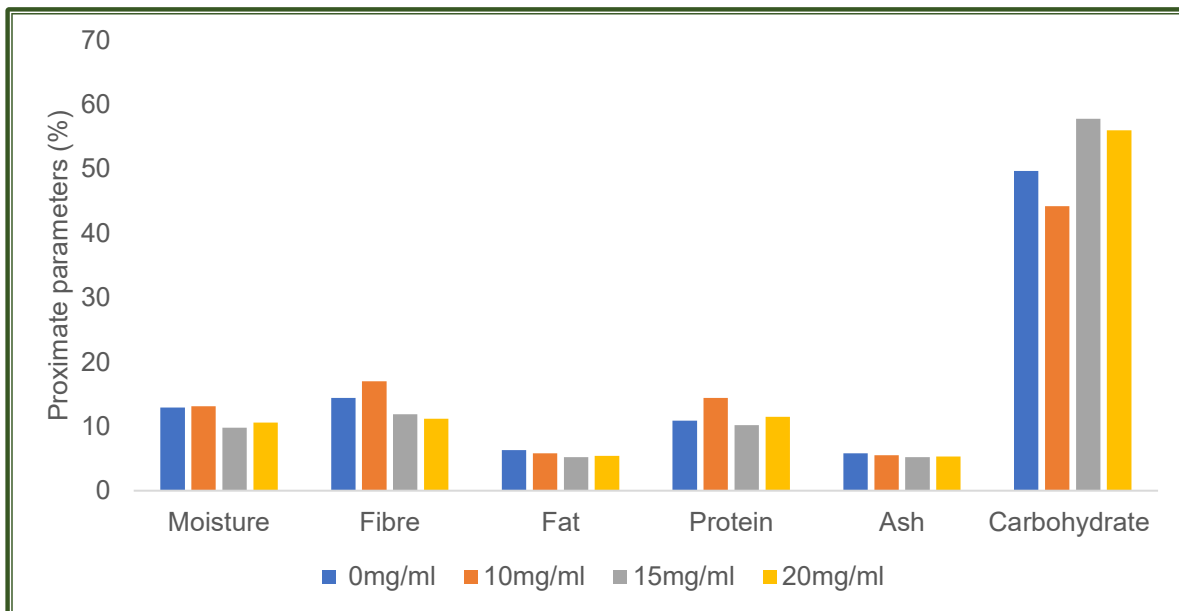


Figure 3: Proximate compositions of rice *Oryza sativa* L. grain yield at 16 weeks treated with different concentrations of biofertilizer (*Bacillus* sp.S9A) at pot experiment (unsterilized soil).



Figure 4: Show Rice Seed *Oryza sativa* L. FARO-44 Obtained from Institute for Agricultural Research, Samaru Zaria, Kaduna State-Nigeria



Figure 5: Show Pot Experiment (Sterilized and Unsterilized Soil) For Growth of Rice *Oryza sativa* L. FARO-44 In Screen House, Green City Garden, Damaturu, Yobe State-Nigeria



Figure 6: Show Rice *Oryza sativa* L. FARO-44 Growth Stages in Pot Experiment



Figure 7: Show Rice *Oryza sativa* L. FARO-44 At Harvest in Pot Experiment



Figure 8: Roots Length Measurement for Sterilized/Control Soil at Post-Harvest 16weeks After Sowing at Pot Experiment



Figure 9: Roots Length Measurement for Unsterilized Soil at Post-Harvest 16weeks After Sowing at Pot Experiment

Discussion

This study evaluated the efficacy of a locally developed *Bacillus* sp.S9A biofertilizer on the growth, yield, and nutritional quality of rice *Oryza sativa* L. FARO 44 rice under controlled microcosm conditions in Damaturu, Nigeria. The findings of this study reveal significant improvements across multiple agronomic and physiological parameters, demonstrating the potential of microbial inoculants as sustainable alternatives to chemical fertilizers to burst food productions and reduce environmental hazard due to overuses of chemical fertilizers in the region. The soil physiochemistry is important to agricultural chemists for plant growth and soil management. The driven nutrient status information can be an efficient tool for farmers and policymakers in adopting site-specific nutrient management practices (Backer *et al.*, 2018; Shrestha *et al.*, 2020; Munir *et al.*, 2025).

Rice *Oryza sativa* (FARO-44) growth, development, and production are all dependent on nutrient availability in the soil (Mus *et al.*, 2016). Therefore, findings of this study reveal the values or percentages of physicochemical parameters; Soil texture were good for water and nutrient retention, pH, E.C, TDS, OC, N, WHC, Na and CEC in sterilized/control, unsterilized soil in pot experiment were normal and favourable for lowland rice cultivation which is similar to findings of Mus *et al.*, 2016; Johnston *et al.*, 2009; Dandwate, 2020; Shaik and Shakir, 2018. The findings of Saeed *et al.*, 2021; Kumar *et al.*, 2021; Vurukonda *et al.*, 2016 are also similar to this finding.

The vegetative growths for number of leaves of rice *Oryza sativa* L. in pot experiment; sterilized/control soil in table 1 at 16 Weeks After Sowing (WAS) in this study shown at 2 WAS there was no significant difference in all the treated pots (T1-T3). Pots treated with T4 (20 mg/ml) *Bacillus* sp.S9A biofertilizer was significantly higher ($p < 0.05$) at 10 WAS through 16 WAS. Similarly, table 3 shown the number of leaves of rice for 16 weeks after sowing (WAS) in pot experiment for unsterilized soil. at 2 WAS there was no significant difference in all the treated pots. At 4 WAS treatments T1-T3 had no significant difference, pots treated with T4 (20 mg/ml) *Bacillus* sp.S9A biofertilizer were significantly higher ($p < 0.05$) at 8 WAS through 16 WAS. In this study, the number of leaves is directly depended on the treatments (0-20 mg/ml) of biofertilizer used, at T4 (20 mg/ml), likewise it depends on the types of soil used, in sterilized/control soil, numbers leave was less compared to unsterilized soil, this is because native microbes likely contributed to nutrient cycling and plant health, creating a more robust plant-growth-promoting system. This synergy is a cornerstone of sustainable agriculture and is supported by recent findings on microbiome engineering and biofertilizer (Munir *et al.*, 2025; Ngui & Melati, 2023; Olayemi & Odedara, 2017; Agu *et al.*, 2021; Trivedi *et al.*, 2020).

The finding in this study on plant height in both sterilized/control and unsterilized soil show in table 2 for sterilized and table 4 for unsterilized soil. Table 2 shows plant height of rice for 16 weeks after sowing (WAS) in pot experiment for sterilized/control soil in pot, treatment 0, 10 and 15 mg/ml at 2 WAS there was no significant difference in all the treated pots whereas pots treated with T4 (20 mg/ml) *Bacillus* sp.S9A biofertilizer was significantly higher ($p < 0.05$) at 6 WAS through 16 WAS, table 4 shows plant height of rice for 16 weeks after sowing (WAS) in pot experiment for unsterilized soil, treatment 0, 10 and 15 mg/ml at 2 WAS there was no significant difference in all the treated pots whereas pots treated with T4 (20 mg/ml) *Bacillus* sp.S9A biofertilizer was significantly higher ($p < 0.05$) at 6 WAS through 16 WAS. Therefore, this study also agreed with findings by Marianus and Maya, 2023 were observed continuous supply of nitrogen nutrient to soils through N₂-fixation by the *Bacillus* species, is explained as other reasons for such highest growth in rice plants height. This is also evidenced on the rice plants fertilized with 0 mg/ml and 10 mg/ml, despite of the reduction of inorganic fertilizers by 75% and 50% respectively plant heights were not significantly different with plants in T5. *Bacillus* species are also known to release phytohormone, indole-3-acetic acid (Talboys *et al.*, 2014) which also has a role in promoting shoots growth and stem elongation. Plant height is interrelated with the photosynthesis process, as the highest plants have more access to capture sunlight as compared to short ones. Studies by Barraquio *et al.*, 2019, Oladele and Awodun, 2014; Singh *et al.*, 2018; Ngui and Melati, 2023; Munir *et al.*, 2025 also reported an increased heights of rice plants due to applications of biofertilizers. Significantly different on plant heights was observed on paddy varieties too, whereby IPB 3S paddy variety had an increase of 33% higher at 9 weeks after sowing. The plant growth and yield parameters

were generally better in unsterilized soil compared sterilized/control soil type in pot experiment. The dose-dependent increase in the number of plant height in both pot and field experiment, with T4 (20 mg/ml) consistently performing best compared to 0, 10 and 15mg/ml treatments. This is a classic and expected response to effective PGPR inoculation. The production of IAA and improved nutrient availability (P, N) directly stimulate cell division and elongation. Similar dose-dependent growth promotion in rice with *Bacillus* spp. and *Pseudomonas* spp. inoculation was reported by Saeed *et al.*, 2021; Musa and Ikhajagbe, 2023. The superior performance in unsterilized soil highlights a synergistic plant-microbiome interaction, a concept central to sustainable agriculture (Trivedi *et al.*, 2020).

The root length and growth of rice increase as a direct consequence of bacterial IAA production, which promotes root cell division and elongation. This leads to a more extensive root system, enhancing the plant's capacity for water and nutrient uptake, which in turn fuels superior shoot growth (plant height, leaf number). This cascade of effects from root to shoot is a well-documented PGPR phenomenon (Vejan *et al.*, 2016; Ngui & Melati, 2023). Table 5 in this study shown the roots length, mean and standard deviation for the both sterilized/control, unsterilized soil pot experiment, rice root length for 16 weeks after sowing (WAS) were measured in centimeter (cm) and recorded. In, sterilized/control soil treatment 20 mg/ml had highest root length and the least is 0mg/ml, while in unsterilized soil 20mg/ml also had highest root length and the least 0mg/ml. Similar studies by Oladele and Awodun (2014); Agu *et al.*, 2021 shows the root lengths were directly due to production of IAA by *Bacillus* spp. and *Pseudomonas* spp. used in growth of rice in lowland. Findings by Ngui and Melati, 2023, also reported improvement in roots growth due to application of biofertilizer in lowland rice plants. However, plants produce natural auxin hormone at their shoot and root tips (endogenous auxin) which promote their elongation and growth. The added exogenous auxin hormone released by *Bacillus* species had significantly affect to the increase of roots length and its volume. As pointed out by Ramos-Solano *et al.*, 2010; Glick, 2012; Shafi *et al.*, 2017 Indole-3-Acetic-Acid has also an essential role in the origination and formation of adventitious roots. Plants having large roots volume are likely to rise the amount of nutrients absorption from the soils hence further crop growth is achieved. The control (0mg/ml) treated plants marked the lowest on growth performance i.e., root length and volume as observed during 9 WAT and at harvest period. Low nutrients availability in the soils could be a reason. Depending on the strain of *Bacillus* bacteria, their general effect to plant is either direct, i.e., through plant growth hormone promotion, or indirect, i.e., through improving plant nutrition by solubilizing mechanisms and making unavailable nutrients into available to the plants during plant-bacterial interaction (Shafi *et al.*, 2017, Patel *et al.*, 2015). *Bacillus megaterium* and *Bacillus subtilis* are referred to as the most important strains (Govindasamy *et al.*, 2010) since, the bacteria are effective in phosphates solubilizes into inorganic forms that are available to plant roots uptake (Goswami *et al.*, 2016; Marianus & Maya, 2023).

A study by Marianus and Maya, 2023 aligned with the finding of this study in a way that high growth performance on both aspects roots length and plant growth was as a result of both plant growth hormone promotion and phosphate solubilization effects. According to Santana *et al.*, 2016 IAA and Phosphate Solubilizing Microbes mineralize soil organic P by the production of phosphatases such as phytase enzyme that hydrolyze organic forms of phosphate compounds, thereby releasing inorganic phosphorous that absorbed by plant roots. A study by Trivedi *et al.*, 2020 shows the superior performance in field, unsterilized soil compared to sterilized/control soil is indicated a synergistic relationship between the inoculated *Bacillus* spp. and the indigenous soil microbiome. This synergy likely creates a more robust rhizosphere environment for nutrient cycling and pathogen suppression. This aligned by finding of this study.

Figure 1 above presents bar chart on the rice grain yield after 16 weeks post-harvest, showing the weight of rice grains with and without husks after treatment with different *Bacillus* sp. biofertilizer concentrations in both sterilized and unsterilized soils in pot experiment, treatment (20 mg/ml) show more grain yield in both soil type, but best and higher grain yield shows in unsterilized soil across the treatment, which is likely due a synergistic effect between the biofertilizer and the native soil microbiome. The remarkable increase in rice grain yield, particularly in 20 mg/ml dose in unsterilized soil in pot is of paramount practical importance. This aligns with numerous studies by Kumar *et al.*, 2021

where they reported a 20-30% yield increase in rice with *Bacillus* spp. inoculation, while Rana *et al.*, 2012 found significant yield improvements in rice *Oryza sativa*, this can be attributed to the combined effects of a highly potent multi-trait of plant growth promoting isolate, an effective biocarrier (rice husk), and positive synergy with the native microbiome in field soil and unsterilized soil in pot. It demonstrates that biofertilizers can be a primary input for rice grain yield enhancement, not just a supplement. Recent work by Marianus and Maya, 2023 also reported high rice grain yield increases in rice *Oryza sativa* using consortia, underscoring the potential of microbial solutions.

Figure 2 above present bar chart on the nutritional composition (proximate analysis) of rice grains harvested from plants grown in sterilized/control soil with different concentrations (0, 10, 15 and 20mg/ml) of *Bacillus* sp.S9A biofertilizer. The most significant effect of the biofertilizer is a major change in the grain's carbohydrate, moisture, and ash content. The carbohydrates contents in control 0mg/ml (38.2%) whereas treatments 10, 15 and 20mg/ml shows higher CHO content over 47%. The moisture and ash contents show a significant decrease, while other variable components such as fat, protein, and fibre content showed some variation. The highest biofertilizer treatment (20mg/ml) provided the most consistent and desirable results compared to 0, 10 and 15mg/ml. The biofertilizer treatments used across improved the nutritional quality of rice grains by increasing carbohydrate content and reducing moisture and ash.

Figure 3 above present bar chart on the proximate analysis of rice grains harvested from plants grown in unsterilized soil in pot with different concentrations (0, 10, 15 and 20mg/ml) of *Bacillus* sp.S9A biofertilizer. Unlike the sterilized soil, the effects in unsterilized soil shows better content which is due to interactions between the biofertilizer and the native soil microbiome. The carbohydrates and protein contents in 15 mg/ml was higher (57.7%) and average protein content in 10mg/ml (14.4%) and 20mg/ml (13.0%). The moisture and ash content were generally lower across all treatments compared to the sterilized soil experiment, indicating a baseline improvement in grain quality from the native microbiome. The highest concentration (15 and 20mg/ml) provided the most consistent and balanced nutritional profile. This demonstrates the role of PGPB in plant growth and yield. The increase in carbohydrates suggests enhanced photosynthetic efficiency and better carbon partitioning to the grains. The increase in protein is directly linked to improved nitrogen nutrition, possibly through ammonia production and enhanced N-uptake efficiency (Ibrahim *et al.*, 2021, Agu *et al.*, 2021; Hapsah *et al.*, 2021; Munir *et al.*, 2025). Guardiola-Márquez *et al.*, 2023 reviewed how PGPB can upregulate plant metabolic pathways leading to improved grain quality. The variability between soil types again underscores the complex interaction between the inoculant and the soil environment, influencing the final nutritional outcome (Hapsah *et al.*, 2021; Foysal & Lisa, 2018; Singh & Prasad, 2014). In this study, the biofertilizer used *Bacillus* sp. positively influenced the quality of the harvest shown in figure 2 and 3 above. The alterations in grain composition highlight that biofertilizers do not merely act as growth stimulants but can modulate the plant's metabolic pathways to improve the nutritional value of food, a finding with significant implications for food security (Singh & Prasad, 2014; Munir *et al.*, 2025). The findings of this study align with previous studies by Eggum *et al.*, 1982; Ibrahim *et al.*, 2021 were the rice samples contained high quantities of carbohydrates ranging from 66.92 to 56.03%. and other compositions within the range, although these values are higher than the values, they are a bit lower than the values (70.37 to 62.37%) reported by Edeogu *et al.*, 2007 who analysed the proximate compositions of rice in Ebonyi State-Nigeria. This low carbohydrate content may be attributed to its high moisture content which also affects the milling quality and other environmental factors. The high percentage carbohydrate contents of the rice show that rice is a good source of energy. The ash content of a rice sample gives an idea of the mineral elements present in the rice sample. Among the five treatments, T5 had the highest protein content (16.22%). This is in agreement with the findings of Ebuehi and Oyewole, 2007; Uzah *et al.*, 2024 who analysed the effect of different biofertilizer concentrations in rice *Oryza sativa* L. (FARO-44) in Nigeria.

Conclusion

In conclusion, it was observed that the findings of this research revealed *Bacillus* species bacteria at higher concentrations (20 mg/ml) applied as biofertilizer to rice grown in pot experiment significantly improved rice plants growth (roots length, height, number leaves and nutritional compositions). *Bacillus* sp.S9A biofertilizer used in this study offers a viable, sustainable option for enhancing rice production in northern Nigeria. Its effectiveness aligns with both regional and global research, underscoring the potential of microbial biotechnology to address food security and nutritional challenges in semi-arid regions. Therefore, these findings support the integration of biofertilizers into Nigeria's Agricultural Policy, as advocated by the FMARD, 2020 and the Yobe State Agricultural Development Strategy.

Conflict of Interest

The authors declare have no conflict of interest.

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