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Yield Response of African Rice Genotypes to Mycorrhizal Fungi and Rhizobium Inoculation

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Authors' contributions

This work was carried out in collaboration among all authors. Authors SO, MA and AO designed the study, author SO performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SO and MA managed the analyses of the study. Author AO managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: A short term field study was conducted to investigate the yield performance of selected African rice genotypes inoculated with biofertilizers.
Study Design: A randomized complete block design laid out in a split-plot arrangement was used to evaluate response of yield components and grain yield of some selected African rice genotypes will be to mycorrhizal fungi and rhizobium inoculation.
Place and Duration of Study: The study was conducted at the Teaching and Research farm of the Federal university of technology, Akure Ondo state, Nigeria during the 2013 planting season.
Methodology: The study was laid out in a split plot arrangement in Randomized Complete Block Design (RCBD), with mycorrhizal fungi, rhizobium inoculation and control in the main plot, while genotypes (N-U-1, N-U-8, WAB 56-104, OFADA GR and MOROBEREKAN) were in the sub-plot and treatments were replicated thrice. There were three main blocks, each block consist of 15 sub-

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plots with a size measurement of 2m x 1m and inter sub-plot spacing of 0.5m in between plots. A total of 50 plants were raised per sub plot. Transplanted seedlings were planted with the soil slurry containing rhizobium and mycorrhizal fungi inoculum into planting holes in the field at two seedlings per stand, according to their respective plot at a spacing of 25cm x 25cm. Yield component data collected include; number of days to 90% maturity, number of days to 50% flowering; plant height at maturity, number of primary tillers per plot, number of grains per panicle, number of panicles, number of filled and unfilled spikelet, weight of 1000 filled grains and grain yield per plot.

Results: Result showed significant ($P<0.05$) single and interactive effect of rhizobium and mycorrhizal fungi inoculation on rice yield and yield components. 61.4% increase in grain yield was observed in rhizobium inoculated genotypes when compared to 37.4% increase in mycorrhized genotypes and the un-inoculated control. WAB56–104 and N-U-8 had the best interactive response amongst genotypes inoculated with rhizobium while genotypes WAB56-104 and MOROBEREKAN responded better amongst mycorrhized genotypes in relation to yield components.

Conclusion: The results from this study indicate that African rice genotypes differ in grain yield response and host specifity when inoculated with mycorrhizal fungi and rhizobium inoculums. However, inoculating specific African rice genotypes with mycorrhizal fungi and rhizobium can positively influence their grain yield and yield component development and this could play an important role in improving African rice productivity.

Keywords: Mycorrhizal fungi; rhizobium; biofertilizer; African rice; grain yield.

1. INTRODUCTION

Rice (*Oryza sativa*) is a major staple food for millions of people in West Africa and the most in-demand staple amongst cereal crops in Nigeria's food basket [1,2]. Rice cultivation and production in Nigeria has increased in recent times due to series of government initiatives, change in policies and increased efforts towards self-sufficiency. However, there has been a considerable lag between production and demand level with imports making up the shortfall. The low productivity of the rice production system in Nigeria is due to a lot of factors such as socio-economic constraint, crop management system and lack or no access to external inputs [3]. Rain fed upland rice production system is the dominant cultivation system across several agro-ecological zones in Nigeria [2]. Several abiotic and biotic factors are responsible for the low productivity of upland rice production system [4]. Studies have shown that nitrogen deficiency, phosphorus fixation, weed build-up, rice blast and drought are the leading constraints to upland rice production in Nigeria [5,2]. Small holder farmers, who are the predominant rice growers in the country are unable to realize the potentials of recently released improved high yielding African rice genotypes such as NERICA which mine soil nutrients rapidly and have higher nutrient use efficiency than traditional genotypes. Furthermore, smallholder farmers lack the financial resources to purchase chemical fertilizer to replenish mined nutrient from the soil. Exploitation of microbial sources such as mycorrhizal fungi and rhizobium as biofertilizers for rice growth promotion and increased yield have been previously tested due to their excellent endophytic plant-microbe interactions [6,7]. Mycorrhizal fungi are excellent colonizer of plant roots. They help colonized plant in accessing water especially during dry spells and also help in the uptake and solubilization of immobile soil nutrients while the plants supplies carbon as food and energy source to the fungi in a symbiotic relationship [8]; [9]. Phosphorus (P) deficiency and fixation can severely limits rice production; colonization of plant root with mycorrhizal fungi may have an influencing effect on P solubilization, uptake, and plant growth [10]. Rhizobium are largely recognized for their role in nodule formation in leguminous crops through biological nitrogen fixation but studies have also shown that they can be inoculated into non-leguminous crops such as rice for plant growth promotion and increase yield [11]; [6]; [7]. They are widely regarded as the most efficient biofertilizer in relation to the quantity of nitrogen fixed. Rhizobium is said to promote plant growth through mobilization and fixation of nutrient, improving plant resistance to abiotic stress, solubilization of nutrients in nutrient fixed soils, release of plant growth-hormones [7,10,12,13, 14]. Therefore, coating African rice genotype seed or soaking seedlings in soil slurry with mycorrhizal fungi and rhizobium inoculum before planting or transplanting could help in improving nitrogen and phosphorus bioavailability and uptake in deficient soils which would help

improve rice yields, increase economic return to farmers and mitigate environmental pollution. There has been scanty experimental evidence in Nigeria on the ability of Rhizobium which are normally associated with leguminous crops and the ability of arbuscular mycorrhizal fungi (AMF) to colonize roots of certain cereals e.g. rice, in nutrient deficient soils and promote their growth and yield. Increased interest in nitrogen fixing bacteria associated with cereals such as rice, wheat and maize has been shown in recent times to reduce the use of expensive mineral fertilizers in cereal production. One of the reasons for the success recorded with nitrogen fixation independent of nodule formation in rice studies is the observation that nitrogen status of rainfed and irrigated lowland soils under rice cultivation has increased due to the activities of nitrogen fixing bacteria which survived under such condition evident with increased growth and population of beneficial microbes [14,15]. Inoculation and improvement of cereals through nitrogen fixing bacteria have been observed in various field studies [16,3,4,17]. However, studies conducted by Shrestha and Ladha [18], suggested that response of rice genotypes to inoculation with beneficial organisms may differ due to specificity of plant-bacterial and fungi associations, gas exchange and differences in root exudation. Therefore, rice genotypes with the best response from inoculations with introduced or native beneficial organisms should be selected for recommendation. With this in hindsight, the study was set up to evaluate the performance of African rice genotypes inoculated with mycorrhizal fungi and rhizobium under field conditions with a view to identify promising and best performing inoculated genotypes in terms of yield for recommendation.

2. MATERIALS AND METHODS

2.1 Description of Location and Experimental Site

The study was conducted at the Teaching and Research farm of the Federal university of technology, Akure Ondo state, Nigeria during the planting season of 2013. The vegetation is a tropical rain forest with an average relative humidity of between 56 and 59% during the dry season and between 80% - 85% during the wet season. The study site is located between Latitude 5°'08 10.5''E and 7°'17' 59.2''N, and at elevation of 140 m above the mean sea level. The site has an average annual rainfall of about 1613mm per annum and an annual mean temperature of 27°C. However, during the course of the experiment, average annual rainfall fell to 1233mm and temperature level increased to a mean average of 31°C due to fluctuations in weather conditions. The Soil at the experimental site was a Sandy clay loam classified under the soil order alfisol according to USDA/NRCS [19] soil classification. The experimental site was ploughed, cleared and pegged before transplanting and experimental blocks were laid out and sectioned accordingly. Seedlings were transplanted with the soil slurry carefully to prevent root damage and also to ensure optimal root colonization by inoculated inoculums. Seedlings of each variety were planted in each designated block. There was no pre or post application of herbicides/pesticides and no basal or recommended fertilizer application was added throughout the duration of the experiment. Weeding was done manually by hoe and hand.

2.2 Nursery Practice

The nursery stage was conducted at the screen house of the Department of Crop Soil and Pest Management of the Federal University of Technology, Akure. Micro polythene pots of about 5cm in diameter and 10cm in length were filled with topsoil and mixed with mycorrhizae (*Glomus intaradices*) and rhizobium strains (RACA 3/5/12) separately to form slurry at a weight of 50g per pot; this was done to ensure maximum colonization of rice roots before transplanting. Rice seeds were sown at 5 seeds per pot and was later thinned to 2 seedlings per pot. The pots were made moist and maintained for about 14 days, and thereafter germinated seedlings were transplanted to the field.

2.3 Pre-planting Soil Analysis

Soil samples were collected at a depth of 0-15cm and bulked together prior to the determination of physico-chemical properties before planting. Soil pH was determined in 1:2.5 (soil: water) ratio using glass electrode pH meter. Soil organic matter was determined according to Walkey and Black [20] method. Total nitrogen in the soil was determined using Kjeldahl method [21]. Available phosphorus was extracted using Bray-1 P followed by molybdenum blue colorimetry. Exchangeable cation (K, Ca, Mg) were extracted with 1 N Ammonium Acetate K and the extract was determined by flame photometry, Ca and Mg were determined by Atomic Absorption Spectrophotometer (AAS) (Table 1).

The pre-plant soil physico-chemical properties of the experimental site as shown above indicate that the soil contains 60.4%, 26%, and 13.6% sand, silt and clay respectively and falls into the textural class of sandy clay loam. The soil organic carbon and total nitrogen values were 1.90% and 0.28g/kg respectively which are below critical limit. The soil was acidic with a pH of 5.03 and has a cation exchange capacity (CEC) of 6.68; potassium level of 2.04cmolkg^{-1}; phosphorus level of 26.58mg/kg^{-1}; magnesium level of 2.13 cmolkg^{-1} and calcium level of 2.51cmolkg^{-1}. Analysis indicate the need for nitrogen and phosphorus fertilization as they are deficient in the soil and in an unavailable form for plant use, which justified the need for inoculation with biofertilizers which will help to increase nutrient availability and uptake for enhanced rice yield.

Table 1. Physico-chemical properties of experimental soil before planting

Soil properties	Values
Sand (%)	60.4
Clay (%)	26
Silt (%)	13.6
Textural class	Sandy clay loam
Nitrogen (g/kg)	0.28
Organic Carbon (%)	1.90
Organic Matter (%)	3.26
Calcium (cmol/kg)	2.51
Magnessium (cmol/kg)	2.13
Potassium (cmol/kg)	2.04
Phosphorus (mg/kg)	26.58
pH	5.03
CEC	6.68

**mean values are presented in the table (n = 4)*

2.4 Experimental Design

The study was a split plot arrangement in Randomized Complete Block Design (RCBD), with mycorrhizal fungi, rhizobium inoculation and control in the main plot, while genotypes were in the sub-plot (N-U-1, N-U-8, WAB 56-104, OFADA GR and MOROBEREKAN) and the treatments were replicated thrice. There were three main plots, each plot consist of 15 sub-plots with a size measurement of 2 m x 1 m and inter sub-plot spacing of 0.5 m in between plots. A total of 50 plants were planted per sub plot. Transplanted seedlings were planted with the soil slurry into planting holes in the field at two seedlings per stand, according to their respective plot at a spacing of 25 cm x 25 cm³.

2.5 Source and Application of Planting Materials

The different rice seeds (genotypes) were acquired from Africa Rice Centre, International Institute of Tropical Agriculture, Ibadan (IITA). The genotypes collected are the recently released improved high yielding genotypes for rice farmers in the study area. Cultured Arbuscular mycorrhizae fungi *(Glomus intaradices*) inoculum with soil as carrier and cultured Rhizobium strains (RACA 3/5/12) were obtained from the International Institute of Tropical Agriculture (IITA) Ibadan, Nigeria.

2.6 Culture Media and Growth Condition

The pure cultures of rhizobium strain RACA 3/5/12 was obtained from the (microbial technology culture department), International Institute of Tropical Agriculture, ibadan Nigeria (IITA). Rhizobium sp, RACA was isolated from root nodules of cowpea, the strain were characterized by biochemical methods. Rhizobium sp, RACA was maintained on yeast extract manitol agar medium. The culture were maintained by periodic transfer and stored in the refrigerator. Photomicrography was used to examine roots of rice genotypes inoculated with mycorrhizal fungi and rhizobium to view and ascertain root colonization by the microbes.

2.7 Mycorrhizal Infection Determination

Portions of rice roots were collected, using a clean knife from all the replicates, in plastic bottles for the mycorrhizal infection determination before the grinding and storage in 50% ethanol. Mycorrhizal fungi staining in the roots was achieved by heating the root samples in 10% KOH, rinsing with distilled water and soaking in 1% HCl for 10 minutes. Trypan blue solution was used to stain the roots. The roots were soaked in the Trypan blue solution for 2 hours, and the stained roots were distained with 50% glycerol. The grid-intersect method of Giovanetti and Mosse [22] was used to evaluate the percentage of root infection. The data in (Table 2) reveals maximum root colonization in rice genotypes treatment inoculated with introduced mycorrhizal fungi (*Glomus intaradices*) (86%). It was also observed that rhizobium inoculated treatments also recorded a (41%) root colonization by native mycorrhizae fungi while the un-inoculated treatments recorded the lowest root colonization (10%) by native mycorrhizal fungi.

Table 2. Mycorrhizal fungi infection in roots of rice plants

Treatments	% Colonization
Mycorrhizal fungi	86
Rhizobium	41
Control (native mycorrhizal fungi colonization)	10

2.8 Data Collection and Statistical Analysis

Data collected were number of days to 90% maturity; Number of days to 50% flowering, Plant height at Maturity; Number of primary tillers per plot; Number of grains per panicle; Number of panicles; Number of filled and unfilled spikelet; Weight of 1,000 filled grains (g); Grain yield per plot (kg); this was taken by converting the grain yield per plot into hectare using the formula ([*weight in grams/m*^{2}]*10) [23]. The data collected were statistically analyzed, all data were checked prior to statistical analysis for probable violation of ANOVA assumption, and means were separated using Duncan multiple range test. SPSS 20th edition statistical package was used for the analysis.

3. RESULTS

3.1 Effects of Mycorrhizal Fungi and Rhizobium Inoculation on Yield Components of Rice Genotypes

3.1.1 Plant height at maturity

The result presented in Table 3, indicate significant (P<0.05) single effect of rhizobium and mycorrhizal fungi inoculation on plant height at maturity. Rice genotypes inoculated with rhizobium recorded higher plant heights (92.42cm) over the un-inoculated control (88.10cm). With respect to interactions between rice genotypes and biofertilizer treatments, no significant (P<0.05) interaction was observed in plant height at maturity for both mycorrhized and rhizobium inoculated genotypes. However, rice genotype N-U-8 recorded the lowest plant height while Moroberekan a local rice genotype was the tallest and had the best response amongst all genotypes studied.

3.1.2 Number of grains per panicle

Significant interaction (P<0.05) was observed between biofertilizers and rice genotypes (Fig.1), biofertilizer inoculated genotypes had better performance when compared with the un-inoculated control genotypes. Rice genotype (N-U-8) produced the highest number of grains per panicle (210) and genotype (OFADA GR) the lowest number of grains per panicle (160) amongst rhizobium inoculated genotypes. Rice genotype (WAB 56-104) produced the highest number of grains per panicle (150) amongst mycorrhized genotypes. Single effect of mycorrhizal fungi and rhizobium inoculation on rice plants are presented in (Table 3). Significant (P<0.05) differences were observed with respect to number of grains per panicle (Table 3). Rhizobium inoculated genotypes recorded the highest number of grains per panicle 187.05 and were significantly different from both mycorrhized genotypes (131.59) and the un-inoculated control (86.15). Mycorrhized genotypes were significantly different with higher number of grains per panicle recorded when compared with the un-inoculated control (Table 3).

3.1.3 Number of panicle

There was no significant (P<0.05) interaction observed between biofertilizer treatments and genotypes. However, rice genotype (N-U-8) and (WAB 56-104) produced the highest panicle number and genotype (OFADA GR) produced the lowest panicle number in both treatments respectively (Fig. 2). Significant (P<0.05) differences were observed in total number of panicles produced by rice genotypes (Table 3). Rhizobium inoculated genotypes recorded the highest panicle number (49.14) closely followed by mycorrhized genotypes (41.70) while the un-inoculated genotypes produced the lowest panicle number (31.08) (Table 3).

3.1.4 Number of filled and unfilled spikelet

Table 3, present the effect of rhizobium and mycorrhizae inoculation on number of filled spikelet and un-filled spikelet produced by inoculated rice genotypes. Significant (P<0.05) differences were observed amongst treatments, rhizobium inoculated genotypes had the highest filled spikelets (139.17) and un-filled spikelet (47.86), mycorrhized inoculated genotypes also recorded high filled spikelet number (102.10), it however produced lower un-filled spikelet number (29.63) than rhizobium inoculated genotypes. The Un-inoculated genotypes recorded the lowest filled spikelet number (60.81) and un-filled spikelet number (25.07). There was however no significant (P<0.05) interaction observed with respect to number of filled spikelet and un-filled spikelet in both mycorrhized and

rhizobium inoculated genotypes (Figs. 3 & 4). Rice genotype (N-U-8) produced the highest filled spikelet and genotype (OFADA GR) produced the highest unfilled spikelet amongst rhizobium inoculated genotypes. Amongst mycorrhized genotypes, no significant ($P < 0.05$) interaction was observed between biofertilizers and genotypes. However, rice genotype (WAB 56-104) recorded the highest number of filled spikelet, while genotype N-U-8 was recorded to have the highest number of unfilled spikelet.

3.1.5 Number of primary tillers

Significant ($P<0.05$) differences were observed in treatments with respect to number of primary tillers produced by rice genotypes (Table 3). Single effects of biofertilizer inoculation indicate that rhizobium inoculated genotypes produced more tillers (11.46) when compared with un-inoculated genotypes (6.37). Mycorrhized genotypes were statistically significant and also produced more tillers (7.06) than the un-inoculated genotypes (Table 3). Significant interactions were observed between biofertilizer inoculation and genotypes (Fig. 5). Genotype OFADA GR inoculated with rhizobium produced more tillers amongst rhizobium inoculated genotypes and across all treatments. Genotype N-U-8 recorded the highest number of tillers amongst mycorrhized genotypes while MOROBEREKAN recorded the lowest tiller numbers in both rhizobium inoculated and mycorrhized genotypes respectively (Fig. 5).

3.1.6 Numbers of days to 50% flowering and 90% maturity

There was no significant ($P<0.05$) difference observed with respect to days-to-50% flowering and days-to-90% maturity amongst treatments (Table 3). However, results indicate that the un-inoculated treatment flowered and matured earlier (71.40 and 85.20 days respectively) than mycorrhizal treatment (86.87 and 102.33 days) and rhizobium treatments (88 and 102.80 days respectively). Figs. 6 and 7 shows the significant interaction between biofertilizers and genotypes in reaching days to 50% flowering and days to 95% maturity. Significant ($P<0.05$) interaction was only recorded in days to 50% flowering for both rhizobium inoculated and mycorrhized genotypes. Rice genotype (N-U-8) flowered the earliest amongst rhizobium inoculated genotypes, while genotype (MOROBEREKAN) flowered late. With respect to days to 90% maturity, genotype N-U-8 also matured the earliest and MOROBEREKAN matured late. In mycorrhized genotypes, significant ($P<0.05$) interaction was observed with respect to days to flowering, N-U-1 flowered earlier while MOROBEREKAN flowered late.

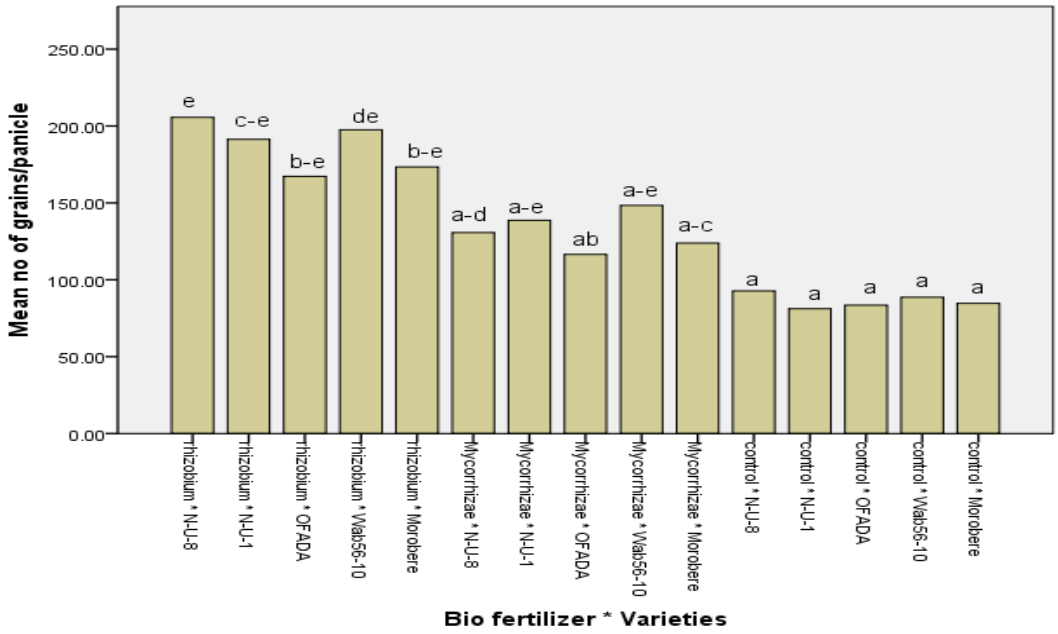

Fig. 1. Interactive effect of mycorrhizae and rhizobium inoculation on rice genotypes and number of grains per panicle

Standard error (P=0.05)

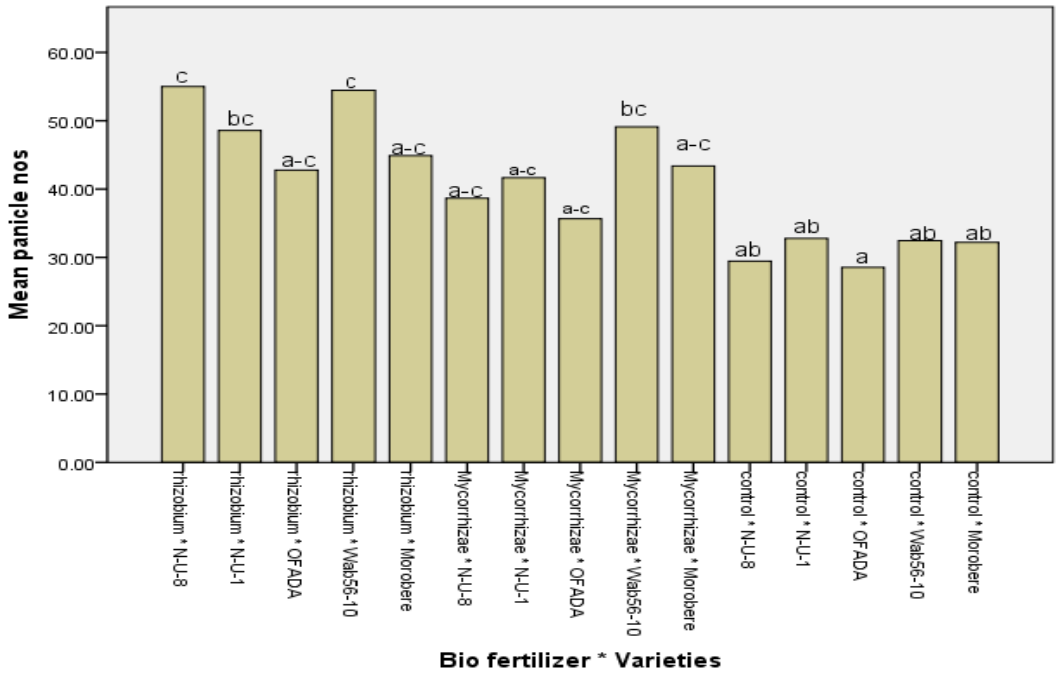

Fig. 2. Interactive effect of mycorrhizae and rhizobium inoculation on rice genotypes and number of panicles

Standard error (P=0.05)

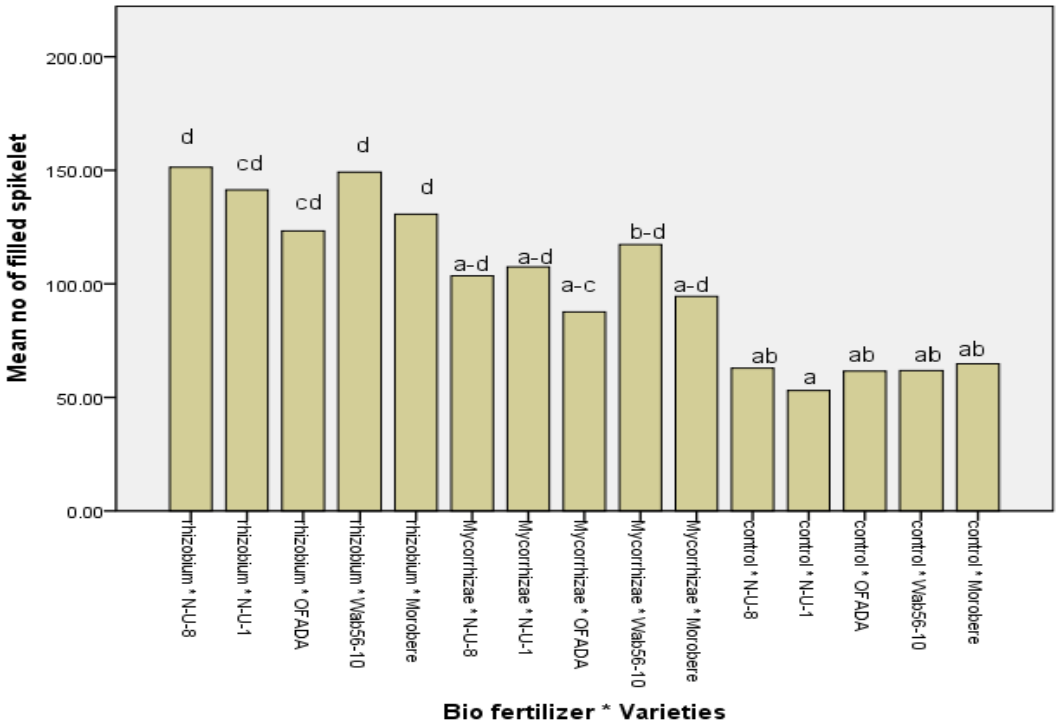

Fig. 3. Interactive effect of mycorrhizae and rhizobium inoculation on rice genotypes and number of filled spikelets

Standard error (P=0.05)

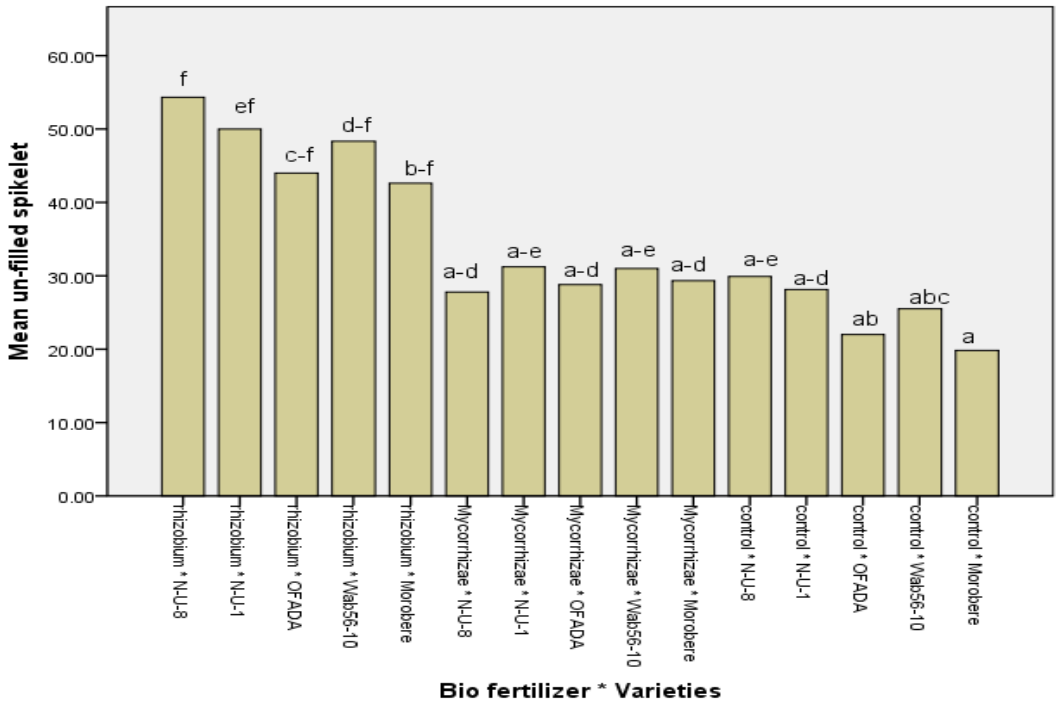

Fig. 4. Interactive effect of mycorrhizae and rhizobium inoculation on rice genotypes and number of unfilled spikelet

Standard error (P=0.05)

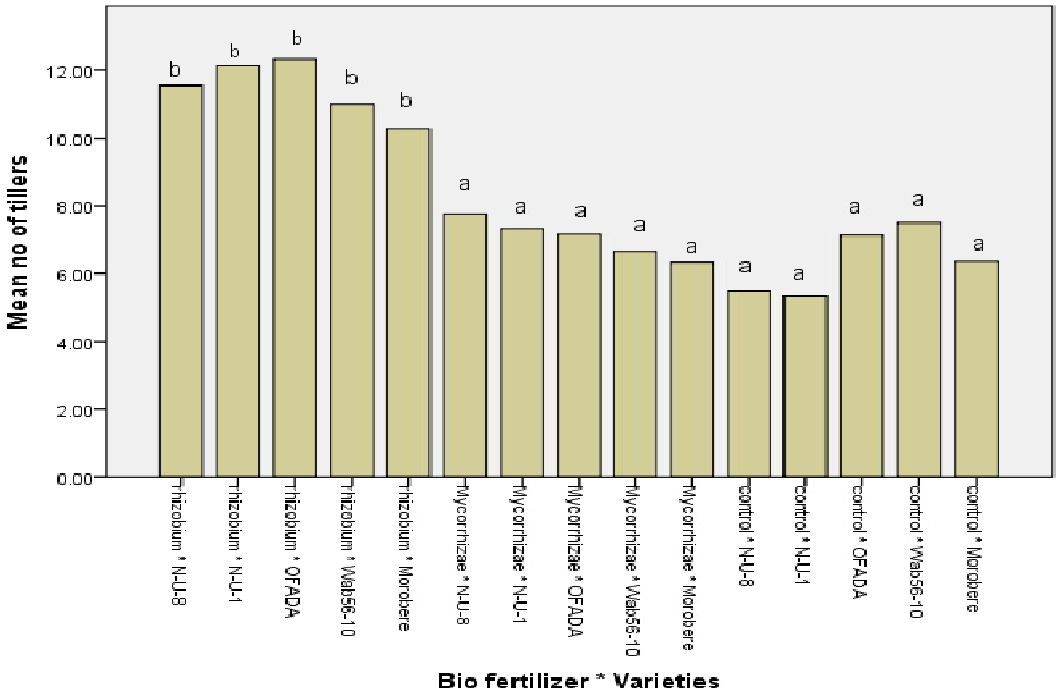

Fig. 5. Interactive effect of mycorrhizae and rhizobium inoculation on rice genotypes and number of primary tillers

Standard error (P=0.05)

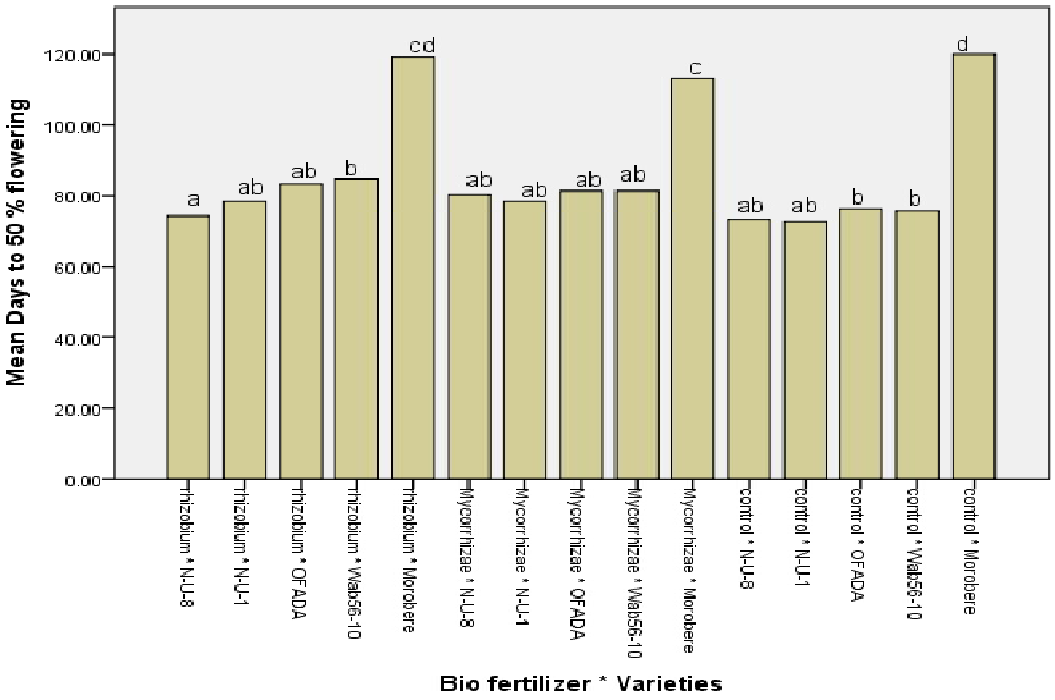

Fig. 6. Interactive effect of mycorrhizae and rhizobium inoculation on rice genotypes and days to 50% flowering

Standard error (P=0.05)

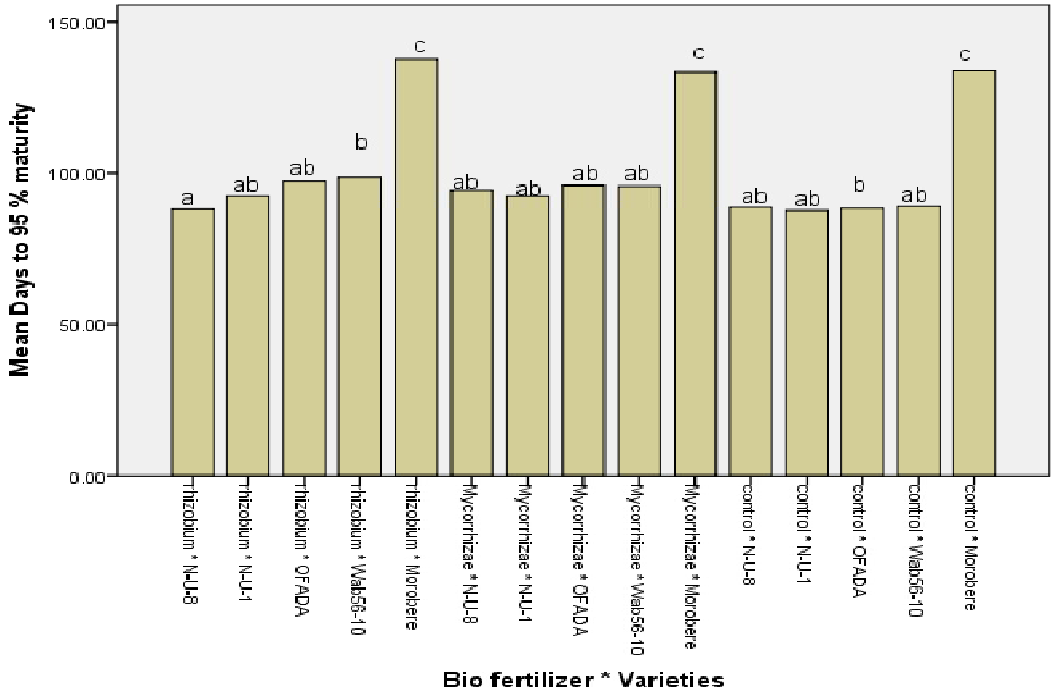

Fig. 7. Interactive effect of mycorrhizae and rhizobium inoculation on rice genotypes and days to 95% maturity

Standard error (P=0.05)

Table 3. Single effect of mycorrhizal fungi and rhizobium inoculation on yield and yield components of rice

Treatments	Number of grains/ panicle	Panicle number	Number of filled spikelet	Number of un-filled spikelet	Plant height at maturity (cm)	Number of primary tillers	Number of days to 50% flowering	Number of days to 95% maturity	Grain yield (kg/ha)	1000 grain weight (g)
Control	86.15c	31.08c	60.81c	25.07c	88.10b	6.37c	71.40a	85.20b	1089.60c	27.1b
Rhizobium	187.05a	49.14a	139.17a	47.86a	92.42a	11.46a	88.00a	102.80a	1759.20a	29.6a
Mycorrhizae	131.59b	41.70b	102.10b	29.63b	86.18b	7.06b	86.87a	102.33a	1497.60b	30.1a

**Means with the same letter in same column are not significantly different from one another using Duncan Multiple Range Test (DMRT) (P = 0.05)*

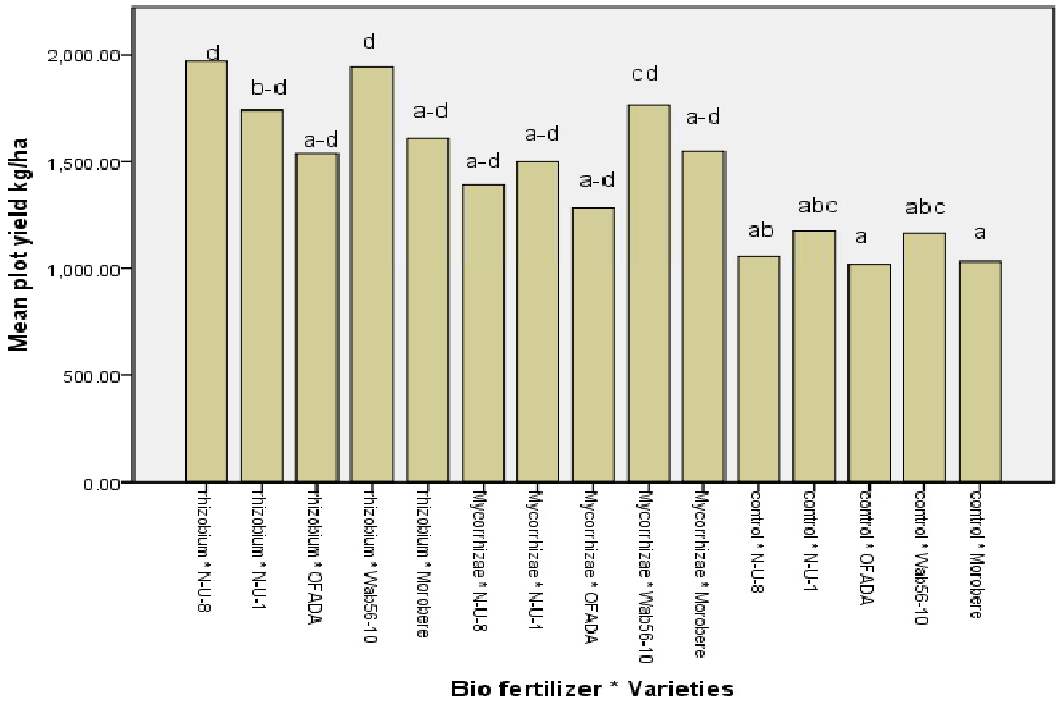

Fig. 8. Interactive effect of mycorrhizae and rhizobium inoculation on rice genotypes and grain yield

Standard error (P=0.05)

3.1.7 Grain yield and 1000 grain weight

Table 3, shows the significant (*P*<0.05) effect of treatments on grain yield and weight of rice grain produced. Rhizobium inoculated treatments recorded higher grain yield than mycorrhizal treatment and the un-inoculated control treatment. Mycorrhizal treatments however had higher 1000 grain weight which wasn't significantly different from rhizobium treatment and the un-inoculated treatment. There was no significant (*P*<0.05) interaction observed in rhizobium inoculated genotypes with respect to grain yield (Fig 8). Rice genotype (N-U-8) produced the highest grain yield while genotype (OFADA GR) produced the lowest. With respect to 1000 grain weight, no significant (*P*<0.05) interaction was observed between treatment and genotypes however, genotype N-U-8 and N-U-1 produced the highest grain weight while genotype (MOROBEREKAN) produced the lowest grain weight. Amongst mycorrhized genotypes, no significant (*P*<0.05) interaction was observed with respect to grain yield. However, genotype (WAB 56-104) produced the highest grain yield. Significant (*P*<0.05) interaction was observed between mycorrhizae and genotypes for 1000 grain weight. Rice genotype (N-U-1) recorded the highest 1000 grain weight while genotype (WAB 56-104) weighed the lowest.

4. DISCUSSION

Increase in yield observed in some African rice genotypes in this study could be attributed to the positive host-plant response to microbial inoculation, biological N fixation and production of plant growth promoting hormones by introduced root colonizing organism. Findings from our study are consistent with field evaluations conducted in Israel and other semi-arid regions [24,25] on performance of cereals such as wheat inoculated with biofertilizer (*Azospirillum* strain Cd) where significant increase in yield were observed. However, some cereal crop genotypes may portray significant differences in their ability to associate with nitrogen fixing bacteria or mycorrhizal fungi. This assertion was observed in our study as genotype WAB56–104 and N-U-8 had better association with rhizobium inoculant, while WAB56-104 and MOROBEREKAN had better association with mycorrhizal fungi inoculants amongst all five genotypes evaluated. This finding was further corroborated by Smith et al. [26], who also

observed better response, growth promotion and an increase in dry plant weight and total N in grain of two select genotypes of sorghum, inoculated with three different strains of *Azospirillum*. Findings from our study indicate that development and yield components of some African rice genotypes were significantly influenced by inoculation with mycorrhizal fungi and rhizobium. These inoculated genotypes recorded higher statistical values over the un-inoculated control, with the rhizobium inoculated rice genotypes recording a 61.4% increase in grain yield over the un-inoculated rice genotypes. Our result established the effectiveness of the introduced rhizobium strain in improving the development and yield of some NERICA lines and two other indigenous genotypes used in the study. The increase in growth, development and yield parameters in response to rhizobium inoculation endorsed the fact that they have one or more growth and yield promoting mechanisms. However, Smith et al. [26] reported that rice plants inoculated with *A. lipoferum*, *A*l 121 and *A. brasilense* did not influence rice growth or grain yield. A field study conducted by Ali et al. [27] in which rice plants were inoculated with nitrogen fixing bacteria indicated that addition of low input of mineral N fertilizer increased rice yield, nitrogen use efficiency and biological nitrogen fixation under flooded lowland conditions. The increase in our studied characters could be ascribed to improvement in soil nutrient availability and nutrient uptake due to the secretion of auxins or hormones and nitrogen fixation by mycorrhizal fungi and bacteria inoculation [28,29]. Findings from our study are in agreement with Husssain et al. [11] who reported 16% increase in number of panicles and grains/panicle per plant of rice and suggested that the improvement was due to increased availability of nutrients and phytohormones like indole acetic acid and ethylene. Our findings was also corroborated by studies conducted by Peng et al. [30] who observed that inoculation of rice varieties with rhizobium enhanced their stomatal conductance which led to an increased photosynthetic rates of about 12% and a 16% increase in grain yield at harvest. Their study also observed a positive correlation between increased grain yield and photosynthetic rate without nitrogen fertilizer application. Furthermore, [7] also reported that inoculation of rice with different rhizobium strains such as *Rhizobium leguminosarum* bv. *trifolii* E11, *Rhizobium* sp. IRBG74 and *Bradyrhizobium* sp. IRBG271 increased rice grain and straw yields by 8 to 22 and 4 to 19%, respectively, at different nitrogen fertilizer rates and a further 10 - 28% increase in N, P and K and 15 - 64% increase in Fe uptake partitioned in analysed rice grain and straw. The increase in 1000 grain weight in our study observed with inoculations with rhizobium and mycorrhizal fungi could be attributed to reduced spikelet number produced by inoculated genotypes which consequently resulted in increased grain filling due to adequate amount of photosynthetic material assimilated [31,32]. Our result also agrees with Chi et al. [33] who observed about 23.63% increase in developments of rice such as number of grains per panicle, filled spikelets, panicle lengths and tillering over un-inoculated control and argued that indole acetic acid (IAA) and gibberellins production could be the key mechanism for that improvement. Maximum yield in inoculated plants may be attributed to the symbiotic relationship of rhizobium (bacteria) with the roots of the plants, which fixed atmospheric nitrogen into the roots of rice and thus the yield was increased. Early flowering and maturity observed in the un-inoculated control than inoculated genotypes is suggested to be an induced phenotypic response to limiting abiotic stress, such as moisture stress and high temperature. Mycorrhizae inoculated genotypes was observed to have benefitted greatly through increased yield component and also a 37.4% increase in grain yield. This positive influence on inoculated genotypes could be attributed to increased phosphorus, nitrogen uptake, phytohormones such as cytokinins, essential micro-nutrients e.g Fe, Zn, Cu by rice plants which lead to better development response and yield. Our result was also in agreement with Sakariyawo et al. [5], who reported that inoculation of AMF resulted in comparatively better performance in growth, development and yield of some selected drought tolerant upland rice genotypes investigated in the rainforest transitory zone of Nigeria. However in the un-inoculated control, where the soil was phosphorus and nitrogen deficient and no biofertilizer added the plants grew poorly and yield was low. The potential benefit of exploiting this endophytic plant-bacterium association for cereal production also extends to decreased environmental pollution and health risks originating from excessive use of mineral N fertilizers to achieve high grain yield [6]. Finally the study has demonstrated that the single use of rhizobium and arbuscular mycorrhizae fungi can enhance rice growth and yield through changes induced in growth physiology and root morphology of rice genotypes. Further studies are required to test this study across differing

agro-ecologies and use of more genotypes and different strains of rhizobium and mycorrhizae for efficient selection and appropriate recommendation.

5. CONCLUSION

This study reveals that inoculation with biofertilizers resulted in comparatively better performance in relation to yield components of African rice genotypes inoculated than the un-inoculated. The yield of genotypes N-U-8, N-U-1, WAB56-104, OFADA Gr and MOROBEREKAN were statistically similar irrespective of the different biofertilizer treatment applied. However, single rhizobium inoculated genotypes had slightly marginal better performance over mycorrhizal inoculated genotypes. In rhizobium inoculated genotypes, WAB56–104 and N-U-8 had the best response, while in mycorrhizal inoculated genotypes, WAB56-104 and MOROBEREKAN recorded better response with respect to yield. Results from this study indicate that African rice genotypes differ in grain yield response and host specifity when inoculated with mycorrhizal fungi and rhizobium inoculums. However, inoculating specific African rice genotypes with mycorrhizal fungi and rhizobium can positively influence their grain yield and yield component development and this could play an important role in improving African rice productivity. Authors acknowledge that the present study was short term which requires further field studies for validation before recommendations and scientific inferences can be made. Furthermore, future studies should be conducted to ascertain reported synergistic effect and performance of dual inoculation of mycorrhizal fungi and rhizobium on rice growth and yield and their comparison with mineral fertilized rice genotypes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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