J. Farm Sci., 34(1) : (49-55) 2021

RESEARCH PAPER

Effect of bioagents on seed yield and quality in biofortified rice genotypes

ARPITA BEPARI AND R. GURUMURTHY

Department of Seed Science and Technology, College of Agriculture, Dharwad
University of Agricultural Sciences, Dharwad - 580 005, Karnataka, India
E-mail : arpitabepari61@gmail.com

(Received: July, 2020 ; Accepted:February, 2021)

Abstract: The present investigation was carried out during *kharif* 2019 at Agricultural Research Station, Mugad to know the effect of bio-agents on seed yield and quality in biofortified rice genotypes. The experiment was laid out in factorial randomized complete block design with three replication. T_1-AM fungi consortium, T_2- Foliar spray with PPFM, T3-AM fungi consortium + Foliar spray with PPFM, T_4- Control and as factor II comprised of four genotypes (G_1:BA32, G_2:BD36, G_3:BD13 and G_4:BPT5204), three genotypes derived from two crosses *viz.,* BPT5204 x A-67 & BPT5204 x D6-2-2 and BPT 5204 as check. The result indicated that the treatment (T3) soil application of AM fungi consortium (8kg acre^{-1}) + foliar spray with PPFM at 60 and 90 DAS (1 litre of PPFM in 100 litres of water acre^{-1}) had significantly higher plant height, dehydrogenase activity of rhizosphere, SPAD value, flag leaf length and breadth, number of panicles, panicle length, thousand seed weight, seed yield and seedling vigour index as compared to control.

Key words: Bioagents, Biofortified, Rice, Seed yield

Introduction

Rice belongs to the Poaceae family and contains 22 species, only two of which are grown *viz*, *O.sativa* and *O.glaberrima* Steud. Rice is the primary staple food for billions of people, over two billion in Asia and hundreds of millions in Africa and Latin America are relying on rice for food. Since ages it has had renowned friendship with humans. Rice is covered in an area of 161.62 million hectares worldwide, yielding 728.06 million tonnes with a yield of 4510 kg ha^{-1} (www.indiastat.com., 2018-19). India ranks first in the world, production and productivity, 44.15 million hectares rice cultivation world, 116.47 million tonnes and 2638 kg ha^{-1} yield respectively (www.indiastat.com., 2018-19). Rice is grown in Karnataka on 1.13 million hectares with 3.43 million tonnes of production and 3012 kg ha^{-1} of productivity per hectare (www.indiastat.com., 2018-19).

Rice is extensively consumed by the poorest to the richest in one form or another, and contain low levels of iron (1.20 mg /100 g) and zinc (0.50 mg/ 100 g), most of which are lost during grain processing. Population with monotonous diets consisting mainly of rice are particularly vulnerable to deficiencies in iron and zinc, which affects around two billion people. Biofortification is an alternative solution by generating cultivars that translocate iron efficiently to the edible parts, especially germ. Iron deficiency is a common nutritional disorder in many crops leading to poor yields and lower nutritional quality. An important strategy for reducing iron deficiency in humans is to increase the iron levels available in staple food crops (Cakmak, 2002). The genetic variation in contents of micronutrients provides a basic for improving quality of micronutrients by breeding. However, it is difficult to manipulate this trait in conventional breeding, since such substantial variation is inherited quantitatively (Shiny *et al*., 1991).

Consequent to uncertain and insufficient rainfall, rice crops often suffer from soil moisture stress. Continued use of conventional varieties due to unavailability of quality seeds and lack of high yielding variety awareness, low soil fertility due to soil erosion leading to loss of plant nutrients and humidity, heavy weed and insect infestation, poor crop population due to economic backwardness of farmers in the event of a broadcasting system and weak acceptance of improved crop production technology are some of the reason for lower yields. The crop also suffers from deficiency of iron and zinc in low-rainfall areas. Bioagents like arbuscular mycorrhizal fungi and pink pigmented facultative methylotrophs play an important role in supplementing nutrients to mother plant and improves soil health condition.

Material and methods

Field experiment was conducted at All India Co-ordinated Rice Improvement Project (AICRP), Mugad. University of Agricultural Sciences Dharwad during *kharif* 2019 to asses the performance of bioagents for improving seed yields and quality of biofortified rice genotypes. The experiment was laid out in factorial randomized complete block design with three replication. The factor I comprised of treatments T_1-AM fungi consortium, T_2- Foliar spray with PPFM, T_3-AM fungi consortium + Foliar spray with PPFM, T_4-Control, respectively in main plots and foliar application of growth regulating compounds in sub plots *viz.*, PPFM at 60 and 90 DAS (One litre of PPFM in 100 litres of water acre^{-1}), Soil application of AM fungi consortium (8kg acre^{-1}), Control (Without any application of bioagents). The factor II comprised of four genotypes (G_1:BA32, G_2:BD36, G_3:BD13 and G_4:BPT5204) three genotypes derived from two crosses *viz.*, BPT5204 x A-67 & BPT5204 x D6-2-2 and BPT 5204 as check. Pink pigmented facultative methylotrophs are associated with most terrestrial plants roots, leaves and seeds, and many are recognised as phytosymbionts. There are at least two mechanisms by which plants, particularly in dry climates, can be influenced positively by PPFMs. Initially, PPFMs extract cytokinins and auxins, plant growth hormones that induce germination and play a key role in the response of the plant to water stress. In dry conditions, plants may have a

competitive advantage over more shallowly rooted species, which quickly send their roots deep after germination. Second, osmoprotectants (sugars and alcohols) exude PPFMs on the surface of the host plants. It can help protect plants from desiccation and high temperatures *via* this matrix. All the agronomic and plant protection measures were adopted as per recommended package of practices for raising healthy crops.

Results and discussion

Growth parameters

The data on plant growth parameters as influenced by bioagents in rice genotypes and their interaction effects are presented in Table 1, 2, 3 and 4.

Table 1. Influence of bioagents on plant height (cm) at different growth stages in rice genotypes

Treatment	30 DAS	60 DAS	90 DAS	120 DAS
Bioagents (T)				
T_1: AMF consortium	47.23*	52.20*	117.17*	124.02*
T_2: PPFM	47.48*	52.30*	117.35*	125.52*
T_3: AMF+PPFM	48.02*	53.10*	117.68*	128.77*
T_4: Control	42.25	46.90	110.95	117.97
Mean	46.25	51.13	115.79	124.07
S.Em.±	1.451	1.305	1.664	1.388
C.D.@ 5%	4.179	3.759	4.793	3.998
Genotypes (G)				
G_1: BA32	47.77*	54.58*	127.73*	142.62*
G_2: BD36	47.37*	52.10*	131.37*	139.68*
G_3: BD 13	49.70*	57.02*	128.23*	132.63*
G_4: BPT 5204	40.15	40.80	075.82	081.33
Mean	46.25	51.13	115.79	124.07
S.Em.±	2.051	1.846	2.353	1.963
C.D.@ 5%	5.909	5.316	6.778	5.654
For comparing the means of Interaction (T×G)				
T_1G_1	43.47	57.87*	134.07*	137.47*
T_1G_2	51.13*	55.93*	131.07*	143.87*
T_1G_3	54.13*	57.47*	130.07*	135.07*
T_1G_4	40.20	37.53	073.47	079.67
T_2G_1	52.33*	56.80*	126.20*	144.33*
T_2G_2	51.33*	53.13*	137.00*	141.60*
T_2G_3	48.53	57.73*	129.73*	135.40*
T_2G_4	37.73	41.53	076.47	080.73
T_3G_1	51.20*	56.20*	131.80*	159.07*
T_3G_2	47.27	54.60*	137.60*	143.87*
T_3G_3	51.27*	61.93*	126.13*	131.87*
T_3G_4	42.33	39.67	075.20	080.27
T_4G_1	44.07	47.47	118.85*	129.60*
T_4G_2	39.73	44.73	119.80*	129.40*
T_4G_3	44.87	50.93*	127.00*	128.20*
T_4G_4	40.33	44.47	078.13	084.67
Mean	46.25	51.13*	115.79	124.07
S.Em.±	4.103	3.691	4.706	3.926
C.D.@ 5%	11.819	10.633	13.556	11.308

T_1 - Arbuscular Mycorrhizal Fungi consortium (8 kg acre^{-1})

T_2 - Foliar spray with PPFM at 60 & 90 DAS (PPFM @1 litre in 100 litres of water acre^{-1})

T_3 - Arbuscular Mycorrhizal Fungi consortium (8 kg acre^{-1}) + Foliar spray with PPFM at 60 & 90 DAS (PPFM @ 1 litre in 100 litres of water acre^{-1})

T_4 - Control

* - Significance at 0.05 % DAS: Days after sowing

Among bioagents treatments, the treatment with soil application of arbuscular mycorrhizal fungi consortium (8 kg acre^{-1}) + foliar spray with PPFM at 60 & 90 DAS (1 litre of PPFM in 100 litres of water acre^{-1}) registered significantly higher values for growth parameters like plant height (48.02, 53.10, 117.68 and 128.77 cm at 30, 60, 90 and 120 days after sowing respectively, higher dehydrogenase activity of rhizosphere 48.33 µg TPF g^{-1} 24 h^{-1} and 34.58 µg TPF g^{-1} 24 h^{-1} at 60 and

Table 2. Influence of bioagents on dehydrogenase activity of soil of rice genotypes

Treatment	Dehydrogenase activity of rhizosphere at 60 DAS (µg TPF g^{-1} 24 hr^{-1})	Dehydrogenase activity of rhizosphere at 90 DAS (µg TPF g^{-1} 24 hr^{-1})
Bioagents (T)		
T_1: AMF consortium	45.33*	31.66*
T_2: PPFM	42.00*	31.33*
T_3: AMF+PPFM	48.33*	34.58*
T_4: Control	35.33*	26.58
Mean	42.75	31.04
S.Em.±	1.009	0.746
C.D. @5%	2.906	2.149
Genotype (G)		
G_1: BA32	42.00	31.25
G_2: BD36	43.33	30.92
G_3: BD 13	42.75	31.08
G_4: BPT 5204	42.92	30.92
Mean	42.75	31.04
S.Em.±	1.427	1.055
C.D.@5%	NS	NS
For comparing the means of Interaction (T×G)		
T_1G_1	46.67*	34.00*
T_1G_2	47.33*	32.33*
T_1G_3	43.67*	30.33
T_1G_4	43.67*	30.00
T_2G_1	43.00*	30.33
T_2G_2	42.00*	31.67*
T_2G_3	42.67*	32.00*
T_2G_4	40.33	31.33*
T_3G_1	45.67*	36.00*
T_3G_2	47.00*	32.67*
T_3G_3	51.00*	33.67*
T_3G_4	49.67*	36.00*
T_4G_1	32.67	24.67
T_4G_2	37.00	27.00
T_4G_3	33.67	28.33
T_4G_4	38.00	26.33
Mean	42.75	31.04
S.Em.±	2.854	2.110
C.D.@5%	8.220	6.080

T_1 - Arbuscular Mycorrhizal Fungi consortium (8 kg acre^{-1})

T_2 - Foliar spray with PPFM at 60 & 90n DAS (PPFM @1 litre in 100 litres of water acre^{-1})

T_3 - Arbuscular Mycorrhizal Fungi consortium (8 kg acre^{-1}) + Foliar spray with PPFM at 60 & 90 DAS (PPFM @ 1 litre in 100 litres of water acre^{-1})

T_4 - Control

* - Significance at 0.05 % DAS: Days after sowing

Table 3. Influence of bioagents on SPAD reading at different growth stages in rice genotypes

Treatment	60 DAS	90 DAS	120 DAS
Bioagents (T)			
T_1: AMF consortium	32.98	36.59	29.23
T_2: PPFM	33.70	35.66	30.11
T_3: AMF+PPFM	34.36	37.24*	33.73*
T_4: Control	32.34	35.19	28.26
Mean	33.35	36.17	30.33
S.Em.±	1.274	0.547	1.071
C.D.@5%	NS	1.576	3.087
Genotypes (G)			
G_1: BA32	34.36	38.35*	30.51
G_2: BD36	32.28	33.19	31.73
G_3: BD 13	35.13	37.72*	29.78
G_4: BPT 5204	31.62	35.42	29.31
Mean	33.35	36.17	30.33
S.Em.±	1.802	0.774	1.515
C.D.@5%	NS	2.229	NS
For comparing the means of Interaction(T×G)			
T_1G_1	34.30	38.68*	31.21
T_1G_2	34.77	32.83	31.77
T_1G_3	32.03	36.55	26.47
T_1G_4	30.83	34.57	27.45
T_2G_1	38.61*	37.49*	27.82
T_2G_2	30.80	33.57	32.12
T_2G_3	37.17	38.86*	29.64
T_2G_4	28.23	36.43	30.85
T_3G_1	35.47	40.41*	36.59*
T_3G_2	33.50	34.02	33.11
T_3G_3	37.77	37.10*	36.05*
T_3G_4	30.70	37.45*	29.17
T_4G_1	29.07	36.81*	26.40
T_4G_2	30.03	32.34	29.91
T_4G_3	33.57	38.36*	26.94
T_4G_4	36.70	33.25	29.79
Mean	33.35	36.17	30.33
S.Em.±	3.603	1.547	3.031
C.D.@5%	10.379	4.458	8.730

T_1 - Arbuscular Mycorrhizal Fungi consortium (8 kg acre^{-1})

T_2 - Foliar spray with PPFM at 60 & 90 DAS (PPFM @1 litre in 100 litres of water acre^{-1})

T_3 - Arbuscular Mycorrhizal Fungi consortium (8 kg acre^{-1}) + Foliar spray with PPFM at 60 & 90 DAS (PPFM @ 1 litre in 100 litres of water acre^{-1})

T_4 - Control

* - Significance at 0.05 % DAS: Days after sowing

Table 4. Influence of bioagents on flag leaf length and breadth in rice genotypes

Treatment	Flag leaf length (cm)	Flag leaf breadth (cm)
Bioagents (T)		
T_1: AMF consortium	28.88	1.67*
T_2: PPFM	29.57	1.69*
T_3: AMF+PPFM	32.13*	1.75*
T_4: Control	27.93	1.48
Mean	29.63	1.65
S.Em.±	0.869	0.025
C.D.@ 5%	2.502	0.071
Genotypes (G)		
G_1: BA32	30.38*	1.71*
G_2: BD36	32.38*	1.75*
G_3: BD 13	32.60*	1.71*
G_4: BPT 5204	23.15	1.43
Mean	29.63	1.65
S.Em.±	1.228	0.035
C.D.@5%	3.539	0.101
For comparing the means of Interaction (T×G)		
T_1G_1	27.13	1.71*
T_1G_2	32.53*	1.77*
T_1G_3	30.87*	1.81*
T_1G_4	25.00	1.39
T_2G_1	32.07*	1.73*
T_2G_2	30.07*	1.92*
T_2G_3	35.07*	1.67*
T_2G_4	21.07	1.43
T_3G_1	32.73*	1.97*
T_3G_2	35.13*	1.81*
T_3G_3	36.00*	1.77*
T_3G_4	24.67	1.45
T_4G_1	29.60*	1.43
T_4G_2	31.80*	1.50
T_4G_3	28.47*	1.57
T_4G_4	21.87	1.43
Mean	29.63	1.65*
S. Em.±	2.457	0.07
C.D.@ 5%	7.078	0.201

T_1 - Arbuscular Mycorrhizal Fungi consortium (8 kg acre^{-1})

T_2 - Foliar spray with PPFM at 60 & 90 DAS (PPFM @ 1 litre in 100 litres of water acre^{-1})

T_3 - Arbuscular Mycorrhizal Fungi consortium (8 kg acre^{-1}) + Foliar spray with PPFM at 60 & 90 DAS (PPFM @ 1 litre in 100 litres of water acre^{-1})

T_4 - Control

* - Significance at 0.05 % DAS: Days after sowing

90 days after sowing respectively. Higher SPAD readings 34.36, 37.24 and 33.73 at 60, 90 and 120 days after sowing respectively and higher flag leaf length (32.13 cm) and flag leaf breadth(1.75 cm), The increase in plant height, dehydrogenase activity of rhizosphere, flag leaf length and breadth may be attributed to symbiotic effect of soil application of arbuscular mycorrhizal fungi with host plant enhanced up take of macro and micro nutrients, provided desired soil health to host plants coupled with the synthesis of phytohormones like auxins and cytokinins promoting active cell division, cell elongation and enlargement as evident from the dehydrogenase activity of rhizosphere at different growth stages of the crop. Similar results were reported by Fernandez *et al*. (2011) in rice and it was related to the development of arbuscular endophyte biomass and ectophyte biomass. Solaiman and Hirata, (1997) noticed that compared to uninoculated rice, arbuscular mycorrhizal fungi found increased growth and nutrient uptake in directly seeded wetland rice.

Among genotypes, the genotype 'BPT5204' found to be short statured compared to others and were on par with each other in plant height. Genotypes did not vary with each other with respect to chlorophyll content and soil dehydrogenase activity.

Similarly the interaction effect due to bioagents and genotypes, the genotypes did not differ significantly with in the treatment block for plant height, chlorophyll content and dehydrogenase activity. Among treatment combinations between bio agent and genotypes the treatment combination, soil application of arbuscular mycorrhizal fungi consortium (8 kg acre^{-1}) + foliar spray with PPFM at 60 and 90 days after sowing (1 litre of PPFM in 100 litres of water acre^{-1}) in 'BA32' genotype had registered significantly higher plant height (159.07 cm) over the treatment combination soil application of arbuscular mycorrhizal fungi consortium (8 kg acre^{-1}) in 'BPT 5204' genotype (79.67 cm) at 120 days after sowing. The treatment combinations, soil application of arbuscular mycorrhizal fungi consortium (8 kg acre^{-1}) + foliar spray with PPFM at 60 and 90 DAS (1 litre of PPFM in 100 litres of water acre^{-1}) in 'BD 13' genotype (T_3G_3) and soil application of arbuscular mycorrhizal fungi consortium (8 kg acre^{-1}) + foliar spray with PPFM at 60 and 90 DAS (1 litre of PPFM in 100 litres of water acre^{-1}) in 'BPT 5204' genotype were on par with each other at 60 and 90 DAS (51.00 and 49.67 µg TPF g^{-1} 24 h^{-1} at 60 DAS and 33.67 and 36.00 µg TPF g^{-1} 24 h^{-1} at 90 DAS respectively). The SPAD readings for chlorophyll content tended to increase up to 90 days after sowing in all the treatment combinations except with 'BPT 5204' genotype in control plot (T_4G_4). However the treatment combinations soil application of arbuscular mycorrhizal fungi consortium (8 kg acre^{-1}) + foliar spray with PPFM at 60 and 90 days after sowing (1 litre of PPFM in 100 litres of water acre^{-1}) in 'BA 32' and 'BD 13' (T_3G_1 and T_3G_3) had registered consistently and significantly higher (40.41 and 36.59 and 37.10 and 36.05, respectively) SPAD readings for chlorophyll content at 60 and 90 days after sowing respectively. These findings can be attributed to vesicles, arbuscules and hyphae in roots and also spores and hyphae in the rhizosphere produced by arbuscular mycorrhizal fungi. The development of the hyphal network of arbuscular mycorrhizal fungi with plant roots significantly improves the access of roots to a wide area of the soil, leading to improvement in plant growth (Bowels *et al.*, 2016). It also increases plant nutrition by increasing nutrient availability and translocation. (Rouphael *et al.*, 2015). PPFM is known to promote growth and development of host plants by producing variety of auxins and cytokinins. The positive response of genotypes and influence of bioagents enhanced plant growth and development in rice genotypes. These findings are in conformity with the findings of Ranjeet kumar and Mahendra sing, (2017) in, rice and Paulraj (2002) in cardamom, rubber, and coffee.

Yield parameters

The data on yield parameters as influenced by bioagents in rice genotypes and their interaction effects are presented in Table 5 and 6.

Among treatments, soil application of arbuscular mycorrhizal fungi consortium (8 kg acre^{-1}) followed by foliar spray with PPFM at 60 & 90 DAS (1 litre of PPFM in 100 litres of water acre^{-1}) registered significantly higher values for yield parameters like number of panicles (10.07), panicle length (22.60 cm), thousand seed weight (30.97 g), seed yield (3.77 kg plot^{-1} and 7547.67 kg ha^{-1}) and straw yield (5.57 kg ha^{-1}) as compared to the controls.

Table 5. Influence of bioagents on number of panicles and panicle length in rice genotypes

Treatment	Number of panicles	Panicle length (cm)
Bioagents (T)		
T_1: AMF consortium	08.97	21.80
T_2: PPFM	09.42	22.47*
T_3:AMF+PPFM	10.07*	22.60*
T_4: Control	08.25	21.62
Mean	09.18	22.12
S.Em.±	0.482	0.249
C.D.@ 5%	1.387	0.718
Genotypes (G)		
G_1: BA32	08.17	25.52*
G_2: BD36	10.15*	22.33*
G_3: BD 13	08.23	21.67*
G_4: BPT 5204	10.15*	18.97
Mean	09.18	22.12
S.Em.±	0.681	0.352
C.D.@ 5%	1.962	1.015
For comparing the means of Interaction(T×G)		
T_1G_1	08.60	24.13*
T_1G_2	09.13	21.53*
T_1G_3	08.40	21.47*
T_1G_4	09.73	20.07*
T_2G_1	07.33	26.20*
T_2G_2	10.73	23.67*
T_2G_3	08.47	21.73*
T_2G_4	11.13*	18.27
T_3G_1	09.73	26.40*
T_3G_2	11.67*	22.33*
T_3G_3	08.27	22.07*
T_3G_4	10.60	19.60
T_4G_1	07.00	25.33*
T_4G_2	09.07	21.80*
T_4G_3	07.80	21.40*
T_4G_4	09.13	17.93
Mean	09.18	22.12
S.Em.±	1.362	0.705
C.D.@ 5%	3.924	2.030

T_1 - Arbuscular Mycorrhizal Fungi consortium (8 kg acre^{-1})

T_2 - Foliar spray with PPFM at 60 & 90 DAS (PPFM @ 1 litre in 100 litres of water acre^{-1})

T_3 - Arbuscular Mycorrhizal Fungi consortium (8 kg acre^{-1}) + Foliar spray with PPFM at 60 & 90 DAS (PPFM @ 1 litre in 100 litres of water acre^{-1})

T_4- Control

*- Significance at 0.05 % DAS: Days after sowing

Among, genotypes 'BD36' recorded significantly higher values for number of panicles (10.15), panicle length (22.60 cm), thousand seed weight (30.97 g), seed yield (3.99 kg plot^{-1} and 7983.33 kg ha^{-1}) and straw yield (5.58 kg plot^{-1}) as compared to other genotypes.

Treatment combinations showed significant difference for yield and yield parameters. Among the treatment combinations, soil application of arbuscular mycorrhizal fungi consortium

Table 6. Influence of bioagents on thousand seed weight and seed yield of rice genotypes

Treatment	1000 seed weight (g)	Seed yield (kg plot^{-1})	Seed yield (kg ha^{-1})	Straw yield (kg plot^{-1})
Bioagents (T)				
T_1: AMF consortium	27.28*	3.38*	6764.83*	4.99*
T_2: PPFM	27.68*	3.57*	7142.00*	5.28*
T_3: AMF+PPFM	30.97*	3.77*	7547.67*	5.57*
T_4: Control	24.92	2.74	5480.50	4.08
Mean	27.71	3.37	6733.75	4.98
S.Em.±	0.066	0.159	317.517	0.115
C.D.@ 5%	0.191	0.457	914.659	0.331
Genotypes (G)				
G_1: BA32	27.63*	2.84	5673.50	4.83*
G_2: BD36	30.35*	3.99*	7983.33*	5.58*
G_3: BD 13	30.20*	3.53*	7067.67*	5.30*
G_4: BPT 5204	22.67	3.11	6210.50	4.22
Mean	27.71	3.37	6733.75	4.98
S.Em.±	0.094	0.224	449.0373	0.163
C.D.@ 5%	0.27	0.647	1293.523	0.469
For comparing the means of Interaction(T×G)				
T_1G_1	19.93*	2.81	5622.00	4.78*
T_1G_2	30.80*	4.13*	8266.66*	5.78*
T_1G_3	30.20*	3.35	6704.00	5.03*
T_1G_4	28.20*	3.23	6466.67	4.39
T_2G_1	30.20*	3.03	6068.00	5.15*
T_2G_2	29.17*	4.76*	9526.67*	6.66*
T_2G_3	30.20*	3.59	7186.67	5.39*
T_2G_4	21.17*	2.89	5786.67	3.93
T_3G_1	33.23*	3.03	6030.67	5.15*
T_3G_2	35.27*	4.58*	9186.67*	6.41*
T_3G_3	32.20*	3.78*	7553.33*	5.67*
T_3G_4	23.17*	3.71	7420.00	5.05*
T_4G_1	27.17*	2.49	4973.33	4.23
T_4G_2	26.17*	2.48	4953.33	3.47
T_4G_3	28.20*	3.41	6826.67	5.12*
T_4G_4	18.13	2.58	5168.67	3.51
Mean	27.71	3.37	6733.75	4.98
S.Em.±	0.187	0.449	898.0745	0.325
C.D.@ 5%	0.539	1.293	2587.046	0.937

T_1 - Arbuscular Mycorrhizal Fungi consortium (8 kg acre^{-1})

T_2 - Foliar spray with PPFM at 60 & 90 DAS (PPFM @ 1 litre in 100 litres of water acre^{-1})

T_3 - Arbuscular Mycorrhizal Fungi consortium (8 kg acre^{-1}) + Foliar spray with PPFM at 60 & 90 DAS (PPFM @ 1 litre in 100 litres of water acre^{-1})

T_4- Control

*- Significance at 0.05% DAS: Days after sowing

(8kg acre^{-1}) followed by foliar spray with PPFM at 60 & 90 DAS (1 litre of PPFM in 100 litres of water acre^{-1}) in genotype 'BD 36' (T_3G_2) significantly higher values for parameters like number of panicles (11.67), panicle length (21.73 cm), thousand seed weight (35.27 g), seed yield (4.58 kg plot^{-1} and 9186.67 kg ha^{-1}) and straw yield (6.66 kg ha^{-1}) compared to other treatment combinations. The higher seed yield may be attributed to combined effect of bioagent and genotype promoted production of more number of productive tillers, enhancing seed weight due proper source and sink relationship, production of higher photosynthates due to increase in chlorophyll content due to PPFM as reported by Madhaiyan *et al*. (2004) observed in the crop plants, increased uptake of essential nutrients mainly due to integrated effect of soil application of AM fungi consortium and foliar spray of PPFM. These findings confirm with the findings of Nysanth *et al*. (2019) in rice, Fernandez *et al*. (2011) reported in rice AM fungi application enhanced more number of panicles. Noori *et al*. (2014) also confirmed the similar trend in wheat

Seed quality parameters

The seed quality parameters as influenced by bioagents in rice genotypes and their interaction effects are presented in Table 7.

The results on seed quality parameters due to bioagents showed significant influence on five seed quality parameters *viz*, root length, shoot length, seedling dry weight, seedling vigour index and electrical conductivity of seed leachate. While, non-significant difference was observed with respect to seed quality parameters like germination and field emergence. The treatment soil application of arbuscular mycorrhizal fungi consortium (8 kg acre^{-1}) followed by foliar spray with PPFM at 60 & 90 DAS (1 litre of PPFM in 100 litres of water acre^{-1}) recorded significantly higher values for seedling root length (20.90 cm), shoot length (13.22 cm), seedling dry weight (166.50 mg/ten seedlings), seedling vigour index (3264) and lower electrical conductivity of seed leachate (0.532 dSm^{-1}) followed by the treatment foliar spray with PPFM at 60 & 90 DAS (1 litre of PPFM in 100 litres of water acre^{-1}) for root length (20.47 cm), seedling dry weight (159.25 mg/ten seedlings) and seedling vigour index (3016) compared to values registered by control for parameters *viz*, seedling root length (19.05 cm), seedling shoot length (11.33 cm), seedling dry weight (151.75 mg/ten seedlings), seedling vigour index (2691) and electrical conductivity of seed leachate (0.634 dSm^{-1}). This may be attributed to better nourishment of the mother plant due to coordinated effects of AM fungi and PPFM spray which promoted better seed development and maturity of embryo.

Genotypes did not exhibit significant difference for seed quality parameters except for parameters like seedling root length, seedling shoot length and seedling vigour index. Among genotypes 'BD 13' found to be significantly superior in seedling root length (22.33cm), seedling shoot length (13.58cm) and seedling vigour index (3356) followed by 'BD 36' in seedling root length (20.01cm) and seedling vigour index (2975) over other genotypes. Although all the genotypes are par with each other in germination but genotype 'BD 13' and 'BD 36' exhibited higher seedling vigour due to significantly higher root length. This finding may be attributed to genotypic effect.

Among different treatment combinations, the treatment combination The treatment soil application of arbuscular mycorrhizal fungi consortium (8 kg acre^{-1}) followed by foliar spray with PPFM at 60 and 90 DAS (1 litre of PPFM in 100

Table 7. Influence of bio agent on seed quality parameters in biofortified rice genotypes

	Germination (%)	Root length (cm)	Shoot length (cm)	Seedling dry weight (mg)	Seedling vigour index	Field emergence (%)	Electrical Conductivity (dSm^{-1})
Bioagents (T)							
T_1: AMF consortium	92.83(74.85)	19.33	11.88	156.00**	2856	87.92	0.615
T_2: PPFM	93.25(75.11)	20.47**	12.25	159.25**	3016**	88.25	0.566
T_3:AMF+PPFM	95.00(77.71)	20.90**	13.22**	166.50**	3264**	90.42	0.532**
T_4: Control	92.33(73.86)	19.05	11.33	151.75	2691	87.08	0.634
Mean	93.35(75.38)	19.94	12.17	158.37	2957	88.42	0.587
S.Em.±	0.667(0.791)	0.144	0.311	0.409	35.315	0.758	0.013
C.D.@ 1%	NS	0.415	0.895	1.181	101.732	NS	0.040
Genotypes (G)							
G_1: BA32	94.08(75.88)	18.39	12.19	158.58	2798	89.33	0.599
G_2: BD36	92.75(75.06)	20.01**	12.53	157.92	2975	89.33	0.591
G_3: BD 13	93.17(75.13)	22.33**	13.58**	158.83	3356**	87.25	0.581
G_4: BPT 5204	93.42(75.45)	19.02	10.39	158.17	2698	87.75	0.576
Mean	93.35(75.38)	19.94	12.17	158.37	2957	88.42	0.587
S.Em.±	0.942(1.118)	0.203	0.439	0.579	49.943	1.072	0.0196
C.D. @ 1%	NS	0.587	1.266	NS	143.871	NS	NS
For comparing the means of Interaction (T×G)							
T_1G_1	93.67(76.03)	18.20**	12.30	161.66**	2856**	90.33	0.612
T_1G_2	93.33(75.42)	17.20	11.28	154.00**	2544	89.67	0.608
T_1G_3	92.33(74.07)	21.25**	13.50	155.33**	3185**	84.33	0.609
T_1G_4	92.00(73.87)	20.68**	10.46	153.00	2839**	87.33	0.633
T_2G_1	93.67(75.56)	20.21**	12.80	157.66**	3037**	88.33	0.584
T_2G_2	93.67(75.69)	19.98**	12.68	160.33**	2946**	89.33	0.576
T_2G_3	92.67(74.51)	22.41**	13.93**	159.67**	3465**	88.66	0.510**
T_2G_4	93.00(74.89)	19.30**	09.61	159.33**	2617	86.66	0.592
T_3G_1	95.00(77.19)	18.43**	12.67	165.33**	2975**	90.66	0.545
T_3G_2	93.33(77.08)	22.78**	15.13**	165.67**	3589**	90.66	0.585
T_3G_3	96.00(78.52)	24.30**	14.11**	168.00**	3700**	91.00	0.561
T_3G_4	95.67(78.06)	18.10**	11.00	167.00**	2793**	89.33	0.437**
T_4G_1	94.00(74.75)	16.71	11.01	149.67	2325	88.00	0.656
T_4G_2	90.67(72.28)	20.10**	11.03	151.67	2823**	87.67	0.595
T_4G_3	91.67(73.41)	21.38**	12.78	152.33	3074**	85.00	0.642
T_4G_4	93.00(74.97)	18.00	10.50	153.33	2545	87.67	0.643
Mean	93.35(75.38)	19.94	12.17	158.37	2957	88.42	0.587
S.Em.±	1.885(2.236)	0.408	0.879	1.159	99.887	2.145	0.039
C.D.@ 1%	NS	1.175	2.533	3.339	287.742	NS	0.113

T_1 - Arbuscular Mycorrhizal Fungi consortium (8 kg $acre^{-1}$)

T_2 - Foliar spray with PPFM at 60 & 90 DAS (PPFM @ 1 litre in 100 litres of water $acre^{-1}$)

T_3 - Arbuscular Mycorrhizal Fungi consortium (8 kg $acre^{-1}$) + Foliar spray with PPFM at 60 & 90 DAS (PPFM @ 1 litre in 100 litres of water $acre^{-1}$)

T_4- Control

* - Significance at 0.05% DAS: Days after sowing

litres of water $acre^{-1}$) in genotype 'BD 13' registered significantly higher seedling vigour index (3700) over other treatment combinations as the seedling root length (24.30 cm) was also significantly higher and numerically higher germination (96.00 per cent) was registered by this treatment combination as compared to other treatment combinations. The present findings may be attributed to better growth and development, chlorophyll content and nutrient uptake promoted by the combined effect of bioagents and genetic factor.

Conclusion

From the experimental results, it can be concluded that the treatment soil application of arbuscular mycorrhizal fungi consortium (8 kg $acre^{-1}$) followed by foliar spray with PPFM (PPFM @ 1 litre in 100 litres of water $acre^{-1}$ at 60 and 90 DAS) recorded significantly higher values for plant growth and seed yield parameters. The study indicated that the soil application of AM fungi and foliar spray with PPFM could be effectively followed for getting higher seed yield with better seed quality in biofortified rice genotypes.

References

Bowles T M, Barrios-Masias F H, Carlisle E A, Cavagnaro T R and Jackson L E, 2016, Effects of arbuscular mycorrhizae on tomato yield, nutrient uptake, water relations, and soil carbon dynamics under deficit irrigation in field conditions. *Science of Total Environment*, 566: 1223-1234.

Cakmak I, 2002, Plant nutrition research: Priorities to meet human needs for food in sustainable ways. *Plant Soil*, 247: 3-24.

Fernandez F, Amico J M D, Angoa M V and Providencia I E D L, 2011, Use of a liquid inoculum of the Arbuscular Mycorrhizal Fungi *Glomus hoi* in rice plants cultivated in a saline Gleysol: A new alternative to inoculate. *Journal of Plant Breeding and Crop Sciences*, 3(2): 24-33.

Madhaiyan M, Poonguzhali S, Senthilkumar M, Seshadri S, Chung H, Yang J, Sundaram S and Sa T M, 2004, Growth promotion and induction of systemic resistance in rice cultivar Co-47 (*Oryza sativa* L.) by *Methylobacterium* spp. *Bot Bull Acad Sin*., 45(4): 315-324.

Noori M, Sobhkhizi A, Adibian M, Mirikomak V and Eyidozehi K, 2014, Effect of phosphorus fertilizer and mycorrhiza on plant height, seed weight per plant and grain per panicle in wheat. *International Journal of Plant Animal and Environmental Sciences*, 5(1): 542-545.

Nysanth N S, Meenakumari K S, Syriac E K and Beena R, 2019, Screening of pink pigmented facultative methylotrophs for growth enhancement in paddy. *International Journal of Plant Animal and Environmental Sciences,* 18: 1878-1881.

Paulraj S and Raj S A, 2018, Effect of Azophos (50: 50), a biofertilizer formulation on cardamom (*Elettaria cardamomum* L. Maton) in primary nursery. *International Journal of Innovative Horticulture*, 7(1): 46-49.

Shiny V V, Sash D V and Sachem J K S, 1991, Inheritance of protein per grain in rice. *Indian Journal of Genetics*, 51: 214-220.

Solaiman M Z and Hirata H, 1997, Responses of directly seeded wetland rice to arbuscular mycorrhizal fungi inoculation. *Journal of Plant Nutrition*, 20(11): 1479-1487.

Ranjeet K and Singh M, 2017, Effect of arbuscular mycorrhizal (AM) fungi inoculation on enzymatic activity and zinc uptake under direct seeded rice system. *Journal of Applied and Natural Science*, 9(2): 1157-1163

Rouphael Y, Franken P, Schneider C, Schwarz D, Giovannetti M, Agnolucci M, De Pascale S, Bonini P and Colla G, 2015, Arbuscular mycorrhizal fungi act as biostimulants in horticultural crops. *Scientia Horticulture,* 196: 91-108.

www.indiastat.com (2018-19)