ARTICLE IN PRESS

Field Crops Research xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Trichoderma harzianum improves the performance of stress-tolerant rice varieties in rainfed ecologies of Bihar, India

Najam Waris Zaidi[a], Mandhata Singh[b], Santosh Kumar[c], U.R. Sangle[c], Nityanand[d], Rajeev Singh[d], Sachitanand[e], Rameshwar Prasad[e], S.S. Singh[f], S. Singh[a], A.K. Yadav[g], Ajeet Singh[h], Showkat A. Waza[a], Uma S. Singh[a,*]

[a] International Rice Research Institute (IRRI), India Office, New Delhi, India
[b] Krishi Vigyan Kendra, Buxar, Bihar, India
[c] Indian Council of Agricultural Research (ICAR) Complex for Eastern Region, Patna, Bihar, India
[d] Krishi Vigyan Kendra, Aurangabad, Bihar, India
[e] Krishi Vigyan Kendra, Sitamarhi, Bihar, India
[f] Indian Institute of Pulses Research, Kanpur, Uttar Pradesh, India
[g] IRRI Cereal Systems Initiative for South Asia (CSISA) Hub, ATIC Building, OUAT, Odisha, India
[h] Catholic Relief Services (CRS), Patna, Bihar, India

ARTICLE INFO

Keywords:
Abiotic stress
Rice
Trichoderma harzianum
Best management practices
Farmer's practice

ABSTRACT

An aggravation in prevalence, magnitude and duration of environmental stresses has posed a serious threat to global food security. Exploitation of microbial organisms has been hypothesized to play an important role in mitigating stresses and enhancing the yields of stress tolerant varieties in major field crops including rice. In this study, preliminary on-station experiments were conducted to evaluate the potential of various microbial formulations for enhancing the performance of stress tolerant rice varieties under rainfed ecologies of Bihar, India. The best performing formulation (*Trichoderma harzianum* strain S2) was selected for on-farm evaluation over years and locations. The studies conducted through on-farm trials and village level demonstrations indicated that the application of *Trichoderma harzianum* strain S2 along with IRRI (International Rice Research Institute) improved BMP (best management practices) was most effective for enhancing the yield and yield attributes of stress tolerant rice varieties. This treatment revealed the highest grain yields of 4.91 t ha^{-1} for Sahbhagi Dhan during 2013 and 4.81 t ha^{-1} for Swarna-Sub1 during 2014. Although, the application of *Trichoderma* strain S2 along with farmer's practice had positive impact on yield parameters over the sole use farmer's practice, the advantage obtained was relatively low. This treatment showed the maximum grain yields of 4.53 t ha^{-1} for Sahbhagi Dhan and 4.08 t ha^{-1} for Swarna-Sub1 during the wet season of 2013. Thus, the present work advocates for an effective use of microbes along with inherent abiotic stress tolerance of the crop and best management practices, to alleviate stresses under field conditions.

1. Introduction

The progressive exacerbation in incidence, intensity and duration of environmental stresses has posed a serious threat to agricultural productivity and food security across the globe (Jones et al., 2014). The menaces are further aggravated by overwhelming pressure on agro-ecosystems laid by ever growing population along with urbanization, persistent climate change and the need to obtain a range of services from agriculture in addition to food production (Arif et al., 2016). Thus, the global food demand necessitates to redesign agricultural systems for major food crops, especially in the areas highly prone to various types of environmental stresses (Singh et al., 2013). Among the major food crops, rice serves as the staple food for more than half of the world's population and two third of Indians depend on rice for their survival (Bishwajit et al., 2013; Huang et al., 2014). However, the production of this crop is increasingly limited by various environmental stresses with about 30% of the 700 million poor effected in rainfed lowlands of Asia alone (Dar et al., 2013). Drought, submergence and the sequential events (drought followed by submergence and vice-versa) are the major constraints for rice production in such areas (Fukao et al., 2011).

In India, approximately 13.6 M ha (million hectare) of area under rice is affected from drought of varying intensities (Singh et al., 2016).

* Corresponding author. Present address: IRRI, India office, CG Block, 1st Floor, NASC Complex, DPS Marg, New Delhi, 110012, India.
E-mail address: u.singh@irri.org (U.S. Singh).

http://dx.doi.org/10.1016/j.fcr.2017.05.003
Received 2 August 2016; Received in revised form 6 May 2017; Accepted 7 May 2017

Table 1
Microbial formulations used in on-station trials during the wet season of 2012.

Product	Microbe	Source
Trichoderma S1–S4	*Trichoderma harzianum*	STRASA Project, International Rice Research Institute, New Delhi, India.
RAU microbial consortia	Undisclosed	Rajendra Agriculture University, Pusa, Samastipur, Bihar.
Trichoderma commercial formulation	*Trichoderma viride*	Arihant Nature Crops Private Limited, Vishwabharti Society, Waghodia Road, Vadodara-390019, Gujarat, India. Corporate Office, Sakaldeep Complex, Surbi Vihar Colony, Dhelma, Patna-20, India.
Azospirillium commercial formulation	*Azospirillium brasilense*	
Pseudomonas commercial formulation	*Pseudomonas fluorescens*	

Table 2
Analysis of variance for agro-morphological parameters of rice variety Sahbhagi Dhan under 15 microbial treatments in the on-station trial at the ICAR Research Farm, Sabajpura during the wet season of 2012.

Source of variation	df	Mean sum of squares				
		Days to 50% flowering	Plant height (cm)	No. of effective tillers m^{-2}	Grain yield ($t\ ha^{-1}$)	Harvest index (%)
Replications	2	4.18	13.73	613.64	0.24	1.32
Treatments	14	16.13*	56.66*	2822.37*	14.33*	18.98*
Error	28	2.63	7.14	544.85	0.10	1.02

* Indicates a significant effect at $p = 0.05$.

Likewise, 30% of the rice area (12–14 M ha) is prone to flash flooding, reducing the average productivity to about 0.5–0.8 $t\ ha^{-1}$ (Bhowmick et al., 2014). Drought and submergence act as major factors limiting the rice yields in India, especially in the stress-prone areas of eastern states (Sarkar et al., 2009). Among the eastern Indian states, Bihar has an area of about 3.6 M ha under rice cultivation, of which 47% is rainfed with a low productivity of about 1.5 $t\ ha^{-1}$. In Bihar, a rice growing area of about 1.1 M ha is prone to flash flooding and 1.0 M ha is susceptible to drought, thereby giving rise to fragile overall yields in the state. Abiotic stress tolerant rice varieties have proved to be a boon for the farmers in such areas (Serraj et al., 2011; Singh et al., 2013). *Sub1* gene introgressed versions of popular rice varieties (such as Swarna-Sub1, Sambha Mahsuri-Sub1, Binadhan 11 and CR1009-Sub1) and drought tolerant varieties (including Sahbhagi Dhan, CR Dhan 405, Sushk Samrat and Abhishek) have been recognized to stabilize rice productivity in the rainfed lowlands of eastern India including Bihar (Ismail et al., 2013).

Although, stress tolerant rice varieties have the potential to increase and stabilize rice productivity in rainfed lowlands, they cannot furnish absolute resistance. There is always the scope of further improvement by manipulating management practices especially under multiple stress conditions (Doni et al., 2014). Exploitation of microbial organisms has been hypothesized to play an important role in mitigating stress and thereby enhancing yields in rice. Various soil microbes including *Pseudomonas* and *Azospirilium* have been reported to alleviate abiotic stresses in various crop species including rice (Vejan et al., 2016). *Trichoderma* is one of the most widely researched microbes and is primarily recognized for its mycoparasitic activities (Mukherjee et al., 2013). It has been reported that root colonization of *Trichoderma* helps in mitigating stresses through morphological, physiological and biochemical adaptations (Ji et al., 2012; Doni et al., 2014). Enhanced root growth, improved seedling vigour, promoted plant development, improved yield parameters, increased absorption of nutrients and inhibited growth of deleterious root microflora have been reported to be related to the presence of *Trichoderma* (Harman et al., 2004; Hermosa et al., 2012; Shukla et al., 2012; Chen et al., 2013; Pandey et al., 2016). *Trichoderma* has been characterized to aid in nutrient solubilisation and to release a variety of compounds (including phytohormones and some secondary metabolites) that induce resistance responses against abiotic stresses (Shukla et al., 2012; Mastouri et al., 2010, 2012). The stress mitigation effect has depended on the specific isolate of *Trichoderma* and plant species and/or cultivar involved (Singh et al., 2011). There are many reports regarding exploitation of microbes for abiotic stress management, but most of these studies are confined to controlled conditions. Thus, there is a need to evaluate microbes along with inherent abiotic stress tolerance of the crop under field conditions in stress prone ecologies. Some cultivars show more tolerance than others. In the present study, preliminary on-station studies were conducted to

Table 3
Values for agro-morphologial parameters of rice variety Sahbhagi Dhan under 15 microbial treatments in the on-station trial at the ICAR Research Farm, Sabajpura during the wet season of 2012.

Treatments	Days to 50% flowering	Plant height (cm)	No. of effective tillers m^{-2}	Grain yield ($t\ ha^{-1}$)	Harvest index (%)
FYM with *Trichoderma* S1	86.67	109.22**	251.50	4.11	47.86
FYM with *Trichoderma* S2	87.33	105.35	248.42	4.21	49.18
FYM with *Trichoderma* S3	87.00	109.28**	276.35**	5.11*,**	49.62**
FYM with *Trichoderma* S4	86.00	105.78	270.57**	5.23*,**	51.43*,**
Trichoderma S1	85.33	109.32**	263.21	4.55**	50.41*,**
Trichoderma S2	87.00	110.58**	285.48**	5.33*,**	50.12*,**
Trichoderma S3	86.67	108.25	256.22	4.35**	48.86
Trichoderma S4	88.33**	105.55	280.85**	5.16*,**	50.03*,**
FYM with RAU microbial consortia	85.33	109.11**	259.38	4.12	46.44
RAU microbial consortia	86.67	108.43	269.71**	4.71**	48.95
Trichoderma commercial formulation	86.33	104.17	268.48**	4.23	47.59
Azospirillum commercial formulation	85.33	105.62	270.17**	4.18	46.61
Pseudomonas commercial formulation	86.67	106.46	262.63	4.18	47.51
FYM only	87.00	107.67	269.32**	4.61**	48.08
Control (no treatment)	85.00	104.29	228.71	3.76	47.68
CD ($p = 0.05$)	2.71	4.47	39.04	0.53	1.69

* Values were significantly higher than FYM only ($p = 0.05$).
** Values were significantly higher than untreated control ($p = 0.05$).