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# Effect of biofertilzer containing nitrogen fixers, phosphate solubilizer and arbuscular mycorrhizal fungus on Growth and yield of aerobic rice

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**Abstract**
A pot experiment was conducted using the nitrogen fixing and phosphate solubilizing organisms and two reference strains *viz., A. chroococcum* and *B. megaterium* along with an arbuscular mycorrhizal fungus, *G. fasciculatum* either singly or in combinations under glass house conditions. The results for growth Parameters recorded at 40 and 80 days after sowing revealed increased plant height, number of tillers and panicles in the inoculated treatments compared to the un-inoculated control plants. The population of the free living nitrogen fixing and phosphate solubilising microorganisms and the activity of soil enzymes (dehydrogenase, urease and phosphatase) in the rhizosphere soil found to be significantly increased during the panicle initiation stage. The plant biomass and grain yield of the aerobic rice was significantly increased due to inoculation of nitrogen fixers and phosphate solubilizers either singly or in combinations. The fresh weight and dry weight production of aerobic rice in dual inoculations and triple inoculation consortia varied between the treatments but showed increased biomass compared to the control. The triple inoculation of *A. salinestris* + *A. calcoaceticus* + *G. fasciculatum* produced highest grains compared to the dual and single inoculations. The nitrogen and phosphorus content of the plants increased in the treatments inoculated with nitrogen fixer and phosphate solubilizer respectively. The Application of consortia performed better than the individual inoculations.

**Keywords:** Aerobic rice, growth, nitrogen fixers, mycorrhizal fungus

## Introduction
Microorganisms play an important role in $N_2$- fixation, phosphate solubilisation, plant growth promotion, mineralization and control of root pathogens. Fungi, bacteria, actinomycetes, algae, protozoa and viruses are the different groups of microorganisms present in soil. Beneficial interactions between soil microorganisms and plant root system have been well established for agriculture, horticulture and forest crops. The major microorganisms include nitrogen fixers (eg. *Azotobacter, Azomonas, Azospirillum, Rhizobium* etc), phosphate solubilizers (eg. *Aspergillus awomorii, A. niger, Bacillus megaterium, B. subtilis,* Pseudomonads etc.) and arbuscular mycorrhizae (eg. *Glomus, Gigaspora, Acaulospora* etc). Apart from these, many new bacteria particularly, plant growth promoting rhizobacteria and biocontrol agents have been isolated and characterized in subsequent investigations.
The symbiotic mycorrhizal fungi known as arbuscular mycorrhiza (AM) form a key component of the microbial population influencing plant growth and uptake of nutrients. The hyphae of these fungi provide an increased area for interactions with other microorganisms and an important pathway for translocation of energy-rich plant assimilates to soil (Johansson, 2004) [3]. Thus, arbuscular mycorrhizal symbiosis occupies a central position in the rhizosphere development. Aerobic rice cultivation is a renewed way of growing rice in non-submerged un-puddled conditions in aerated soil as it can be grown similar to any other field crops like maize or sorghum on dry soils with surface irrigation (Shashidhar, 2007) [6]. At present, aerobic rice projected sustainable rice production methodology to address immediate future of water scarcity and global warming.
Aerobic rice plant produces long fibrous root system which could harbor variety of microbial communities. However, information about the microbial communities associated with the rhizosphere of rice plants grown under both irrigated as well as upland conditions at different

depths is very scarce (Eilers *et al.*, 2012) [1]. Inoculation of free living nitrogen fixers, phosphate solubilizers and arbuscular mycorrhizal fungi to non-legume crops significantly influenced the growth and yield of both agricultural and horticultural crops including aerobic rice (Earanna and Muruli, 2011; Panhwar *et al.*, 2013) [2, 5]. Application of Azotobacter vinelandii isolated from aerobic rice rhizosphere enhanced the growth and biomass of Anethum gravelens (Nandhini *et al*., 2014) [4]. Further, interaction studies using efficient nitrogen fixers, phosphate solubilizers and arbuscular mycorrhiza in aerobic rice cultivation is limited. Therefore, further studies are required to understand the effect of microbial inoculants in aerobic rice cultivation to evaluate the interaction effects of nitrogen fixers, $PO_4$-solubilizers and *Glomus fasiculatum* and their combinations on the growth and yield of aerobic rice.

## Materials and Methods

An experiment was conducted to enumerate the effect of microbial communities present in the rhizosphere soil of aerobic rice at different depths under glass house conditions in the Department of Agricultural Microbiology, UAS, GKVK, Bengaluru – 560065. The 3 feet length 4 inches diameter PVC pipes filled with soil were placed in battery boxes and seeds of aerobic rice varieties BI-33 (renamed as ARB-6) and AM- 72 were sown after seed treatment with various nitrogen fixers, phosphate solubilizer and AM fungus and watered as and when required. After germination, three plants were maintained in each pipe with three replications. Soil samples were collected on 40$^{th}$ and 80$^{th}$ day of sowing by cutting the rhizosphere soil profile at 5 cm, 10 cm, 20 cm, 40 cm, 60 cm, 80 cm and 100 cm depth. Soil was thoroughly mixed and random soil sample was collected at each depth. The rhizosphere microflora *viz.,* bacteria, fungi, actinomycetes, free living nitrogen fixer and phosphate solubilizers present at different depths (5 cm, 10 cm, 20 cm, 40 cm, 60 cm, 80 cm and 100 cm) were enumerated by serial dilution plate method using nutrient agar, Martin's Rose Bengal agar, Kuster's agar, Waksman No.77 agar and Pikovaskaya's agar respectively using appropriate dilutions. The root and shoot yield, plant height, no. of tillers etc, were estimated to study the influence of rhizosphere microbes communities.

To understand the influence of newly isolated free living nitrogen fixer and phosphate solubilising bacterium, a pot experiment was conducted under glass house conditions, at the Department of Agricultural microbiology, UAS, GKVK, Bengaluru-65. Seeds of two varieties of aerobic rice namely, BI-33 and AM-72 were obtained from the Department of Plant Biotechnology, University of Agricultural Sciences, GKVK Campus, Bengaluru and used for the pot experiment. The two reference cultures namely, *Azotobacter chroococcum* (nitrogen fixer) and *Bacillus megaterium* (phosphate solubilizer) were obtained from the Department of Agricultural Microbiology. *Azotobacter salinestris* and *Acinetobacter calcoaceticus* isolated and identified in this study (conducted in PVC pipes) along with arbuscular mycorrhizal fungus, *Glomus fasciculatum* either singly or in combinations was used to study their interaction effects on two varieties of Aerobic rice.

The nitrogen fixers *viz., A. chroococcum* and *A. salinestris* were grown in Waksman No.77 broth and the phosphate solubilizers, *B. megaterium* and *A. calcoaceticus* were grown in Pikovaskaya's broth for 7days. The soil based auxenic culture of *G. fasciculatum* was obtained from the Department of Agricultural microbiology, University of Agricultural Sciences, Dharwad-560005, India. The initial population of the bacterial cultures was estimated by the serial dilution plate method using appropriate agar medium and the arbuscular mycorrhizal spore present in the original inoculum was estimated by wet sieving and decanting method before application. Plastic pots of 10 kg soil filling capacity were used for the pot experiment. The pots were filled with red sandy loam soil and watered one day prior to sowing. At the centre of the pot, shallow planting hole was made using wedge. Into the planting hole, twenty grams of soil based arbuscular mycorrhizal inoculum (~92 chlamydospores) was added. Then, the two varieties of aerobic rice seeds (4-5 seeds/pot) were separately sown, watered and allowed for germination. After 15 days of germination, 10 ml liquid bacterial cultures *viz*., *A. chroococcum* (2.91x $10^7$ cfu/ml), *A. salinestris* (3.12x $10^7$ cfu/ml), *B. megaterium* (4.31X $10^8$ cfu/ml) and *A. calcoaceticus* (3.33x$10^8$ cfu/ml) were added in to the small hole made at the centre using wedge.

## Results

### At 40 days after sowing

The results pertaining to inoculation of nitrogen fixer, phosphate solubilizers and AM fungus individually and in combinations on plant height, number of leaves and tillers at 40 days after sowing are presented in Table, 1. There were no significant variations in plant height, number of leaves and tillers between the single inoculation as well as combined inoculation treatments in both the varieties compared to control.

### At 80 days after sowing

The results pertaining to plant height and number of panicles at 80 days of plant growth of both the varieties namely BI-33 and AM -72 are presented in the Table, 2. The highest plant height was recorded in the triple inoculation treatment (*A. salinestris* + *A. calcoaceticus* + *G. fasciculatum*) for both the varieties. Plant height for the variety BI-33 and AM-72 are 97.66 cm and 124.33 cm respectively. Among the single inoculations, the new strain *A. salinestris* performed better compared to the reference nitrogen fixing strain *A. chroococcum* in BI33 variety but in case of AM-72 variety they were on par with each other. However, the dual inoculated treatments performed better for variety AM-72 compared to the variety BI-33.

Significantly highest average panicle numbers were recorded in the treatments inoculated with *A. salinestris* either singly (10.33) or in combination with *G. fasciculaltum* (10.33) for the variety BI33. However, triple inoculation of *A. salinestris* + *A. calcoaceticus* + *G. fasciculatum* (13.33) was found to be superior over others. Similarly, the variety AM-72 produced more number of panicles (9.66) in the triple inoculated plants (Table, 2) with *A. salinestris* + *A. calcoaceticus* + *G. fasciculatum,* followed by the dual inoculation with *A. salinestris* + *A. calcoaceticus* (9.00). The least number of panicles were recorded in the treatment *A. calcoaceticus* + *G. fasciculatum* (3.00) and the dual inoculation of *A. calcoaceticus* + *G. fasciculatum* (3.0).

**Table 1:** Effect of inoculation of nitrogen fixers, phosphate solubilizers and AM fungus on plant height, number of leaves and tillers of aerobic rice at 40 DAS

| Treatments | Variety BI-33 | | | Variety AM-72 | | |
|---|---|---|---|---|---|---|
| | Plant height (cm) | No. of leaves | No. of tillers | Plant height(cm) | No. of leaves | No. of tillers |
| Control | 59.00 | 22.00 | 5.66 | 59.33 | 26.00 | 6.33 |
| *Azotobacter chroococcum* (Ref.) | 57.66 | 25.00 | 6.33 | 65.66 | 23.33 | 6.00 |
| *Bacillus megaterium* (Ref.) | 59.33 | 20.33 | 5.00 | 75.83 | 27.66 | 7.00 |
| *Azotobacter salinestris* | 60.33 | 23.00 | 5.66 | 67.66 | 33.33 | 8.66 |
| *Acinetobacter calcoaceticus* | 61.33 | 22.00 | 5.33 | 69.00 | 32.66 | 7.66 |
| *Glomus fasciculatum* | 57.66 | 28.00 | 7.00 | 64.50 | 35.33 | 8.66 |
| *A. chroococcum + G. fasciculatum* | 62.66 | 23.33 | 6.33 | 70.16 | 23.00 | 5.66 |
| *B. megaterium + G. fasciculatum* | 63.66 | 29.66 | 7.66 | 67.83 | 22.33 | 5.00 |
| *A. salinestris + G. fasciculatum* | 60.00 | 29.00 | 6.66 | 64.50 | 19.33 | 4.33 |
| *A. calcoaceticus + G. fasciculatum* | 59.50 | 24.00 | 6.00 | 68.50 | 20.66 | 5.33 |
| *A. salinestris + A. calcoaceticus* | 60.33 | 24.00 | 6.33 | 69.50 | 27.33 | 7.33 |
| *A. Salinestris + A. calcoaceticus + G. fasciculatum* | 63.50 | 28.00 | 7.33 | 64.33 | 24.66 | 6.33 |
| S.Em | 2.23 | 3.55 | 1.05 | 2.97 | 4.75 | 1.14 |
| LSD @ 5% | NS | NS | NS | NS | NS | NS |

**Note:** NS: Non-significant.

**Table 2:** Effect of inoculation of nitrogen fixers, phosphate solubilizers and AM fungus on plant height and number of panicles of aerobic rice at 80 DAS

| Treatments | Plant height (cm) | | Number of panicles | |
|---|---|---|---|---|
| | BI-33 | AM-72 | BI-33 | AM-72 |
| Control | 81.33$^{g}$ | 98.00$^{fg}$ | 7.00$^{cd}$ | 6.00$^{bcde}$ |
| *Azotobacter chroococcum* (Ref.) | 84.83$^{ef}$ | 110.86$^{bcd}$ | 8.00$^{bcd}$ | 5.00$^{cde}$ |
| *Bacillus megaterium* (Ref.) | 92.66$^{bc}$ | 93.66$^{g}$ | 9.33$^{bc}$ | 8.33$^{abc}$ |
| *Azotobacter salinestris* | 90.33$^{bc}$ | 108.83$^{cde}$ | 10.33$^{ab}$ | 7.00$^{abcd}$ |
| *Acinetobacter calcoaceticus* | 92.50$^{bc}$ | 98.00$^{fg}$ | 7.00$^{cd}$ | 3.00$^{e}$ |
| *Glomus facsiculatum* | 93.50$^{b}$ | 85.00$^{h}$ | 10.33$^{ab}$ | 5.00$^{cde}$ |
| *A. chroococcum + G. fasciculatum* | 91.73$^{bc}$ | 117.00$^{b}$ | 6.33$^{cd}$ | 5.00$^{cde}$ |
| *B. megaterium + G. fasciculatum* | 86.66$^{de}$ | 107.33$^{de}$ | 6.00$^{d}$ | 4.00$^{de}$ |
| *A. salinestris + G. fasciculatum* | 83.30$^{fg}$ | 111.10$^{bcd}$ | 10.33$^{ab}$ | 6.00$^{bcde}$ |
| *A. calcoaceticus + G. fasciculatum* | 84.16$^{efg}$ | 102.33$^{ef}$ | 8.33$^{bcd}$ | 3.00$^{e}$ |
| *A. salinestris + A. calcoaceticus* | 89.50$^{cd}$ | 114.66$^{bc}$ | 7.66$^{bcd}$ | 9.00$^{ab}$ |
| *A. salinestris + A. calcoaceticus + G. fasciculatum* | 97.66$^{a}$ | 124.33$^{a}$ | 13.33$^{a}$ | 9.66$^{a}$ |
| S.Em | 1.12 | 2.45 | 1.10 | 1.16 |
| LSD@ 5% | 3.28 | 7.16 | 3.21 | 3.39 |

**Note:** Means followed by the same letters in the column do not differ significantly.

**Table 3:** Effect of inoculation of nitrogen fixers, phosphate solubilizers and AM fungus on fresh weight of aerobic rice

| Treatments | Fresh weight (g) Var. BI-33 | | Fresh weight (g) Var. AM-72 | |
|---|---|---|---|---|
| | Shoot | Root | Shoot | Root |
| Control | 100.00$^{d}$ | 61.34$^{cd}$ | 91.67$^{d}$ | 51.66$^{e}$ |
| *Azotobacter chroococcum* (Ref.) | 136.67$^{abc}$ | 96.67$^{a}$ | 146.67$^{bc}$ | 76.66$^{bcd}$ |
| *Bacillus megaterium* (Ref.) | 165.00$^{a}$ | 71.67$^{bc}$ | 180.00$^{ab}$ | 85.00$^{abc}$ |
| *Azotobacter salinestris* | 150.00$^{ab}$ | 69.34$^{bc}$ | 178.34$^{ab}$ | 71.00$^{cd}$ |
| *Acinetobacter calcoaceticus* | 150.00$^{ab}$ | 68.34$^{bc}$ | 163.34$^{abc}$ | 66.66$^{de}$ |
| *Glomus fasiculatum* | 141.67$^{abc}$ | 68.34$^{bc}$ | 185.00$^{a}$ | 75.00$^{cd}$ |
| *A. chroococcum + G. fasciculatum* | 166.67$^{a}$ | 80.00$^{b}$ | 188.34$^{a}$ | 75.00$^{cd}$ |
| *B. megaterium + G. fasciculatum* | 166.67$^{a}$ | 78.34$^{b}$ | 160.00$^{abc}$ | 66.66$^{de}$ |
| *A. salinestris + G. fasciculatum* | 113.34$^{cd}$ | 66.00$^{bc}$ | 135.00$^{c}$ | 91.66$^{ab}$ |
| *A. calcoaceticus + G. fasciculatum* | 125.00$^{bcd}$ | 61.67$^{cd}$ | 170.00$^{ab}$ | 65.00$^{de}$ |
| *A. salinestris + A. calcoaceticus* | 138.33$^{abc}$ | 73.34$^{bc}$ | 166.67$^{abc}$ | 71.66$^{cd}$ |
| *A. salinestris + A. calcoaceticus + G. fasciculatum* | 140.00$^{abc}$ | 101.67$^{a}$ | 171.67$^{ab}$ | 96.66$^{a}$ |
| S.Em | 10.83 | 4.49 | 11.70 | 5.39 |
| LSD@ 5% | 31.62 | 13.11 | 34.17 | 15.74 |

**Note:** Means followed by the same letters in the column do not differ significantly.

**Table 4:** Effect of inoculation of nitrogen fixers, phosphate solubilizers and AM fungus on dry weight of shoot, root and grain yield of the aerobic rice

| Treatments | Dry weight (g) Var. BI-33 | | Dry weight (g) Var. AM-72 | | Grain yield (g/plant) | |
|---|---|---|---|---|---|---|
| | Shoot | Root | Shoot | Root | BI-33 | AM- 72 |
| Control | 19.39$^{ef}$ | 4.4e | 22.88$^{g}$ | 9.73$^{f}$ | 18.33$^{fg}$ | 15.20$^{f}$ |
| *Azotobacter chroococcum* (Ref.) | 30.34$^{b}$ | 20.2$^{a}$ | 32.31$^{cd}$ | 18.53$^{b}$ | 15.40$^{g}$ | 27.73$^{ef}$ |
| *Bacillus megaterium* (Ref.) | 24.21$^{de}$ | 14.13$^{bc}$ | 26.50f$^{g}$ | 16.86$^{bc}$ | 19.55$^{efg}$ | 27.57$^{e}$ |
| *Azotobacter salinestris* | 20.67$^{ef}$ | 10.06$^{d}$ | 27.64$^{defg}$ | 12.16$^{def}$ | 22.40$^{defg}$ | 37.23$^{bcd}$ |
| *Acinetobacter calcoaceticus* | 37.30$^{a}$ | 10.86$^{cd}$ | 27.18$^{efg}$ | 15.29$^{bcd}$ | 28.56$^{bcde}$ | 29.00$^{de}$ |
| *Glomus fasciculatum* | 39.05$^{a}$ | 10.40$^{d}$ | 30.23$^{cdef}$ | 11.14$^{ef}$ | 25.00$^{cdef}$ | 30.86$^{cde}$ |
| *A. chroococcum* + *G. fasciculatum* | 30.67$^{b}$ | 15.64$^{b}$ | 29.32$^{def}$ | 14.30$^{cde}$ | 35.61$^{ab}$ | 31.04$^{cde}$ |
| *B. megaterium* + *G. fasciculatum* | 29.67$^{bc}$ | 12.60$^{bcd}$ | 32.03$^{cdef}$ | 10.96$^{ef}$ | 29.55$^{bcd}$ | 37.60$^{bc}$ |
| *A. salinestris* + *G. fasciculatum* | 30.90$^{b}$ | 9.46$^{d}$ | 31.44$^{cde}$ | 11.33$^{ef}$ | 26.36$^{cdef}$ | 43.25$^{ab}$ |
| *A. calcoaceticus* + *G. fasciculatum* | 22.28$^{def}$ | 5.23$^{e}$ | 34.91$^{bc}$ | 10.86$^{ef}$ | 31.43$^{abcd}$ | 40.51$^{ab}$ |
| *A. salinestris* + *A. calcoaceticus* | 25.50$^{cd}$ | 14.10$^{bc}$ | 37.86$^{b}$ | 11.56$^{def}$ | 31.61$^{abc}$ | 48.03$^{a}$ |
| *A. salinestris* + *A. calcoaceticus* + *G. fasciculatum* | 30.69$^{b}$ | 20.18$^{a}$ | 54.13$^{a}$ | 23.70$^{a}$ | 39.50$^{a}$ | 48.96$^{a}$ |
| S.Em | 1.56 | 1.12 | 1.64 | 1.34 | 3.11 | 2.93 |
| LSD@5% | 4.56 | 3.27 | 4.80 | 3.91 | 9.09 | 8.58 |

**Note:** Means followed by same letters in the column do not differ significantly.

**Table 5:** Effect of inoculation of nitrogen fixers, phosphate solubilizers and AM fungus on nitrogen content of aerobic rice

| Treatments | Nitrogen content (%) | | | |
|---|---|---|---|---|
| | Variety: BI-33 | | Variety: AM-72 | |
| | Shoot | Root | Shoot | Root |
| Control | 0.75$^{de}$ | 0.45$^{g}$ | 0.91$^{h}$ | 0.55$^{f}$ |
| *Azotobacter chroococcum* (Ref.) | 1.07$^{ab}$ | 0.84$^{a}$ | 0.99$^{g}$ | 0.83$^{a}$ |
| *Bacillus megaterium* (Ref.) | 0.74$^{de}$ | 0.61$^{e}$ | 1.14$^{de}$ | 0.70$^{d}$ |
| *Azotobacter salinestris* | 1.08$^{a}$ | 0.67$^{cd}$ | 1.20$^{bc}$ | 0.85$^{a}$ |
| *Acinetobacter calcoaceticus* | 0.84$^{c}$ | 0.58$^{f}$ | 1.21$^{bc}$ | 0.74$^{c}$ |
| *Glomus fasciculatum* | 0.78$^{d}$ | 0.59$^{ef}$ | 0.99$^{g}$ | 0.70$^{d}$ |
| *A. chroococcum* + *G. fasciculatum* | 0.85$^{c}$ | 0.60$^{ef}$ | 1.08$^{ef}$ | 0.76$^{bc}$ |
| *B. megaterium* + *G. fasciculatum* | 0.49$^{f}$ | 0.61$^{e}$ | 1.27$^{a}$ | 0.66$^{e}$ |
| *A. salinestris* + *G. fasciculatum* | 0.74$^{de}$ | 0.61$^{e}$ | 1.29$^{a}$ | 0.70$^{d}$ |
| *A. calcoaceticus* + *G. fasciculatum* | 0.72$^{e}$ | 0.69$^{c}$ | 1.03$^{fg}$ | 0.67$^{e}$ |
| *A. salinestris* + *A. calcoaceticus* | 1.04$^{b}$ | 0.65$^{d}$ | 1.25$^{ab}$ | 0.75$^{bc}$ |
| *A. Salinestris* + *A. calcoaceticus* + *G. fasciculatum* | 0.87$^{c}$ | 0.81$^{b}$ | 1.17$^{cd}$ | 0.76$^{b}$ |
| S.Em | 0.018 | 0.0002 | 0.0183 | 0.00012 |
| LSD@5% | 0.038 | 0.029 | 0.056 | 0.019 |

**Note:** Means followed by the same letters in the column do not differ significantly.

**Table 6:** Effect of inoculation of nitrogen fixers, phosphate solubilizers and AM fungus on phosphorus content of aerobic rice

| Treatments | Phosphorus content (%) | | | |
|---|---|---|---|---|
| | Variety: BI-33 | | Variety: AM-72 | |
| | Shoot | Root | Shoot | Root |
| Control | 0.21$^{e}$ | 0.46$^{cd}$ | 0.22$^{i}$ | 0.81$^{b}$ |
| *Azotobacter chroococcum* (Ref.) | 0.23$^{e}$ | 0.65$^{a}$ | 0.41$^{f}$ | 0.68$^{de}$ |
| *Bacillus megaterium* (Ref.) | 0.32$^{d}$ | 0.38$^{e}$ | 0.53$^{b}$ | 0.60$^{g}$ |
| *Azotobacter salinestris* | 0.15$^{f}$ | 0.64$^{a}$ | 0.20$^{j}$ | 0.70$^{cd}$ |
| *Acinetobacter calcoaceticus* | 0.41$^{c}$ | 0.56$^{b}$ | 0.37$^{g}$ | 0.86$^{a}$ |
| *Glomus fasciculatum* | 0.31$^{d}$ | 0.45$^{cd}$ | 0.41$^{f}$ | 0.68$^{de}$ |
| *A. chroococcum* + *G. fasciculatum* | 0.46$^{b}$ | 0.64$^{a}$ | 0.61$^{a}$ | 0.57$^{g}$ |
| *B. megaterium* + *G. fasciculatum* | 0.20$^{e}$ | 0.50$^{bc}$ | 0.51$^{c}$ | 0.73$^{c}$ |
| *A. salinestris* + *G. fasciculatum* | 0.51$^{a}$ | 0.46$^{cd}$ | 0.48$^{d}$ | 0.69$^{d}$ |
| *A. calcoaceticus* + *G. fasciculatum* | 0.41$^{c}$ | 0.54$^{b}$ | 0.50$^{c}$ | 0.60$^{fg}$ |
| *A. salinestris* + *A. calcoaceticus* | 0.30$^{d}$ | 0.43$^{de}$ | 0.31$^{h}$ | 0.64$^{ef}$ |
| *A. salinestris* + *A. calcoaceticus* + *G. fasciculatum* | 0.50$^{a}$ | 0.46$^{cd}$ | 0.44$^{e}$ | 0.78$^{b}$ |
| S.Em | 0.0003 | 0.025 | 0.0001 | 0.0182 |
| LSD@5% | 0.027 | 0.069 | 0.019 | 0.041 |

**Note:** Means followed by same letters in the column do not differ significantly.

## Discussion

### Fresh weight of shoot and root

The fresh weight of shoot and root as influenced by the inoculation of nitrogen fixers, phosphate solubilizers and arbuscularlr mycrorrhizal fungi for both the varieties of aerobic rice is presented in the Table, 3. In general, all the inoculated treatments increased the fresh weight of shoot significantly in both the varieties (BI-33 and AM-72) compared to un-inoculated plants. The highest biomass was recorded in the treatments inoculated with *B. megaterium* alone, *A. chroococcum* + *G. fasciculatum* and *B. megaterium* + *G. fasciculatum*. The root biomass was highest in triple inoculation treatments compared to the other treatments. The next best was single inoculation treatment of *A. chroococcum*.

Similarly in the variety AM-72, the highest fresh weight of shoot was recorded in *A. chroococcum* + *G. fasciculatum* (188.34g) and *G. fasciculatum* (185.00 g) alone inoculated treatments. The control plants recorded least biomass compared to inoculated treatments. The root fresh weight was significantly higher in case of triple inoculation treatment (*A. salinestris* + *A. chroococcum* + *G. fasciculatum*) followed by the dual inoculation treatment with *A. salinestris* and *G. fasciculatum*.

**Dry weight of shoot, root and grain yield**

The data pertaining to the dry weight of shoot and root of aerobic rice varieties as influenced by the inoculation of nitrogen fixers, phosphate solubilizers and arbusculalr mycrorrhizal fungus is presented in Table, 4. The highest dry weight was recorded in *G. fasciculatum* inoculated treatment (39.05g) and *A. calcoaceticus* treated plants (37.30g) which were on par with each other and significantly superior over other inoculated treatments including control (24.21g). The next best treatments were *A. chroococcum* inoculation (30.34g) followed by the dual inoculation treatments of *A. chroococcum* + *G. fasiculatum* (30.67g) and *A. salinestris* + *G. fasiculatum* (30.90g) and triple inoculation treatment with *A. salinestris* + *A. calcoaceticus* + *G. fasiculatum* (30.69g) which were on par with each other. The lowest dry matter production was recorded in *B. megaterium* treated plants (19.39g). The *A. salinestris* (20.67g) and *A. calcoaceticus* + *G. fasciculatum* treatments (22.28g) though produced higher biomass, did not differ significantly.

The dry weight of shoot was highest in triple inoculation treatment having combination of *A. salinestris* + *A. calcoaceticus* + *G. fasciculatum* (54.13g) for the variety AM 72. The next best treatment producing higher biomass was the dual inoculation of *A. Salinestris* + *A. calcoaceticus*. In general, all the inoculated treatments produced increased biomass compared to the control plants. The un-inoculated treatment produced the least shoot dry weight (22.88g).

The data pertaining to the dry weight of root as influenced by different inoculation treatments is presented in the Table, 4. The highest root dry weight of the variety BI-33 was observed in single inoculation of the *Azotobacter chroococcum* and the consortia of *A. salinestris* + *A. calcoaceticus*+ *G. fasiculatum* (20.18g). The inoculated treatments except *A. calcoaceticus* + *G. fasciculatum* treated recorded higher dry matter production. The lowest dry weight was recorded in control plants (4.4g). Similarly, AM-72 variety also recorded significantly highest root dry matter (23.70g) followed by *A. chroococcum* alone treated plants (18.53g). The overall performance of the inoculated treatments proved to be better in increasing the biomass compared to the control.

**Grain yield**

The data pertaining to grain yield as influenced by different inoculation treatments is presented in the Table, 4. The highest grain yield was recorded in the consortia of triple organisms (*A. salinestris* + *A. calcoaceticus* + *G. fasciculatum*) followed by the consortia of dual inoculation. However, *A. calcoaceticus* alone inoculated treatment increased the grain yield similar to dual inoculation. Single inoculation of *A. chroococcum* and *B. megaterium* were on par with the control by recording lesser grain yield. Grain yield production in case of AM-72 variety was also highest in the consortia of three organisms (*A. salinestris* + *A. calcoaceticus* + *G. facsiculatum*) and the dual inoculation treatment (*A. salinestris* + *A. calcoaceticus*). Rest of the dual inoculation treatments though produced slightly lesser grain yield compared to *A. salinestris and A. calcoaceticus* treatment, they differed with the control. However, *A. chroococcum* alone inoculated plants though produced higher grain yield, did not differ significantly over the control.

**Nitrogen content of shoot and root**

The results pertaining to shoot and root nitrogen content in rice plants as influenced by different inoculation treatments are presented in the Table, 5. The highest nitrogen content of shoot was recorded in *A. salinestris* inoculated treatment (1.08%) for BI-33 variety, followed by *A. chroococcum* (1.07%) and then *A. salinestris* + *A. calcoaceticus* (1.04%) treatment. Nitrogen content of treatments with single inoculation of *A. calcoaceticus* (0.84%), dual inoculation of *A. chroococcum* + *G. fasciculatum* (0.85%) and triple inoculation of *A. calcoaceticus* + *A. calcoaceticus* + *G. fasciculatum* (0.87%) were found to be on par with each other. The remaining treatments were found to be similar control. Similarly, the root nitrogen was highest in *A. chroococcum* (0.84%) inoculated plants followed by the triple inoculation treatment with *A. salinestris* + *A. calcoaceticus* + *G. fasciculatum* (0.81%). The other treatments also recorded higher nitrogen content compared to the control for variety BI-33.

The treatments with dual inoculation of *B. megaterium* + *G. fasciculatum* (1.27%) and *A. salinestris* + *G. fasciculatum* (1.29%) recorded significantly highest percent nitrogen compared to other inoculated treatments in the variety AM-72. The un-inoculated treatment recorded the least percent nitrogen. The root nitrogen content increased in the single inoculation of *A. salinestris* (0.85%) and *A. chroococcum* (0.83%) treated plants compared to the other inoculated treatments. In general, all the inoculated plants either singly or in combinations showed increased N content compared to the control.

**Phosphorus content**

The results pertaining to the shoot and root P content of both the varieties (BI-33 and AM-72) is presented in Table, 6. The highest shoot P was recorded in *A. salinestris* + *G. fasciculatum* treatment (0.51%) which was on par with the treatment receiving *A. salinestris* + *A. calcoaceticus* + *G. fasciculatum* (0.50%) and significantly superior over rest of the treatments including control (0.21%). The least P content was observed in treatment *A. salinestris* (0.15%). Similarly, highest root P content was observed in treatment *A. chroococcum* (0.65%) which was on par with the treatments *A. salinestris* (0.64%) and *A. chroococcum* + *G. fasciculatum* (0.64%) and were statistically superior over all other inoculated treatments and also with the uninoculated control (0.46%). Whereas, treatments *A. salinestris* + *A. calcoaceticus* and *A. salinestris* + *A. calcoaceticus* + *G. fasciculatum* recorded 0.46% root P as in case of control. The least root P content was recorded in the treatment *B. megaterium* (0.38%).

The highest shoot P content was recorded in *A. chroococcum* + *G. fasciculatum* (0.61%) inoculated treatment which was significant compared to the treatments and control (0.22%) which showed the least shoot P content in the variety AM-72. Whereas, treatments with dual inoculation of *B. megaterium* + *G. fasciculatum* (0.51%) and *A. calcoaceticus* + *G. fasciculatum* (0.50%) treated plants were found to be on par with each other. The root P content was highest in *A. calcoaceticus* (0.86%) followed by the control (uninoculated) plants (0.81%). The least root P content was observed in treatments *B. megaterium* (0.60%) and *A. calcoaceticus* + *G. fasciculatum* (0.60%).

## Conclusion
The plant biomass and grain yield of the aerobic rice was significantly increased due to inoculation of nitrogen fixers and phosphate solubilizers either singly or in combinations. The fresh weight and dry weight production of aerobic rice in dual inoculations and triple inoculation consortia varied between the treatments but showed increased biomass compared to the control. The triple inoculation of *A. salinestris* + *A. calcoaceticus* + *G. fasciculatum* produced highest grains compared to the dual and single inoculations. The nitrogen and phosphorus content of the plants increased in the treatments inoculated with nitrogen fixer and phosphate solubilizer respectively. The application of consortia performed better than the individual inoculations

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