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Rhizobium sp. BARIRGm901 INOCULATION RESPONSE TO SOYBEAN GENOTYPES IN NORTHERN REGION OF BANGLADESH

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ABSTRACT

Alam F, Rahman MW, Hossain MM, Banu MB, Alam SS, Bhuiyan MAH (2016) *Rhizobium* sp. BARIRGm901 inoculation response to soybean genotypes in northern region of Bangladesh. *J. Soil Nature* 9(2), 11-19.

A field experiment was conducted by soybean (*Glycine max* L. Merill) genotypes with *Rhizobium* sp. BARIRGm901inoculation at the Breeder Seed Production Centre (BSPC), Bangladesh Agricultural Research Institute (BARI), Debigonj, Panchagarh, Bangladesh during 2009-2010 and 2011-2012 with the objectives to find out the response of *Rhizobium* sp. BARIRGm901 inoculation with different plant genotypes of soybean. Two soybean varieties *viz*. Shohag and BARI Soybean-6, and two advance lines MTD-10 and BGM-02026 were studied with and without *Rhizobium* sp. BARIRGm901inoculationin Factorial Randomized Complete Block Design (RCBD) with four replications. Peat based rhizobial inoculum (strain BARIRGm901) was used at the rate of 1.5 kg ha^{-1} as seed inoculant. *Rhizobium* sp. BARIRGm901inoculation significantly increased nodulation, dry matter production, pods $plant^{-1}$ and seed yields of soybean in both years. Nodulation was higher in BARI Soybean-6 and this variety also performed better in respect of shoot weight, pods per plant, stover and seed yield. Among the varieties and advance lines, the highest seed yield 1.73 t ha^{-1} in 2009-2010 and 1.44 t ha^{-1} in 2011-2012 was recorded. Interaction effects revealed that inoculated BARI Soybean-6 gave the highest seed yield (1.84 t ha^{-1} in 2009-2010 and inoculated BGM-02026 (1.60 t ha^{-1})in 2011-2012. Nodule number and nodule weight was the highest in inoculated BARI Soybean-6 in both years. Therefore, *Rhizobium* sp. BARIRGm901inoculation established a symbiotic relationship with soybean genotypes and thus increased the nodulation, growth, and yield of soybean grown in northern region of Bangladesh.

Key words: *variety, advanced line,inoculum, nodulation, yield*

INTRODUCTION

Nitrogen is one of the most abundant elements on earth, but its availability often limits plant growth and crop production (Alam *et al.* 2015a). Rhizobial bacteria play an important role in the nitrogen cycle of agro-ecosystems by infecting the roots of legumes plants and inducing the formation of nitrogen fixing nodules (Alam *et al.* 2015a). These nodules provide an appropriate environment for fixation of atmospheric nitrogen into ammonium by nitrogenase, a bacterial enzyme sensitive to high oxygen tensions (Alam *et al.* 2015a; Burris and Roberts, 1993). Large amounts of nitrogen are fixed by the bacteria and transferred to the plants, reducing need for nitrogenous fertilizer (Alam *et al.* 2015a; Prakamhang *et al*. 2015). It is estimated that 150–200 million tons of mineral nitrogen are required annually for plant growth, of which almost 100 million tons of nitrogen are fixed via the industrial Haber–Bosch process (Unkovich *et al.* 2008) and 175 million tons of atmospheric nitrogen are fixed biologically (Chafi and Bensoltane, 2003). The ability of legumes to fix nitrogen reduces the need to supply crops with synthetic nitrogen fertilizers and, hence, the negative environmental impacts of fertilizer application (Lupwayi *et al.* 2010). The processes of symbiotic nitrogen fixation and transformation of molecular nitrogen into a form available to the plant are more efficient in varieties of soybean than in other plants (Brewin 2010). Nitrogen is the major nutrient for plant growth, and biological N fixation (BNF) in soil may reduce chemical fertilizer load for crop production (Islam *et al.* 2013; Alam *et al*. 2015b). Many environmental factors such as soil conditions (Sylvia *et al.* 2005), N and P levels (Palmer and Young, 2000), and soil types (Groffman *et al.* 1996), salinity and soil management practices (Drew and Ballard, 2010) influence the efficiency of biological nitrogen fixation (Alam *et al.* 2015b). The BNF capability of soybean depends mostly on the mass of the root nodules and the specific activity of the nitrogenase enzyme produced by bacteria (Alam *et al.* 2015a). There is scope to enhance the crop yield of soybean by improving nodulation, and thereby nitrogen fixation, by using effective nitrogen-fixing bacteria as inoculants by applying them to the seed or soil. Soybean (*Glycine max*) plants require a large amount of nitrogen as their seeds contain high concentrations of protein, and the total amount of nitrogen accumulating in the shoot is proportional to the seed yield (Alam *et al.* 2015a; Ohyama *et al.* 2013).

Soybean (*Glycine max*) has high potential oil crop for Bangladesh. It is not popular yet as a crop in Bangladesh but its oil is very popular as cooking oil. However, the crop gained popularity in the poultry industry recently. Soybean oil is imported at the cost of huge foreign exchange and most of the soybean produced in the country is used for making nutritious food items like soyadal, soyakhechuri, soyamisti, soyaploao, soyamilk, soyacake, soyabiscuits and soyabreadetc (Kaul and Das, 1986). Soybean seeds contain 42-45% protein and 20-22% edible oil. Crushed seeds are used as important component of poultry feed as a source of protein. The yield of soybean is low in Bangladesh. There is scope to increase yield of this crop by improving nodulation and thereby N_2-

fixation through use of effective nitrogen fixing bacteria as seed inoculant. Bangladesh Agricultural Research Institute has developed different varieties of soybean. Some of these varieties are waiting for cultivation in the farmers' level but were not screened in respect to nodulation, nitrogen fixation and as well as yield. There is a great possibility to increase its production by exploiting better colonization of the roots and rhizospheres through the application of effective nitrogen fixing bacteria to the seed or to the soil. This can minimize uses of nitrogenous fertilizer, which is very costly in our country. Using high yielding varieties/advanced lines of soybean in combination with effective rhizobial strains along with management practices including manures and fertilizers can enhance the yield. This can minimize use of nitrogenous fertilizer and might help to reduce adverse effects chemical fertilizer on soil environment. Their response might be different under different agro-ecological situation because of variation in native rhizobial population. Cultivar variation affects levels of nitrogen fixation in many legume crop species and in some crops particular combinations of strain and cultivar have been shown to be especially efficient at fixing nitrogen (Graham 2000). There were varying reports on the interaction between variety and strain in soybean. Thao *et al*. (2002) found a significant interaction between variety and strain on different parameters whereas Munyinda *et al*. (1988) reported a non-significant interaction. Therefore, the specific objectives of this research were to study the effects of inoculated *Rhizobium* sp. BARIRGm901strain on nodulation, dry matter production and yield of soybean (*Glycine max* L. Merill) varieties/advance lines, and to determine the main and interaction effects of *Rhizobium* sp. BARIRGm901strain and soybean varieties under northern region soils of Bangladesh.

MATERIALS AND METHODS

Experimental setup

The experiment was conducted on 20 December 2009 and 13 December 2011 at the Breeder Seed Production Centre (BSPC), Bangladesh Agricultural Research Institute (BARI), Debigonj, Panchagarh (Old Himalayan Piedmont Plain, AEZ-1; latitude 26°11´N, and longitude 88°73 E), Bangladesh. The experiment was laid out in Factorial Randomized Complete Block Design (RCBD) with four replications. The treatments included four soybean genotypes, two soybean varieties (Shohag and BARI Soybean-6), and two advance lines (MTD-10 and BGM-02026) which were each studied with and without *Rhizobium* (*Rhizobium* sp. BARIRGm901) inoculation. The unit plots were 2 × 3 m in size and seeds were planted at 70 kg ha^{-1}. The seeds of newly released varieties and advanced lines were collected from Oilseed Research Center of BARI, Gazipur, Bangladesh. *Rhizobium*sp. was grown in YEM liquid medium to a population density of 1.2×10^8 (CFU ml^{-1}, estimated by serial dilution method) and injected into peat soil (100 g packet). The peat based rhizobial inoculum was used in field experiment at 1.5 kg ha^{-1}. Soybean seeds were mixed thoroughly with the peat based inoculum and small quantity of water before sowing. Fertilizers were used at the rate of 22/42/40/5 kg PKSZn ha^{-1}, respectively, as a basal dose. Triple super-phosphate, muriate of potash, gypsum and zinc sulphates were used as the sources of phosphorus, potassium, sulphur and zinc, respectively. Weeding, thinning and other intercultural operations were done when necessary. Nodules were collected by carefully uprooting five sample plants selected randomly from each unit plot at the 50% flowering stage. The crop was finally harvested on 15 April 2010 and 25 April 2012.

Nodules and biomass collection, and soybean harvesting

Nodules were separated from the roots aseptically during harvesting and nodule properties were studied without damaging roots and biomass. Fresh weight of roots and above ground biomass was carefully measured. The samples of nodules, root, and above ground biomass were dried at 70ºC for 72 h for dry weight measurements. The dried plant samples were ground and stored for further chemical analysis. At maturity stage, five plants were sampled randomly from each plot, pods were counted for all the five plants and the average value was reported as number of pod per plant. The soybean pods, stover (leaves with stem) and seeds were separated from plants and measured the fresh weight. The pods, stover, and seeds were dried at 70ºC for 72 h for measurements of dry weight of yield parameters.

Soil and plant analysis

Soil samples were collected, air dried, and ground (2 mm sieve) for chemical analysis. Soil pH was measured (soil: water, 1:5 w/v) by a combined glass calomel electrode (Jackson 1958). Organic carbon was determined by wet oxidation method (Walkley and Black). Total N was determined by modified kjeldahl method. Soil samples were digested with di-acid mixture (HNO_3:$HCLO_4$ 3:1 v/v). The extract containing Ca, K and Mg were determined by NH_4OAc extraction method. Copper, Fe, Mn and Zn were determined by DTPAextraction followed by AAS reading. Boron was determined by $CaCl_2$ extraction method. Phosphorus was determined by Bray and Kurtz method. Sulphur was determined by $CaH_4(PO_4)_2.H_2O$ extraction followed by turbidimetric method with $BaCl_2$.

Table 1. The chemical properties ofinitial soilsof the experimental fields under study during 2009-2010

Location	pH	OM (%)	Ca	Mg	K	Total N (%)	P	S	B	Cu	Fe	Mn	Zn
			meq 100 g^{-1}				µg g^{-1}						
Debigonj	5.3	0.98	2.9	1.20	0.23	0.051	12	7	0.29	1.90	37	5.3	1.42
Critical limit	-	-	2.0	0.50	0.12	-	7	10	0.20	0.20	4.0	1.0	0.60

Statistical analyses

Statistical analyses will be conducted using standard statistical procedures implement in Statistix 10. The data will be examined by analysis of variance (ANOVA) and differences between the treatments will be determined by Fisher's protected least significant difference (LSD) will be calculated at the 0.05 probability level for treatment mean comparisons.

RESULTS AND DISCUSSION

Effect of *Rhizobium* inoculation

Effect of *Rhizobium* inoculation on nodulation, yield and yield components of different soybean varieties and advance lines have been presented in Tables 2 and 3. *Rhizobium* sp. BARIRGm901 inoculation in soybean roots significantly increased nodule number (15.44 plant^{-1} in 2009-2010 and 18.41 plant^{-1} in 2011-2012), nodule weight (66.3 mg plant^{-1} in 2009-2010 and 77.0 mg plant^{-1} in 2011-2012), root weight (0.55 g plant^{-1} in 2009-2010 and 0.57 g plant^{-1} in 2011-2012) and shoot weight (3.66 g plant^{-1} in 2009-2010 and 4.37 g plant^{-1} in 2011-2012) (Table 2). It also significantly increased pod (37.6 pods plant^{-1} in 2009-2010 and 50.4 pods plant^{-1} in 2011-2012), seed (2.38 seeds pod^{-1} in 2009-2010 and 2.36 seeds pod^{-1} in 2011-2012), stover (3.56 t ha^{-1} in 2009-2010 and 2.91 t ha^{-1} in 2011-2012) and seed yields (1.69 t ha^{-1} in 2009-2010 and 1.49 t ha^{-1} in 2011-2012) (Table 3). This is in agreement with observations of Wu and Arima (1992) in Chinese milk vetch. Bhuiyan *et al.* (1996) reported that inoculated plant produced significantly higher nodule number (15.2 plant^{-1} and nodule weight (166 mg plant^{-1}) over non-inoculated plants. Alam *et al.* (2015a) found that both number and weight of nodules were higher in soybean plants inoculated with *Rhizobium* sp. BARIRGm901 than the non-inoculated plants. Bhuiyan *et al.* (1998) observed that *Bradyrhizobium* strains (BARI RGm-907) produced 14.35 nodules plant^{-1} and nodule weight (165.5 mg plant^{-1}) while non-inoculated plant produced minimum nodule number and nodule weight. In the same study, they opined that plant height of soybean significantly increased due to different *Bradyrhizobium* inoculation (different strains) over non-inoculated control. Bhuiyan *et al.* (2001) noted that seed inoculated with *Bradyrhizobium* strains increased significantly higher nodule number and nodule weight over non-inoculated control. They also found that soybean plant inoculated with *Bradyrhizobium* produced 22.5% to 48.1% higher dry matter production. Bhuiyan *et al.* (2001) found 3.3% to 40.7% higher in dry matter due to *Bradyrhizobium* inoculation by different strains in soybean. Significant or non-significant response due to inoculated by different *Bradyrhizobium* strains was observed on plant height in soybean (Bhuiyan *et al.* 2001). It also significantly increased pods plant^{-1}, seeds pod^{-1}, stover seed and seed yields of soybean. Bhuiyan *et al.* (1996) found that inoculated plant increased 20.7% to 22.5% higher stover and 61-66% higher seeds over non-inoculated plant. *Bradyrhizobium* inoculation significantly increased soybean yield upto 67.1% to 82.2% increase over non-inoculated control (Bhuiyan *et al.* 1998). Khanam *et al.* (1999) observed 19-102% increase in yield due to *Bradyrhizobium* inoculation at different locations of Bangladesh. Bhuiyan *et al.* (2001) found that soybean seed inoculated by different *Bradyrhizobium* strains gave significantly the highest stover yield. They opined that inoculated plant gave 1.80 to 1.98 t ha^{-1} seed yield while non-inoculated plant gave only 1.63 t ha^{-1} seed yield. They also observed 10.4 to 15.3% higher seed yield due seed inoculated by different *Bradyrhizobium* strains. Bhuiyan *et al.* (2005) reported that inoculated soybean plant produced significantly higher nodule number and nodule weight, stover yield and seed yield. In the present study, the yield components were higher by the influenced by *Rhizobium* sp. BARIRGm901 inoculation. Such increase in yield and yield components of the crop might be due to production of significantly higher number and weight of nodules per plant enhancing higher N_2-fixation. An increase in the above-ground dry biomass was observed because rhizobial inoculation is known to increase the yields of several legumes by way of increasing the nodulation and the biomass of root and shoot (Rao *et al*. 1986).

Table 2. Effect of *Rhizobium* sp. BARIRGm901 inoculant on nodulation, dry matter production and plant height of soybean atDebigonj during 2009-2010 and 2011-2012

***Rhizobium* inoculation**	**Nodule number plant^{-1}**	**Nodule weight (mg plant^{-1})**	**Root weight (g plant^{-1})**	**Shoot weight (g plant^{-1})**	**Plant height (cm)**
2009-2010					
Uninoculated	8.01b	34.5b	0.49b	3.55b	50.1b
Inoculated	15.44a	66.3a	0.55a	3.66a	54.0a
SE(±)	0.34	1.16	0.01	0.09	1.07
F-Test	**	**	**	**	**
2011-2012					
Uninoculated	4.31b	18.6b	0.48b	3.16b	54.5b
Inoculated	18.41a	77.0a	0.57a	4.37a	68.3a
SE(±)	0.24	1.69	0.02	0.17	1.18
F-Test	**	**	**	**	**

Means followed by common letter did not significantly different at 5% level by DMRT

Table 3. Effect of *Rhizobium* sp. BARIRGm901 inoculant on yield and yield attributes of soybean atDebigonj during 2009-2010 and 2011-2012

***Rhizobium* inoculation**	**Pods plant^{-1}**	**Seeds pod^{-1}**	**Stover yield (t ha^{-1})**	**1000-seed yield (g)**	**Seed yield (t ha^{-1})**
2009-2010					
Uninoculated	35.7b	2.33b	3.03b	79.9b	1.48b
Inoculated	37.6a	2.38a	3.56a	80.9a	1.69a
SE(±)	1.28	0.05	0.06	1.33	0.05
F-Test	**	**	**	**	**
2011-2012					
Uninoculated	41.5b	2.19b	2.46b	80.7	1.22b
Inoculated	50.4a	2.36a	2.91a	82.2	1.49a
SE(±)	1.60	0.04	0.04	0.92	0.02
F-Test	**	**	**	NS	**

Means followed by common letter did not significantly different at 5% level by DMRT

Effect of variety

Performance of different soybean varieties and advance lines has been presented in Tables 4 and 5. Nodule number and weight in soybean genotypes were differ significantly. Nodule number was the highest with BARI Soybean-6 (13.88 plant^{-1} in 2009-2010 and 13.00 plant^{-1} in 2011-2012) which was identical with advance line BGM-02026. The highest nodule weight (53.5 mg plant^{-1} in 2009-2010 and 60.5 mg plant^{-1} in 20011-2012) was also recorded in BARI Soybean-6 which was significantly higher over all other varieties/advance line in 2011-2012 but identical to Shohag and BGM-02026 in 2009-2010. Nodule number and biomass appeared to influence the seed yield of soybean. Plant height, pods plant^{-1} and stover yield were significant in 2009-2010 while plant height, pods plant^{-1}, seeds pod^{-1}, 1000-seed weight and seed yield were significant in 2011-2012. Among the two varieties and two advance lines, BARI Soybean-6 produced the highest nodule number (13.88 plant^{-1} in 2009-2010 and 13.00 plant^{-1} in 2011-2012), nodule weight (53.5 mg plant^{-1} in 2009-2010 and 60.5 mg plant^{-1} in 2011-2012), seed yield (1.73 t ha^{-1} in 2009-2010 and 1.44 t ha^{-1} in 2011-2012). Alam *et al.* (2015a) reported that *Rhizobium* sp. BARIRGm901 inoculated plant of all genotypes yielded significantly ($p \leq 0.05$) higher nodule numbers and weights than non-inoculated plants in both 2010 and 2011. The highest nodule weight (53.5 mg plant^{-1} and 60.5 mg plant^{-1}) was recorded in BARI Soybean-6 which was identical with Shohag and MTD-10 in 2009-2010. However, Danso *et al*. (1987) reported varietal differences in terms of nodule numbers due to inoculation of different rhizobial strains. Solomon *et al.* (2012) reported that main effect of soybean variety did not affect nodule number and nodule dry weight significantly. Nodule number and biomass appeared to influence the seed yield of soybean. Soybean varieties, irrespective of rhizobial inoculation, did not vary significantly in relation to root weight and shoot weight in both the years. Vasilas and Ham (1984) and Sparrow *et al.* (1995) have also reported similar findings on several legumes. Herridge *et al*. (1990) reported 60% to 85% higher dry matter production in Bragg variety of soybean than K466 and K468. Pods plant^{-1}, stover yield, 1000-seed yield and seed yield were observed higher in BARI Soybean-6. Only plant height was the highest in MTD-10. Lindermann and Ham (1979) have also reported significant varietal differences in soybean in relation to dry matter. Among the two varieties and two advance lines, BARI Soybean-6 produced significantly the highest seed yields. A significant effect of varieties alone on seed yield of soybean was also found by Danso *et al.* (1987). Similar increases in seed yield have been recorded by a number of researchers (Vasilas and Ham, 1984;

Abendroth and Elmore, 2006; Vitosh 1997). Singh and Tomer (1989) observed that dry matter at 45 and 60 days was significantly different in cultivars while it was not so at 30 days and harvest. In another study, Maqsood *et al.* (2001) found that mash bean genotypes did not differ significantly regarding plant height, number of seeds pod^{-1}, 1000-seed weight and seed yield.

Table 4. Effect of varieties on nodulation, dry matter production and plant height of soybean atDebigonj during 2009-2010 and 2011-2012

Variety/ advance line	Nodule number plant^{-1}	Nodule weight (mg plant^{-1})	Root weight (g plant^{-1})	Shoot weight (g plant^{-1})	Plant height (cm)
2009-2010					
Shohag	9.40b	49.4ab	0.41b	3.25c	38.2c
MTD-10	10.74b	47.1b	0.58a	3.44bc	60.2a
BGM-02026	12.90a	51.4ab	0.54a	3.68b	54.1b
BARI Soybean-6	13.88a	53.5a	0.54a	4.05a	55.6b
SE(±)	0.49	1.65	0.02	0.12	1.51
F-Test	**	**	**	**	*
2011-2012					
Shohag	9.25c	25.6d	0.47	3.40	59.6b
MTD-10	10.58b	46.9c	0.54	3.49	66.0a
BGM-02026	12.63a	58.3b	0.55	3.90	59.8b
BARI Soybean-6	13.00a	60.5a	0.55	4.27	60.3b
SE(±)	0.34	2.39	0.03	0.24	1.67
F-Test	**	**	NS	NS	*

Means followed by common letter did not significantly different at 5% level by DMRT

Table 5. Effect of varieties on yield and yield attributes of soybean at Debigonj during 2009-2010 and 2011-2012

Variety/ advance line	Pods plant^{-1}	Seeds pod^{-1}	Stover yield (t ha^{-1})	1000-seed weight (g)	Seed yield (t ha^{-1})
2009-2010					
Shohag	38.2ab	2.34	3.13b	80.1	1.55
MTD-10	33.0b	2.32	2.98b	78.5	1.50
BGM-02026	36.0ab	2.35	3.42a	79.1	1.55
BARI Soybean-6	39.4a	2.41	3.65a	83.8	1.73
SE(±)	1.80	0.07	0.09	1.86	0.08
F-Test	*	NS	**	NS	NS
2011-2012					
Shohag	46.3ab	2.05b	2.66	85.5a	1.23b
MTD-10	41.0b	2.40a	2.71	80.5b	1.32b
BGM-02026	44.2b	2.26a	2.64	71.0c	1.43a
BARI Soybean-6	52.3a	2.38a	2.73	88.9a	1.44a
SE(±)	2.26	0.05	0.06	1.68	0.03
F-Test	*	**	NS	**	**

Means followed by common letter did not significantly different at 5% level by DMRT

Interaction effect of *Rhizobium* inoculation and variety

Interaction effect of *Rhizobium* sp. BARIRGm901 inoculation and variety on nodule number, nodule weight and plant height were significant in both the years and rest of the parameters was found non-significant (Tables 6 and 7). Such non-significant interactions indicate that *Rhizobium* sp. BARIRGm901 inoculation was equally effective to all the soybean varieties and advance lines studied. Interaction effects revealed that inoculated BARI Soybean-6 produced the highest seed yields (1.84 t ha^{-1}) in 2009-2010 which was identical with inoculated Shohag, inoculated MTD-10, inoculated BGM-02026 and non-inoculated BARI Soybean-6; and inoculated BGM-02026 produced the highest seed yields (1.60 t ha^{-1}) in 2011-2012. Non-inoculated MTD-10 gave the lowest seed yield in 2009-2010 while non-inoculated Shohag gave the lowest seed yield in 2011-2012. BARI Soybean-6 inoculated with *Rhizobium* sp. BARIRGm901 gave the highest nodule (19.65 plant^{-1} in 2009-2010 and 21.08 plant^{-1} in 2011-2012) and nodule weight (74.8 mg plant^{-1} in 2009-2010 and 100.2 mg plant^{-1} in 2011-2012). The interaction between soybean varieties and rhizobial strains was found significant in relation to number of nodules (Solomon *et al*. 2012). The interaction of soybean variety Cheri with strain TAL 379 resulted in the highest number of nodules (13.47 nodules plant^{-1}) followed by inoculation with TAL 379 on variety

Jalele(13.0 nodules plant^{-1}) (Solomon *et al*. 2012). Nodule dry weight was significantly affected by the interaction of soybean variety and rhizobial strain (Solomon *et al*. 2012). They reported that soybean variety Jalele produced significantly higher nodule dry weight (206.67 mg plant^{-1}) when inoculated with *B. japonicum* strain TAL 379 followed by variety Cheri (193.33 mg plant^{-1}) with the same rhizobial strain. The present study is in agreement with the report of Lindermann and Ham (1979) who observed that nodule dry weight was significantly dependent on *B. japonicum* strain and soybean variety interaction. Irrespective of the soybean variety, inoculation of *Bradyrhizobium japonicum* strain TAL 379 resulted in highest dry matter production (Solomon *et al*. 2012). Vasilas and Ham (1984) and Sparrow *et al*. (1995) have also reported similar findings on several legumes. On the other hand, the variety and strain interaction was found to be non-significant in relation to dry matter yield. The dry matter production was highly significantly affected by the main effect of both variety and inoculant but the variety-strain interaction showed a non-significant response on the dry matter yield (Solomon *et al.* 2012). Interaction effects revealed that inoculated BARI Soybean-6 produced significantly the highest seed yields (3.41 t ha^{-1} in 2009-2010 and 2.80 t ha^{-1} in 2013-2014) which were 14.1% higher over non-inoculated BARI Soybean in 2009-2010 and 27.9% higher over non-inoculated BARI Soybean-6 in 2013-2014, and non-inoculated BGM-02026 recorded the lowest seed yield. Solomon *et al*. (2012) observed that interaction of variety and strain resulted in a non-significant influence on the number of pods plant^{-1}, number of seeds pod^{-1}, 1000-seed weight, stover yield and also seed yield of soybean.

Successful nodulation of leguminous crops by *Rhizobium* largely depends on the presence of a specific and compatible strain in soil for a particular legume. Soybean is a relatively new crop to Bangladeshi farmers. Large-scale production of soybean is lacking in the study area. The crop was recently introduced in Northern area of Bangladesh which is mainly limited to the Agricultural Research Center and few surrounding farmers. It had not been planted previously at the particular experimental site. Therefore, a field study was conducted in 2009-2010 and 2011-2012 growing season to assess the effects of *Rhizobium* sp. BARIRGm901on two varieties (Shohag and BARI Soybean-6) and two advance lines of soybean in relation to nodulation, dry matter production and yield.

Table 6. Interaction effect of varieties and *Rhizobium* sp. BARIRGm901 inoculant on nodulation, dry matter production and plant height soybean at Debigonj during 2009-2010 and 2011-2012

Treatments	**Nodule number plant^{-1}**	**Nodule weight (mg plant^{-1})**	**Root weight (g plant^{-1})**	**Shoot weight (g plant^{-1})**	**Plant height (cm)**
2009-2010					
Shohag x U	7.06d	31.5d	0.40e	3.20c	38.1d
Shohag x I	11.74c	67.3b	0.43de	3.29c	38.3d
MTD-10 x U	7.96d	36.8d	0.57ab	3.40c	58.4ab
MTD-10 x I	13.52c	57.5c	0.58a	3.49bc	62.0a
BGM-02026 x U	8.93d	37.4d	0.51bc	3.61abc	53.8bc
BGM-02026 x I	16.86b	65.5b	0.57ab	3.76abc	54.5bc
BARI Soybean-6 x U	8.11d	32.3d	0.47cd	3.98ab	50.0c
BARI Soybean-6 x I	19.65a	74.8a	0.61a	4.12a	61.2a
SE(±)	0.69	2.33	0.02	0.17	2.13
F-Test	**	**	*	*	*
CV (%)	11.8	9.3	9.3	9.6	8.2
2011-2012					
Shohag x U	3.25e	14.0d	0.42	2.58	56.4cde
Shohag x I	15.25c	37.2c	0.52	4.22	62.8bc
MTD-10 x U	4.20e	19.5d	0.47	2.48	57.9cd
MTD-10 x I	16.95b	74.3b	0.61	4.51	74.1a
BGM-02026 x U	4.88d	20.3d	0.52	3.60	49.4e
BGM-02026 x I	20.38a	96.3a	0.58	4.20	70.2ab
BARI Soybean-6 x U	4.93d	20.8d	0.51	3.99	54.4de
BARI Soybean-6 x I	21.08a	100.2a	0.59	4.55	66.2b
SE(±)	0.48	3.38	0.04	0.34	2.36
F-Test	**	**	NS	NS	*
CV (%)	8.4	14.1	13.5	18.1	7.7

Means followed by common letter did not significantly different at 5% level by DMRT

Table 7. Effect of varieties and *Rhizobium* sp. BARIRGm901 inoculant on yield and yield attributes of soybean at Debigonj during 2009-2010 and 2011-2012

Treatments	Pods plant^{-1}	Seeds pod^{-1}	Stover yield (t ha^{-1})	1000-seed weigh (g)	Seed yield (t ha^{-1})	% Yield increase over control
2009-2010						
Shohag x U	37.0ab	2.23	2.79c	79.55	1.47b	-
Shohag x I	39.4ab	2.35	3.46b	80.72	1.64ab	11.6
MTD-10 x U	31.6b	2.30	2.63c	77.88	1.39b	-
MTD-10 x I	34.5ab	2.34	3.33b	79.18	1.61ab	15.8
BGM-02026 x U	35.9ab	2.33	3.25b	78.97	1.44b	-
BGM-02026 x I	36.2ab	2.38	3.60ab	79.25	1.66ab	15.3
BARI Soybean-6 x U	38.3ab	2.36	3.46ab	83.23	1.62ab	-
BARI Soybean-6 x I	40.5a	2.45	3.85a	84.50	1.84a	1.6
SE(±)	2.55	0.10	0.12	2.65	0.11	-
F-Test	*	NS	*	NS	*	-
CV (%)	13.9	8.5	7.3	6.6	13.4	-
2011-2012						
Shohag x U	39.9	1.95	2.40	84.7	1.07	-
Shohag x I	52.8	2.15	2.92	86.3	1.40	30.8
MTD-10 x U	37.4	2.33	2.48	80.2	1.24	-
MTD-10 x I	44.6	2.48	2.93	80.9	1.41	13.7
BGM-02026 x U	40.8	2.23	2.51	70.7	1.26	-
BGM-02026 x I	47.7	2.30	2.77	71.4	1.60	27.0
BARI Soybean-6 x U	48.2	2.25	2.44	87.3	1.32	-
BARI Soybean-6 x I	56.5	2.50	3.03	90.5	1.57	18.9
SE(±)	3.20	0.073	0.078	1.83	0.048	-
F-Test	NS	NS	NS	NS	NS	-
CV (%)	13.9	6.4	5.8	4.5	7.1	-

Means followed by common letter did not significantly different at 5% level by DMRT

Legumes have a high internal phosphorous requirement for their symbiotic nitrogen fixation. Singleton *et al*. (1985) reported that, in addition to the nodule formation, deficiency of phosphorous in legumes also markedly affects the development of effective nodules and the nodule leghaemoglobin content. It is therefore suggested that the presence of high amount of available phosphorous in soils as in the soils of the experimental field may be beneficial to nodule nitrogen fixation through the prevention of the decrease of the phosphorous concentration in the plants at the later growth stage.

The ability of *Rhizobium* sp. BARIRGm901 to produce nodules on soybean roots could be attributed to compatibility of this strain with soybean varieties used in the present study. Kuykendall *et al*. (1996) reported that soybean plants inoculated with strain TA-11 NOD+ were significantly better nodulated than those inoculated with strain I-110 ARS. Danso *et al*. (1987) also observed that Nitragin inoculant induced production of more nodules than strain D in soybean.

CONCLUSION

The results of the present study have indicated that it is important to promote the appropriate use of biofertilizers through national fertilizer programs. Efforts should be made, wherever possible, to introduce inoculation technology to the farming community. More research based on standard methods needs to be undertaken to assess the contribution of nitrogen-fixing plants to the overall nitrogen budget. The use of rhizobial inoculants is at its infancy in Bangladesh, and so far it is not one of the research priorities of Agricultural Research Institutions in the country. Rhizobial inoculants are not locally available, and farmers are not aware about this new technology. Therefore, more efforts need to be done to popularize this cheap and eco-friendly technology among resource poor farming community of the nation. For an alternative use, *Rhizobium* sp. BARIRGm901 can be recommended for soybean inoculum production.

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