EFFECT OF BRADYRHIZOBIUM INOCULUM AND LEVELS OF PHOSPHORUS ON THE YIELD AND QUALITY OF SOYBEAN †

[EFECTO DEL INÓCULO DE BRADYRHIZOBIUM Y NIVELES DE FÓSFORO EN EL RENDIMIENTO Y CALIDAD DE LA SOYA]

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SUMMARY

Background: Soybean is one of the major oil seed crops in Bangladesh. Combine application of *Rhizobium* inoculation and phosphorus fertilizer could be an important factor to get maximum yield and quality of soybean. **Objective:** To evaluate the effect of Bradyrhizobium inoculum and levels of phosphorus on yield and quality of soybean varieties. **Methodology**: The experiment evaluated three factors namely, varieties, Bradyrhizobium inoculum and phosphorus levels. The three varieties were: i) Binasoybean-1 ii) Binasoybean-2 and iii) BARI Soybean-6. Bradyrhizobium inoculum levels were: i) control (no inoculum), ii) 50% of recommended dose (RD) (25 g kg^{-1} seed) iii) 100% of RD (50 g kg^{-1} seed). The phosphorus levels were: i) control (no phosphorus) ii) 50% of RD (18 kg ha^{-1}), iii) 100% of RD (36 kg ha^{-1}). The experiment was laid out in a randomized complete block design with three replications. Data were recorded on yield, yield contributing characters and quality parameters of seeds. **Results:** Binasoybean-1 performed superiorly in terms of all the yield and yield contributing characters. Application of 100% of RD of Bradyrhizobium inoculum and application of 100% of RD of phosphorus also showed superior performance. Considering the interaction effect, the findings of the study indicate that Binasoybean-1 responded well to the application of 100% of RD of phosphorus and 100% of RD of Bradyrhizobium and gave maximum seed yield. The highest protein content (39.21%) was found in Binasoybean-2, 50% of RD of phosphorus with no Bradyrhizobium inoculum and the highest oil content was found (19.33%) in Binasoybean-2, no phosphorus and 50% of RD of Bradyrhizobium inoculum. **Implication:** Binasoybean-1 with the application of 100% of RD of phosphorus and 100% of RD of Bradyrhizobium might be recommended to obtain higher yield soybean in Bangladesh. **Conclusion:** From this study it may be concluded that recommended dose of phosphorus and Bradyrhizobium is beneficial for a higher yield of Binasoybean-1.
Keywords: Rhizobial inoculation; fertilization; productivity; oil; protein.

RESUMEN

Antecedentes: La soja es uno de los principales cultivos de semillas oleaginosas en Bangladesh. La aplicación combinada de inoculación de Rhizobium y fertilizante de fósforo podría ser un factor importante para obtener el máximo rendimiento y calidad de la soja. **Objetivo**: Evaluar el efecto del inóculo de Bradyrhizobium y niveles de fósforo en el rendimiento y la calidad de variedades de soja. **Metodología:** El experimento evaluó tres factores: Tres variedades de soya: i) Binasoybean-1 ii) Binasoybean-2 y iii) BARI Soybean-6. Tres niveles de inóculo de Bradyrhizobium: i) control (sin inóculo), ii) 50% de la dosis recomendada (DR) (25 g kg^{-1} semilla) iii) 100% de DR (50 g kg^{-1} semilla). Tres niveles de fósforo: i) control (sin fósforo) ii) 50% de DR (18 kg ha^{-1}), iii) 100% de DR (36 kg ha^{-1}). El experimento se planteó en un diseño de bloques completos al azar con tres repeticiones. Se registraron datos sobre el rendimiento, los caracteres que contribuyen al rendimiento y los parámetros de calidad de las semillas. **Resultados:** En el caso de la variedad Binasoybean-1 se desempeñó de manera superior en términos de todos los caracteres de rendimiento y contribución al rendimiento. La aplicación del 100% de DR de inóculo de Bradyrhizobium y la aplicación del 100% de DR de fósforo también mostraron un rendimiento superior. Considerando el efecto de interacción, los hallazgos del estudio indican que Binasoybean-1 respondió bien a la aplicación de 100% de DR de fósforo y 100% de DR de Bradyrhizobium y dio el máximo rendimiento de semilla. El mayor contenido de proteína

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(39.21%) se encontró en Binasoybean-2, 50% de DR de fósforo sin inóculo de Bradyrhizobium y el mayor contenido de aceite se encontró (19.33%) en Binasoybean-2, sin fósforo y 50% de DR de Bradyrhizobium inóculo. **Implicaciones**: Binasoybean-1 con la aplicación de 100% de DR de fósforo y 100% de DR de Bradyrhizobium podría recomendarse para obtener soja de mayor rendimiento en Bangladesh. **Conclusión:** De este estudio se puede concluir que la dosis recomendada de fósforo y Bradyrhizobium es beneficiosa para un mayor rendimiento de Binasoybean-1.
Palabras clave: Inoculación con Rhizobium; fertilización; productividad; aceite; proteína.

INTRODUCTION

Soybean (*Glycine max* L) is an important economic crop among grain legumes, mostly grown in a wide range of environments all over the world. It covers 120.30 million ha of land worldwide with the production of 333.67 million tons (FAO, 2021). Protein and oil are two significant components of soybeans that contribute to their overall quality. It contains oil 20-22%, protein 42-45%, carbohydrates 30-35% and total sugar 10-12% and also high amount of the amino acid, thiamin, vitamins, niacin, riboflavin, phosphorus, calcium and iron (Wahhab *et al.*, 2001). It contributes 25% of the global edible oil production (Jaybhay *et al*., 2021). The multipurpose use of soybean is gradually increasing day by day in Bangladesh. About 0.717 lac hectares of land is under soybean cultivation and annual production is approximately 1.35 lac metric tons with an average yield of 1.717 t ha^{-1} (DAE, 2021). But the supply of soybean is very lower than the demand (Rashid *et al*., 2023). Considering the ever-increasing demand of edible oil of our country, it is extremely needed to increase the total production of oil crops by fitting the existing cropping patterns by replacing the high yielding variety (HYV) with low yielding varieties through improving management practices as well as increasing the area of cultivation wherever possible (Salam and Kamruzzaman, 2015). Proper nutrient management is one of the cultivation techniques that are expected to contribute substantially in increasing soybean production (Bagale, 2021).

Varietal differences in response to nutrient levels and plant efficiencies for nutrient uptake have been reported for many species (Pal *et al*., 2016; Paul *et al.,* 2018; Jha *et al*., 2023). The search for efficient plants in nutrient uptake and use has been stimulated since large genetic variability was reported for these characters within germplasm of several species (Furlani *et al.,* 2002; Paul *et al*., 2019). Variety has been reported to affect the yield and quality of soybean. Bangladesh Agricultural University, Bangladesh Agricultural Research Institute and Bangladesh Institute of Nuclear Agriculture have developed different high yielding soybean varieties (Nimu *et al*., 2020; Das *et al*., 2022; Rabbani *et al*., 2023). Different varieties can respond differently with different fertilizer levels. Also, studies elsewhere show that low native soil phosphorus availability coupled with poor utilization efficiency of added nutrients is a major constraint limiting the productivity of soybean. In soybean, phosphate fertilizer shows a significant effect in stimulating the development of roots, so the plants will be more resistant on drought, accelerate the harvest and add nutritional value from seeds. Phosphorus has been demonstrated to increase root nodule weight and quantity as well as to improve seed yield of soybean (Khanam *et al.,* 2016; Barman *et al*., 2023) and faba bean (Yasmin *et al*., 2020).

Legume plants particularly soybean have the ability to fix nitrogen from atmosphere by symbiotic relationship with *Rhizobial* bacteria (Coskan and Dogan, 2011). These bacteria are located around root hair and fixes atmospheric nitrogen using particular enzyme called nitrogenase. When this mutualistic symbiosis established, rhizobia use plant resources for their own reproduction whereas fixed atmospheric nitrogen is used to meet nitrogen requirement of both itself and the host plants. Supply of nitrogen through biological nitrogen fixation has ecological and economic benefits (Ndakidemi *et al*., 2006). The symbiotic relationship between the soybean root and Rhizobial root colonies and subsequent symbiotic nitrogen fixation is one of the most important physiological processes, which occurs in the growth, and development of the soybean plant. Research done by Bambara and Ndakidemi, (2009) concluded that *Rhizobium sp.* inoculation in legumes stimulated growth and is an alternative source to the expensive commercial nitrogen fertilizers. Nitrogen is highly needed for all enzymatic reactions in a plant, also is a major part of the chlorophyll molecules and plays a necessary role in photosynthesis and is a major component of several vitamins (Uchida, 2000). In legumes and other leafy vegetables, nitrogen improves the quality and quantity of dry matter and protein (Uchida, 2000).

In soybean production, phosphorus and inoculation with the appropriate Bradyrhizobium strains have quite prominent effects on yield parameters (Kumaga and Ofori, 2004). Inoculation is an activity of transferring microorganisms in the form of bacteria and fungi from the place or source of origin to the new medium. *Rhizobium* inoculation on soybean plants has a long been known as one of the biological fertilizers. In soybean plants to produce 1 kg of seeds, plants absorb 70-80 grams of nitrogen from the soil so that if the yield of 1.5 tons/ha it will absorb 105-120 nitrogen from the soil (Purwaningsih *et al.*, 2015). The factors which control the amount of nitrogen fixed include available soil nitrogen, genetic determinants of compatibility in both symbiotic partners and lack of other yield-limiting factors like edaphic factors associated with phosphorus deficiency (Harold *et al*., 1992). The absence of the required Rhizobia species and optimal phosphorus levels limit legume production in different parts of the world. Inoculation with compatible and suitable Rhizobia with optimum phosphorus levels may be essential where a low population of native Rhizobial strains prevail and is one of the key components of which grain legume farmers can use to optimize yields and seed quality. Therefore, there is a scope to work on effect of Bradyrhizobium inoculum and phosphorus fertilization on yield and quality of soybean varieties.

MATERIALS AND METHODS

Features of the experimental location

To find out the effect of Bradyrhizobium inoculum and levels of phosphorus on yield and quality of soybean varieties an experiment was carried out at the experimental field of Farm Management Section, Bangladesh Agricultural University (90º 50' E and 24º 75' N and at an altitude of 18 meter) during the *Rabi* (winter) season of 2019. The experimental area belongs to the non-calcareous dark grey floodplain soil under Old Brahmaputra Floodplain Agro-ecological Zone (AEZ-9). The land was well drained medium high with silt-loam textured soil. The soil almost neutral in reaction (pH 6.8), low in organic matter content (1.27%) and the general fertility level of the soil was low (1.1% total N, 25 ppm available P and 0.16 me % exchangeable K). The experimental area characterized by subtropical monsoon climate with a humid environment.

Experimental treatments and design

The experiment consisted of three factors namely, varieties, Bradyrhizobium inoculum (*Brdyrhizobium japonicum*) and phosphorus levels. Three varieties included i) Binasoybean-1 ii) Binasoybean-2 and iii) BARI Soybean-6. While three different Bradyrhizobium inoculum were i) control (no *Bradyrhizobium* inoculum), ii) 50% of RD (25 g kg^{-1} seed) iii) 100% of RD (50 g kg^{-1} seed) and phosphorus levels were i) control (no phosphorus) ii) 50% of RD (18 kg ha^{-1}), iii) 100% of RD (36 kg ha^{-1}). Triple super phosphate was used as a source of phosphorus. The recommended dose (RD) of *Brdyrhizobium japonicum* was 50 g per kg soybean seed (BINA, 2020). The experiment was laid out in a Randomized Complete Block Design with three replications. The unit plot size was 4.0 m × 2.5 m.

Field preparation and fertilizer application

The piece of land selected for carrying out the experiment was opened with a power tiller and was exposed to the sun for a week after which the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain a good tilth. Manures and fertilizers were applied by following Fertilization Recommendation Guide-2012 (FRG, 2012). Well decomposed cowdung at the rate of 20 t ha^{-1} was applied during final land preparation. Urea, muriate of potash (MoP), gypsum and boric acid were applied at the rate of 60, 120, 110 and 10 kg per ha, respectively without triple superphosphate (TSP). Entire amount of urea, MoP, gypsum and boric acid were applied at the time of final land preparation. Triple superphosphate was applied as per experimental treatment specification. The recommended dose of TSP was 36 kg per ha.

Seed inoculation application

The seeds were inoculated with commercial *Bradyrhizobium japonicum* inoculant (*Legumefix)* as per treatment specification before sowing. The soybean seeds were put in a plastic bucket and moistened with ordinary tap water, stirred uniformly with a wooden spatula. The inoculants were added to the moistened seeds, stirred gently and uniformly, until the seeds were evenly coated. The seeds were then spread on a sheet of canvas material under a shade for at least one hour to allow the inoculants adequately adhere to the surface of the seeds. The sowing was done early in the morning to avoid exposing the inoculants to direct sunrays, which might affect the quality of the inoculants.

Agronomic management of the crop

Furrows were made for sowing seeds when the land was in proper moisture condition and seeds were sown. The seed rate was 80 kg ha^{-1}. During seed emergence period, weeding and thinning were done on the 25 days after the emergence (DAE). Keeping only the vigorous seedling, the rest of the seedlings were removed. Two irrigations were applied in the experimental plots during the growing period. The first irrigation was applied on the 4^{th} week after emergence and the second irrigation was applied on the 8^{th} week after emergence by flood irrigation method. The crop was harvested at 80-85% pod maturity of the terminal raceme. Prior to harvest five plants were selected randomly from each unit plot and uprooted to record data on branches per plant (no.), length of pod (cm), effective pods per plant (no.), seeds per pod (no.), 1000-seed weight (g), protein (%) and oil (%) content of soybean seeds. The harvesting was done at different dates, as the maturity period of the genotypes was not same. The plants were sun dried properly. Seeds were separated from pods and finally seed and stover yields were recorded and converted to ton per ha.

Measurement quality parameters

Protein content was computed by multiplying N content in soybean seed determined by Microkjeldahl assay by a conventional factor of 6.25 (Jackson, 1973). The oil content of soybean seed was extracted by Folsch method (Folsch *et al*., 1957) by using chloroform:methanol in 2:1 ratio in a beaker with stirring. The extractant was removed by heating and oil obtained was expressed in percentage.

Data analysis

Data were compiled and analyzed to find out the significance of variation resulting from the experimental treatments. All the collected data were analyzed following three way factorial analysis of variance (ANOVA) technique and mean differences were adjudged by the Duncan Multiple Range Test (Gomez and Gomez, 1984) using the program MSTAT-C (Russel, 1986).

RESULTS

Effect of variety on yield, yield contributing and quality parameters

All the yield and yield contributing characters were significantly influenced by varietal effect except seeds per pod, 100-seed weight and harvest index. The maximum number of branches per plant (2.88), pods per plant (44.08), seed yield (2.43 t ha^{-1}) and stover yield (4.37 t ha^{-1}) were produced by Binasoybean-1. The longest pod (3.36 cm) was found in Binasoybean-2. The minimum number of branches per plant (2.68), pod length (3.21 cm), pods per plant (40.48), seed yield (2.21 t ha^{-1}) and stover yield (3.96 t ha^{-1}) were found in BARI Soybean-6. The protein and oil content of soybean were significantly influenced by the variety. From the Table 1, it is observed that the difference between protein content and oil content was huge. The highest protein content (37.48%) was found in Binasoybean-1 and oil content was found (17.76%) in the same variety. The lowest protein content (36.77%) was found in Binasoybean-2 and lowest oil content (16.84%) was recorded in the BARI Soybean-6 (Table 1).

Effect of Phosphorus on yield, yield contributing and quality parameters

Application of different level of phosphorus had significant ($p<0.01$) effect on all the yield and yield contributing characters except branches per plant, seeds per pod, 100-seed weight and harvest index. The maximum number of pods per plant (43.78), seeds per pod (2.98) were observed at 100% of RD of phosphorus. Maximum pod length (3.31 cm), seed yield (2.51 t ha^{-1}) and stover yield (4.49 t ha^{-1}) were recorded in 100% of RD of phosphorus. On the other hand, minimum no. of pods per plant (40.07), seeds per pod (2.56), seed yield (2.15 t ha^{-1}) and stover yield (3.87 t ha^{-1}) were documented in control treatment. The protein and oil content of soybean were not significantly influenced by the effect of phosphorus (Table 2).

Table 1. Effect of variety on yield, yield contributing and quality parameters of soybean.

Variety	Branches Per plant (no.)	Length of pod (cm)	Effective pods per plant (no.)	Seeds per pod (no.)	100-seed weight (g)	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index (%)	Protein content (%)	Oil content (%)
Binasoybean-1	2.88a*	3.21b	44.08a	2.73	12.11	2.43a	4.37a	35.66	36.77b	17.26b
Binasoybean-2	2.76b	3.36a	41.90b	2.97	11.95	2.38b	4.26b	35.73	37.48a	17.76a
BARI Soybean-6	2.68b	3.21b	40.48b	2.75	12.00	2.21c	3.96c	35.76	36.99ab	16.84c
Level of significance	**	**	**	NS	NS	**	**	NS	*	**
CV%	7.30	3.80	8.05	17.80	11.64	2.77	3.20	2.99	2.95	2.48

*In a column, figures with the same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

*= Significant at 5% level of probability,

** =Significant at 1% level of probability, NS = Non significant

Table 2. Effect of level phosphorus on yield, yield contributing and quality parameters of soybean.

Phosphorus	Branches per plant (no.)	Length of pod (cm)	Effective pods per plant (no.)	Seeds per pod (no.)	100-seed weight (g)	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index (%)	Protein content (%)	Oil content (%)
Control (No Phosphorus)	2.85	3.25ab*	40.07b	2.56	12.10	2.15c	3.87c	35.71	36.9	17.34
50% of RD (18 kg ha^{-1})	2.76	3.31a	42.61a	2.91	12.22	2.35b	4.24b	35.63	37.38	17.27
100% of RD (36 kg ha^{-1})	2.71	3.22b	43.78a	2.98	11.73	2.51a	4.49a	35.8	36.96	17.25
Level of significance	NS	**	**	NS	NS	**	**	NS	NS	NS
CV(%)	7.30	3.80	8.05	17.80	11.64	2.77	3.20	2.99	2.95	2.48

*In a column, figures with the same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)
** =Significant at 1% level of probability, NS = Non significant

Effect of Bradyrhizobium inoculum on yield, yield contributing and quality parameters

Level of *Bradyrhizobium japonicum* inoculum had significant ($p<0.01$) effect on all the yield and yield contributing characters except 100-seed weight. The maximum number of branches per plant (2.93), pods per plant (44.66), seeds per pod (3.05) were observed at 50% of RD of Bradyrhizobium inoculum. Maximum pod length (3.42 cm), seed yield (2.59 t ha^{-1}), stover yield (4.42 t ha^{-1}) and harvest index (37.00 %) were recorded in 50% of RD of Bradyrhizobium inoculum. The minimum number of branches per plant (2.68) was documented in 100% of RD of Bradyrhizobium inoculum. On the other hand, minimum no. of pods per plant (40.60), seeds per pod (2.52), seed yield (2.08 t ha^{-1}), stover yield (3.98 t ha^{-1}) and harvest index (34.37 %) were registered with control treatment. The protein and oil content of soybean were significantly influenced by the effect of Bradyrhizobium inoculum. From the table 3, it is seen that, the highest protein content (38.13%) was found in no Bradyrhizobium inoculum and oil content was found (18.00%) with application of 50% of RD of Bradyrhizobium inoculum. On the other hand, the lowest protein content (35.58%) was found in 50% of RD of Rhizobium inoculum and the lowest oil content (16.52%) was recorded when no Bradyrhizobium inoculum was applied (Table 3).

Interaction effect of variety and phosphorus on yield, yield contributing and quality parameters

The interaction effect of variety and phosphorus inoculum was significant ($p<0.01$) on all the yield and yield contributing characters except 100-seed weight and harvest index. The maximum no. of branches per plant (3.14) was found in Binasoybean-2 with control treatment whilst minimum (2.35) was obtained with BARI Soybean-6 and control treatment. Longest pod (3.49 cm) was recorded in treatment combination of Binasoybean-2 with 50% of RD of phosphorus and the shortest length of pod (3.14 cm) was recorded in treatment combination of BARI Soybean-6 and 100% of RD of phosphorous. The maximum number of pods per plant (57.06), seeds per pod (2.98), seed yield (2.69 t ha^{-1}) and stover yield (4.81 t ha^{-1}) were found in Binasoybean-1 with 100% of RD of phosphorus. The minimum number of pods per plant (35.30), seeds per pod (2.07), seed yield (2.13 t ha^{-1}) and stover yield (3.84 t ha^{-1}) was produced in Binasoybean-1 with control treatment. The protein and oil content of soybean were not significantly influenced by the interaction effect of variety and phosphorus (Table 4).

Interaction effect of variety and Bradyrhizobium inoculum on yield, yield contributing and quality parameters

Effect of interaction of variety and Bradyrhizobium inoculum on number of branches per plant was significant ($p<0.01$). The interaction of Binasoybean-1 and 50% of RD of Bradyrhizobium inoculum produced the highest number (3.09) of branches per plant. The lowest number of branches per plant (2.46) was recorded in Binasoybean-2 with 100% of RD of Bradyrhizobium inoculum. The longest pod (3.48 cm) was found in Binasoybean-2 with 100% of RD of Bradyrhizobium inoculum and the lowest pod length (2.84 cm) was found in Binasoybean-1 with no Bradyrhizobium inoculum. The highest number of pods per plant (48.13) was found in Binasoybean-2 with 50% of RD of Bradyrhizobium inoculum and the lowest one (36.10) was found in Binasoybean-2 and no Bradyrhizobium inoculum. The interaction of variety and Bradyrhizobium inoculum exerted significant effect on seed yield. The highest seed yield

(2.69 t ha^{-1}) and stover yield (4.60 t ha^{-1}) was obtained in Binasoybean-1 with 100% of RD of Bradyrhizobium inoculum and the lowest seed yield (2.01 t ha^{-1}) was obtained from BARI Soybean-6 with no Rhizobium inoculum. The protein and oil content of soybean were not significantly influenced by the interaction effect of variety and Bradyrhizobium inoculum (Table 5).

Table 3. Effect of level Bradyrhizobium on yield, yield contributing and quality parameters of soybean.

Bradyrhizobium	Branches per plant (no.)	Length of pod (cm)	Effective pods per plant	Seeds per pod (no.)	100-seed weight (g)	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index (%)	Protein content (%)	Oil content (%)
Control (No Bradyrhizobium)	2.71b*	3.06c	40.60b	2.52b	11.14	2.08c	3.98c	34.37c	38.13a	16.52c
50% of RD (25 g kg^{-1})	2.93a	3.30b	44.27a	3.05a	12.67	2.34b	4.21b	35.78b	35.58c	18.00a
100% of RD (50 g kg^{-1})	2.68b	3.42a	41.59b	2.88a	12.24	2.59a	4.42a	37.00a	37.52b	17.34b
Level of significance	**	**	**	**	NS	**	**	**	**	**
CV(%)	7.30	3.80	8.05	17.80	11.64	2.77	3.20	2.99	2.95	2.48

*In a column, figures with the same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)
** =Significant at 1% level of probability, NS = Non significant

Table 4. Interaction effect of variety and level of phosphorus on yield and yield contributing and quality parameters of soybean.

Variety× Phosphorus	Branches per plant (no.)	Length of pod (cm)	Effective pods per plant	Seeds per pod (no.)	100-seed weight (g)	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index (%)	Protein content (%)	Oil content (%)
V_1 P_0	3.05ab*	3.212cd	34.50e	2.07b	12.86	2.13g	3.84fg	35.62	37.13a	17.76ab
V_1 P_1	2.66c	3.24bcd	40.67d	3.14a	11.80	2.47c	4.48b	35.49	37.25a	16.71d
V_1 P_2	2.94b	3.185cd	57.06a	2.98a	11.66	2.69a	4.81a	35.87	35.93b	17.31c
V_2 P_0	3.14a	3.26bc	43.96bc	2.94a	11.43	2.21f	3.95ef	35.76	37.65a	17.94a
V_2 P_1	2.56c	3.49a	46.43b	2.85a	12.06	2.38d	4.28c	35.64	37.05a	17.59abc
V_2 P_2	2.58c	3.34b	35.30e	3.10a	12.36	2.55b	4.56b	35.78	37.74a	17.76ab
V_3 P_0	2.35d	3.28bc	41.74cd	2.68a	12.02	2.13g	3.82g	35.76	35.92b	16.32d
V_3 P_1	3.06ab	3.215cd	40.72d	2.72a	12.79	2.21f	3.97e	35.76	37.85a	17.52bc
V_3 P_2	2.62c	3.145d	38.99d	2.86a	11.18	2.29e	4.10d	35.76	37.20a	16.70d
Level of significance	**	*	*	*	NS	**	**	NS	**	**
CV (%)	7.30	3.80	8.05	17.80	11.64	2.77	3.20	2.99	2.95	2.48

*In a column, figures with the same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)
*= Significant at 5% level of probability, ** =Significant at 1% level of probability, NS = Non significant V_1= Binasoybean-1, V_2= Binasoybean-2 and V_3= BARI Soybean-6
P_0= Control (No Phosphorus), P_1= 50% of RD (18 kg ha^{-1}) and P_2= 100% of RD (36 kg ha^{-1})

Interaction effect of phosphorus and Bradyrhizobium inoculum on yield, yield contributing and quality parameters

Interaction of phosphorus and Bradyrhizobium inoculum showed significant ($p<0.01$) effect on number of branches per plant. The interaction of no phosphorus with 100% of RD of Bradyrhizobium inoculum and 100% of RD of phosphorus with 50% of RD of Bradyrhizobium inoculum produced the highest number of branches per plant (2.97), respectively. The lowest number of branches per plant (2.33) was recorded in 100% of RD of phosphorus with 100% of RD of Bradyrhizobium inoculum. The longest pod (3.54 cm) was found in 100% of RD of phosphorus with 100% of RD of Bradyrhizobium inoculum. The lowest pod length (2.95 cm) was found in 100% of RD of phosphorus with no Bradyrhizobium inoculum. The highest number of pods per plant (48.81) was found in 100% of RD of phosphorus with 50% of RD of Bradyrhizobium inoculum and the lowest pods per plant (38.33) was found in no phosphorus with 100% of RD of Bradyrhizobium inoculum. The highest seed yield (2.74 t ha^{-1}) and stover yield (4.65 t ha^{-1}) was obtained in 100% of RD of phosphorus with 100% of RD of Bradyrhizobium inoculum and the lowest seed yield (1.89 t ha^{-1}) and stover yield (3.60 t ha^{-1}) was obtained from no phosphorus with no Bradyrhizobium inoculum. The protein and oil content of soybean were significantly influenced by the interaction effect of phosphorus and Bradyrhizobium inoculum (Table 6). The highest protein content (38.90%) was found in 100% of RD of phosphorus with no Bradyrhizobium inoculum and oil content was found (18.19%) in 100% of RD of phosphorus with 50% of RD of Bradyrhizobium inoculum. On the other hand, the lowest protein content (35.12%) was found in 100% of RD of phosphorus with 50% of RD of Bradyrhizobium inoculum and the lowest oil content (16.37%) was recorded in 50% of RD of phosphorus with no Bradyrhizobium inoculum (Table 6).

Interaction effect of variety, phosphorus and Bradyrhizobium inoculum on yield, yield contributing and quality parameters

Interaction effect of variety, phosphorus and *Bradyrhizobium* inoculum had significant ($p<0.01$) effect on number of branches per plant. The highest number of branches per plant (3.23) was found in combination of Binasoybean-2, no phosphorus and 50% of RD of Bradyrhizobium inoculum, Binasoybean-2, no phosphorus and 100% of RD of Rhizobium inoculum and BARI Soybean-6, 50% of RD of phosphorus and 100% of RD of Bradyrhizobium inoculum. The lowest number of branches per plant (1.96) was recorded in Binasoybean-2, 100% of RD of phosphorus and 100% of RD of Bradythizobium inoculum. The longest pod (3.72 cm) was found in Binasoybean-2, 50% of RD of phosphorus and 100% of RD of Bradyrhizobium inoculum. The lowest (2.54 cm) was found in Binasoybean-1, 100% of RD of phosphorus and no Bradyrhizobium inoculum and BARI Soybean-6, 100% of RD of phosphorus with 50% of RD of Bradyrhizobium inoculum.

Table 5. Interaction effect of variety and Bradyrhizobium on yield, yield contributing characters of soybean.

Variety× Bradyrhizobium	**Branches per plant (no.)**	**Length of pod (cm)**	**Effective pods per plant**	**Seeds per pod (no.)**	**100-seed weight (g)**	**Seed yield (t ha^{-1})**	**Stover yield (t ha^{-1})**	**Harvest index (%)**	**Protein content (%)**	**Oil content (%)**
$V_1 I_0$	2.66c*	2.84e	40.69de	2.42	10.80	2.18c	4.19c	34.23	38.25ab	16.00e
$V_1 I_1$	3.09a	3.46a	46.94ab	3.08	13.33	2.42b	4.34b	35.85	34.80d	18.82a
$V_1 I_2$	2.91ab	3.32b	44.61bc	2.69	12.20	2.69a	4.60a	36.90	37.26b	16.96c
$V_2 I_0$	2.81bc	3.19c	36.10f	2.83	11.29	2.05d	3.92de	34.39	38.68a	16.88c
$V_2 I_1$	3.02a	3.42ab	48.13a	2.99	12.11	2.41b	4.33b	35.75	35.88c	18.84a
$V_2 I_2$	2.46d	3.48a	41.46cd	3.08	12.44	2.67a	4.55a	37.04	37.87ab	17.57b
$V_3 I_0$	2.67c	3.16c	45.02ab	2.31	11.34	2.01d	3.82e	34.49	37.46b	16.69cd
$V_3 I_1$	2.67c	3.02d	37.73ef	3.09	12.56	2.20c	3.95d	35.73	36.07c	16.34de
$V_3 I_2$	2.68c	3.46a	38.70def	2.87	12.08	2.42b	4.12c	37.06	37.44b	17.50b
Level of significance	**	*	**	NS	NS	**	**	NS	**	**
CV(%)	7.30	3.80	8.05	17.80	11.64	2.77	3.20	2.99	2.95	2.48

*In a column, figures with the same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)
*= Significant at 5% level of probability, ** =Significant at 1% level of probability, NS = Non significant.
V_1= Binasoybean-1, V_2= Binasoybean-2 and V_3= BARI Soybean-6
I_0= Control (No Bradyrhizobium), I_1= 50% of RD (25 g kg^{-1}) and I_2= 100% of RD (50 g kg^{-1})

Table 6. Interaction effect of level phosphorus and Bradyrhizobium on yield and yield contributing characters of soybean.

Phosphorus × Bradyrhizo-bium	Branches per plant (no.)	Length of pod (cm)	Effective pods per plant	Seeds per pod (no.)	100-seed weight (g)	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)	Protein content (%)	Oil content (%)
P_0 I_0	2.71cd*	3.15ef	40.90cd	2.19	11.46	1.89g	3.60f	5.50f	34.50c	37.19c	16.78c
P_0 I_1	2.86abc	3.27de	40.96cd	2.89	12.34	2.12f	3.82e	5.94e	35.73b	35.85d	17.92a
P_0 I_2	2.97a	3.33cd	38.33d	2.60	12.50	2.45c	4.19cd	6.64c	36.91a	37.65bc	17.32b
P_1 I_0	2.60d	3.08f	39.94cd	2.51	11.01	2.10f	4.07d	6.17d	34.11d	38.90a	16.42c
P_1 I_1	2.94ab	3.46ab	43.03bc	3.18	13.38	2.36d	4.24c	6.61c	35.73b	35.77d	18.19a
P_1 I_2	2.75bcd	3.40bc	44.85b	3.03	12.26	2.60b	4.43b	7.03b	37.05a	37.48bc	17.22b
P_2 I_0	2.84abc	2.95g	40.96cd	2.85	10.96	2.24e	4.26c	6.51c	34.51c	38.31ab	16.37c
P_2 I_1	2.97a	3.17ef	48.81a	3.09	12.28	2.55b	4.56a	7.12b	35.87b	35.12d	17.90a
P_2 I_2	2.33e	3.54a	41.59c	3.00	11.96	2.74a	4.65a	7.39a	37.04a	37.44bc	17.49b
Level of significance	**	**	*	NS	NS	**	**	**	*	**	**
CV(%)	7.30	3.80	8.05	17.80	11.64	2.77	3.20	2.95	2.99	2.95	2.48

*In a column, figures with the same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)
*= Significant at 5% level of probability,
** =Significant at 1% level of probability, NS = Non significant
P_0= Control (No Phosphorus), P_1= 50% of RD (18 kg ha^{-1}) and P_2= 100% of RD (36 kg ha^{-1})
I_0= Control (No Bradyrhizobium), I_1= 50% of RD (25 g kg^{-1}) and I_2= 100% of RD (50 g kg^{-1})

The highest number of pods per plant (60.00) was found in Binasoybena-1, 100% of RD of phosphorus and 50% of RD of Bradyrhizobium inoculum and the lowest one (31.76) was found in Binasoybena-1, 50% of RD of phosphorus with no Bradyrhizobium inoculum and BARI Soybean-6, 50% of RD of phosphorus with 50% of RD of Bradyrhizobium inoculum. The interaction of variety, phosphorus and Rhizobium inoculum exerted significant in respect of seed yield. The highest seed yield (2.90 t ha^{-1}) and stover yield (4.94 t ha^{-1}) wasobtained in Binasoybean-1, 100% of RD of phosphorus with 100% of RD of Bradyrhizobium inoculum and the lowest seed yield (1.89 t ha^{-1}) and stover yield (1.89 tha^{-1}) was obtained from BARI Soybean-6, no phosphorus and no Bradyrhizobium inoculum. The protein and oil content of soybean were significantly influenced by the interaction effect of variety, phosphorus and Bradyrhizobium. The highest protein content (39.21%) was found in Binasoybean-1, 50% of RD of phosphorus with no Bradyrhizobium inoculum and BARI Soybean-6, 50% of RD of phosphorus with no Bradyrhizobium inoculum. The highest oil content (19.33%) was found in Binasoybean-1, no phosphorus and 50% of RD of Bradyrhizobium inoculum. On the other hand, the lowest protein content (33.00%) was found in Binasoybean-2, 100% of RD of phosphorus with 50% of RD of Bradyrhizobium inoculum and the lowest oil content (15.18%) was recorded in BARI Soybean-6, no phosphorus with 50% of RD of Bradyrhizobium inoculum (Table 7).

DISCUSSION

In Bangladesh, soybean has great potential as it is the crop with the richest source of protein (Salam and Kamruzzam*,* 2015), and it requires less fertilizer, reducing the input cost. Previously neglected, soybean cultivation is now gaining popularity due to the availability of high-yielding, short-duration varieties and a suitable climatic condition (Islam *et al*., 2022). In this experiment, various soybean cultivars responded differentially to phosphorus and Bradyrhizobium inoculation levels. The varietal effect had a considerable impact on all yield and yield contributing factors. In comparison to the other two varieties, the Binasoybean-1 variety produced the highest yield. Seed yield differences among the three varieties may be due to their variant genetic make-up. Seed yield variation of soybean in different varieties was reported by previous studies (Khan *et al.,* 2015; Nimu *et al*., 2020; Das *et al*., 2022; Rabbani *et al*., 2023). Protein and oil content are affected by the variety since they are a property of that variety, even if the oil and protein content might alter due to changes in agronomic techniques, the soil, or the climatic conditions in which the varieties are cultivated (Araujo *et al*., 2008).

Table 7. Interaction effect of variety, level of phosphorus and Bradyrhizobium **on yield and yield contributing characters of soybean.**

Variety × Phosphorus × *Rhizobium*	**Branches per plant (no.)**	**Length of pod (cm)**	**Effective pods per plant**	**Seeds per pod (no.)**	**100-seed weight (g)**	**Seed yield (t ha^{-1})**	**Stover yield (t ha^{-1})**	**Harvest index (%)**	**Protein content (%)**	**Oil content (%)**
$V_1P_0I_0$	3.00abc*	2.86h	34.34fg	1.59f	11.66	1.90k	3.61l	34.52d	37.68a-f	16.78efg
$V_1P_0I_1$	3.10abc	3.43bcd	34.89fg	2.55b-e	13.94	2.05j	3.68kl	35.75c	36.04f-i	19.33a
$V_1P_0I_2$	3.06abc	3.33b-e	34.28fg	2.05ef	12.99	2.43efg	4.22efg	36.61ab	37.67a-f	17.16c-f
$V_1P_1I_0$	2.20f	3.13fg	31.76g	2.73a-e	9.98	2.19hi	4.33de	33.67e	39.21a	15.55h
$V_1P_1I_1$	2.96abc	3.45bcd	45.75d	3.52a	13.55	2.48def	4.46cd	35.74c	35.37hi	18.20b
$V_1P_1I_2$	2.83cde	3.15efg	44.51de	3.18a-d	11.88	2.73bc	4.64bc	37.06a	37.18b-g	16.39g
$V_1P_2I_0$	2.80cde	2.54i	55.97ab	2.93a-d	10.76	2.44d-g	4.63bc	34.51d	37.88a-e	15.66h
$V_1P_2I_1$	3.20ab	3.52b	60.00a	3.18a-d	12.50	2.75bc	4.87a	36.06bc	33.00j	18.94a
$V_1P_2I_2$	2.83cde	3.49bc	55.05ab	2.83a-e	11.72	2.90a	4.94a	37.04a	36.92c-h	17.33cde
$V_2P_0I_0$	2.96abc	3.15efg	32.40g	2.47de	11.41	1.90k	3.60l	34.50d	38.94ab	17.00d-g
$V_2P_0I_1$	3.23a	3.31c-f	53.11b	3.31abc	9.71	2.18hi	3.93ij	35.73c	35.73ghi	19.25a
$V_2P_0I_2$	3.23a	3.33b-f	46.38cd	3.06a-d	13.16	2.54d	4.32de	37.05a	38.28abc	17.57bcd
$V_2P_1I_0$	2.60e	3.26d-g	44.04de	3.22a-d	11.41	2.07j	4.00hij	34.17de	38.45abc	16.92d-g
$V_2P_1I_1$	2.90b-e	3.49bc	51.60bc	2.50cde	13.03	2.39fg	4.30de	35.72c	35.58ghi	18.16b
$V_2P_1I_2$	2.20f	3.72a	43.66de	2.85a-e	11.73	2.68c	4.56bc	37.04a	37.11c-h	17.70bc
$V_2P_2I_0$	2.86cde	3.16efg	31.86g	2.81a-e	11.06	2.19hi	4.16e-h	34.50d	38.66abc	16.73efg
$V_2P_2I_1$	2.93a-d	3.46bc	39.70ef	3.16a-d	13.59	2.66c	4.76ab	35.82c	36.34e-i	19.11a
$V_2P_2I_2$	1.96f	3.40bcd	34.35fg	3.33ab	12.43	2.80ab	4.76ab	37.03a	38.23abc	17.43cde
$V_3P_0I_0$	2.16f	3.45bcd	55.97ab	2.52b-e	11.32	1.89k	3.59l	34.49d	34.96i	16.55fg
$V_3P_0I_1$	2.26f	3.08g	34.89fg	2.81a-e	13.37	2.13ij	3.84jk	35.72c	35.80ghi	15.18h
$V_3P_0I_2$	2.63de	3.32b-f	34.35fg	2.70a-e	11.36	2.37g	4.03g-j	37.06a	37.00c-h	17.23c-f
$V_3P_1I_0$	3.00abc	2.86h	44.04de	1.59f	11.66	2.04j	3.88ijk	34.49d	39.03a	16.78efg
$V_3P_1I_1$	2.96abc	3.45bcd	31.76g	3.52a	13.55	2.21hi	3.98hij	35.73c	36.37d-i	18.20b
$V_3P_1I_2$	3.23a	3.33b-f	46.38cd	3.06a-d	13.16	2.40fg	4.07f-i	37.05a	38.15a-d	17.57bcd
$V_3P_2I_0$	2.86cde	3.16efg	35.05fg	2.81a-e	11.06	2.11ij	4.00g-j	34.51d	38.40abc	16.73efg
$V_3P_2I_1$	2.80cde	2.54i	46.55cd	2.93a-d	10.76	2.25h	4.05fg-j	35.73c	36.04f-i	15.66h
$V_3P_2I_2$	2.20f	3.72a	35.36fg	2.85a-e	11.73	2.51de	4.26def	37.05a	37.17b-h	17.70bc
Level of significance	**	**	*	*	NS	**	**	*	**	**
CV%	7.30	3.80	8.05	17.80	11.64	2.77	3.20	2.99	2.95	2.48

*In a column, figures with the same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

*= Significant at 5% level of probability, ** =Significant at 1% level of probability, NS = Non significant

V_1= Binasoybean-1, V_2= Binasoybean-2 and V_3= BARI Soybean-6

P_0= Control (No phosphorus), P_1= 50% of RD (18 kg ha^{-1}) and P_2= 100% of RD (36 kg ha^{-1})

I_0= Control (No Bradyrhizobium), I_1= 50% of RD (25 g kg^{-1}) and I_2= 100% of RD (50 g kg^{-1})

Among the various elements that can contribute to the success of soybean cultivation, phosphorus has a considerable impact on yield and yield qualities (Kumaga and Ofori, 2004). Phosphorus-treated plants in this experiment demonstrated a much higher soybean yield. Utilizing 100% of the recommended dose of phosphorus produced better results in terms of yield and factors leading to yield. The outcome is consistent with those made by Pauline *et al.* (2010) and Aise *et al.* (2011), who found a similar conclusion on soybean seed yield under the assumption of the right P application. Because nutritional deficit affected the growth and development of soybean, the decrease in seed production at the lower P level was probablycaused by this (Xiang *et al*., 2012). Phosphorus is also an essential ingredient for Bradyrhizobium bacteria to convert atmospheric N (N_2) into an ammonium (NH_4) form which is usable by plants. Inadequate P restricts root growth, the process of photosynthesis, translocation of sugars and other such functions which directly influenced N fixation by legume plants. In this study protein and oil content was not significantly influenced by phosphorus. While Yi *et al.* (2016) observed that higher P treatment raised the protein concentration while decreasing the oil concentration, Abbasi *et al.* (2012) showed that P application increased the oil (lipid) and protein concentrations. According to Krueger *et al.* (2013), P fertilization had no effect on the concentrations of protein and oil (lipid). Additionally, Bethlenfalvay *et al.* (1997) discovered that the concentrations of lipid and protein in soybean seeds were not substantially connected but the association between seed P and lipid concentration was extremely significant.

Legumes, such as soybeans, are frequently used as habitats by Rhizobium, a group of symbiotic bacteria that naturally fix atmospheric nitrogen. In the present study, inoculated plants showed a significant improvement in yield of soybean. Rhizobia seed inoculation outperformed uninoculated treatments in a substantial way. It was found that applying 100% of the recommended dose (RD) of Bradyrhizobium produced the best results in terms of seed production. The N fixed by Bradyrhizobium improved the vegetative development of soybean, which boosted the yield properties. *Rhizobium* strains produce nodules that fix atmospheric nitrogen, improving soil fertility and crop productivity because biologically fixed nitrogen is more durable and less likely to be lost by leaching and volatilization (Sidhu *et al.,* 2019). These findings are quite identical to those of Mottalib (2009), who discovered that Bradyrhizobium inoculation considerably boosted the soybean yields for grain and stover when compared to the control. Mahanty *et al.* (2017) also noted improved plant growth and yield as a result of the inoculation of Bradyrhizobium and *Pseudomonas*. According to Singh *et al*. (2015), *Bradyrhizobium japonicum* treatment increased soybean seed output by 14.9%, and Bradyrhizobium 's capacity to produce growth regulators including auxin, gibberellin, and cytokinin contributed to the plant's growth and yield. A crop's quality is determined by the amount of protein and oil in the seed, which is the main component of the seed in legumes. The protein and oil content of soybean was significantly influenced by Bradyrhizobium inoculum. Bradyrhizobium -host plant associations might be accompanied by characteristic alterations in protein metabolism of host plant tissues, and by redistribution of carbon among protein and nonprotein fractions of tissues throughout the plant. Similar findings were reported by Bardan (2003) and Tomar *et al*. (2004). They showed that both inoculation and increasing levels of phosphorus have significant effects on protein contents of soybean.

Bradyrhizobium inoculation can boost soybean output, but its effectiveness depends on a number of factors, including the genotype of the crop. In this investigation, the greatest yield was achieved when Binasoybean-1 interacted with 100% RD of phosphorus and 100% RD of Bradyrhizobium. When variety coupled with phosphorus and variety coupled with Bradyrhizobium inoculum, it is observed that Binasoybean-1 with 100% of the RD of P, or Binasoybean-1 with 100% of RD of Bradyrhizobium inoculum produced the highest seed yield which was statistically identical to Binasoybean-2 with 100% of RD of Bradyrhizobium inoculum. In the case of combination of P and Bradyrhizobium inoculum, 100% of the RD of P with 100% of RD of Bradyrhizobium inoculum also produced the highest seed yield of soybean. In the case of combination of variety, phosphorus and Bradyrhizobium inoculum, Binasoybean-1 with combination of 100% of RD of phosphorus and 100% of RD of Bradyrhizobium inoculum produced the highest seed yield of soybean. Begum *et al.* (2015) studied the effect of phosphorus on the performance of soybean and reported that application of P at 54 kg ha^{-1} showed the highest number of effective pods per plant. Ashraf *et al.* (2002) reported a specific combination of soybean genotype with Bradyrhizobium strains resulting in many folds increase in the amount of N_2 fixed and grain yield of soybean. Ghasem *et al.* (2015) reported RI inoculated treatment increased 23% seed in pod compared with non-inoculated treatment. Few reports also stated that RI increased the number of nodule and yield in soybean (Majid *et al.* 2009). Several scientists reported that soybean growth, 100-grain weight and seed yield is significantly increased by the adding of 90 and 100 kg P_2O_5 ha^{-1} (Taj *et al.,* 1986). Matusso *et al.* (2015) reported that the combination of RI and P significantly increased seed yield in soybean. Abbasi *et al.* (2008) used the combination of Rhizobium inoculum and P and reported that there was a positive effect of Rhizobium inoculum and P on growth, nodulation and yield of soybean. Few reports showed that application of Rhizobium inoculum and P significantly increased the number of pods per plant (Matusso *et al.,* 2015). Akter *et al.* (2021) revealed that use of Rhizobium inoculum at 50 g kg^{-1} seed in combination with 54 kg ha^{-1} P appeared as the best practice for producing the highest grain yield of Binasoybean-1.

CONCLUSION

The findings of the study indicate that Binasoybean-1 responded well to the application of 100% of RD of phosphorus and 100% of RD of Bradyrhizobium and gave maximum seed yield with highest protein content. Finally, it may conclude that Binasoybean-1 with the application of 100% of RD of phosphorus and 100% of RD of Bradyrhizobium might be recommended to obtain optimum yield and quality of soybean. However, further trial with the treatment combinations on different agro-ecological zones of Bangladesh will be useful to confirm the result of the present study.

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Compliance with ethical standards. The nature of the work did not require approval by a (bio) ethical committee.

Data availability Data is available with Md. Golam Rabbani (rabbaniagls@gmail.com) upon reasonable request.

Author contribution statement (CRediT). M. A. Salam—Conceptualization, Methodology, Formal analysis, Supervision**, M. G. Rabbani—** Funding acquisition, Data curation, Writing-review, Formal analysis **S. A. Kheya—**Writing original draft**,** Formal analysis **S. K. Paul—**Investigation, Supervision, Resources, Writing review & editing.

REFERENCES

Abbasi, M.K., Tahir, M.M., Abbas, W.A. and Rahim, N., 2012. Soybean yield and chemical composition in response to phosphorus-potassium nutrition in Kashmir. *Agronomy Journal,* 104, pp. 1476–1484. https://doi.org/10.2134/agronj2011.0379

Aise, D., Erdal, S., Hasan, A. and Ahment. M., 2011. Effects of different water, phosphorus and magnesium doses on the quality and yield factors of soybean (*Glycine max* L.) in Harran plain conditions. *International Journal of Physical Science*, 6(6), pp. 1484-1495.

Akter, S., Hoshain, S., Das, R.C., Chakma, P., Rabbani M.G. and Islam, M.R., 2021. Estimating the effect of combine use of rhizobium inoculation and phosphorus fertilizer on growth, nodulation and yield of Binasoybean-1. *International Journal of Sustainable Crop Production,* 16(2), pp. 4-10.

Araújo, A.P., Plassard, C. and Drevon, J.J., 2006. Phosphatase and phytase activities in nodules of common bean genotypes at different levels of phosphorus supply. *Plant and Soil*, 312, pp. 129–138. https://doi.org/10.1007/s11104-008-9595-3

Ashraf, M., Ali, S. and Hassan, I., 2002. Interaction of *Rhizobium japonicum* strains and soybean genotypes. *Pakistan Journal of Soil Science*, 21, pp. 49-54.

Badran, M.M., 2003. Effect of nitrogenous and phosphatic fertilization on some economical characters of soybean crawford cultivar under calcareous soil conditions. *Egyptian Journal of Agricultural Research,* 81(2), pp. 433-440. https://doi.org/10.21608/ejar.2003.276546

Bagale, S., 2021. Nutrient management for soybean crops. *International Journal of Agronomy*, 2021, 3304634. https://doi.org/10.1155/2021/3304634.

Bambara, S. and Ndakidemi, P.A., 2009. Effects of Rhizobium inoculation, lime and molybdenum on photosynthesis and chlorophyll content of *Phaseolus vulgaris*. *African Journal of Microbial Research*, 3(11), pp. 791–79. http://www.academicjournals.org/ajmr

Barman, D.K., Sarkar, S.K., Salam, M.A. and Paul, S.K., 2023. Response of Yield and Quality of Soybean (cv. BARI Soybean-6) to Phosphorus and Sulphur Fertilization under Old Brahmaputra Floodplain Soil of Bangladesh. *Agricultural Science Digest*, 43(3): 301-305. https://doi.org/10.18805/ag.DF-408.

Begum, M.A., Islam, M.A., Ahmed, Q.M., Islam, M.A. and Rahman, M.M., 2015. Effect of nitrogen and phosphorus on the growth and yield performance of soybean. *Research in Agriculture Livestock and Fisheries*, 2(1), pp. 35-42. https://doi.org/10.3329/ralf.v2i1.23027

Bethlenfalvay G.J., Schreiner R.P. and Mihara K.L., 1997. Mycorrhizal fungi effects on nutrient composition and yield of soybean seeds. *Journal of Plant Nutrition,* 20, pp. 581–591.

BINA (Bangladesh Institute of Nuclear Agriculture)., 2020. BINA *Udvabito Krishi Projukti Poriciti,* 7 th Edition. pp. 65-69. http://www.bina.gov.bd

Coskan, A. and Dogan, K. 2011. Symbiotic nitrogen fixation in soybean. *Soybean Physiology and Biochemistry*, 307, pp.167-182.

DAE (Department of Agricultural Extension)., 2021. Crop Production Report. http://www.dae.gov.bd

Das, S., Paul, S.K., Rahman, M.R., Roy, S., Uddin, F.M.J. and Rashid, M.H., 2022. Growth and Yield Response of Soybean to Sulphur and Boron Application. *Journal of Bangladesh Agricultural University*, 19(4), pp. 12–19. https://doi.org/10.5455/JBAU.100644

FAO., 2021. FAOSTAT Database. Food and Agriculture Organization of the United Nations. Available at: www.fao.org/faostat

Folsch, J., Lees. M, and Stanley, G.H.S., 1957. A simple method for the isolation and purification of total lipids from animal's tissues. *Journal of Biological Chemistry,* 226, pp. 497-509.

FRG. 2012. Fertilizer Recommendation Guide. Bangladesh Agricultural Research Council. Farmgate, New Airport Road, Dhaka-1215. 274p.

Furlani, A.M.C., Furlani, P.R., Tanaka, R.T., Mascarenhas, H.A.A. and Delgado, M.D.P., 2002. Variability of soybean germplasm in relation to phosphorus uptake and use efficiency. *Scientia Agricola*, 59 (3), pp. 529-536. https://doi.org/10.1590/S0103-90162002000300018

Ghasem, S., Hamid, R.M. and Hamid, R.F., 2015. Effect inoculation of soybean cultivars with bacteria *Rhizobium japonicum* in sistan. *Biological Forum-An International Journal,* 7(1), pp. 552-558.

Gomez, M.A. and Gomez, A.A., 1984. Statistical Procedures for Agricultural Research. John Willey and Sons. New York, Chichesten, Brisbane, Toronto. pp. 97-129, 207-215.

Harold, H., Keyser and Li, F., 1992. Potential for increasing biological nitrogen fixation in soybean. *Plant and Soil*, 141, pp. 119-135. https://doi.org/10.1007/BF00011313

Islam, K.S., Ali, M.M., Shahrin, S., Cheesman, S., Alam, S.N. and Krupnik, T.J., 2022. Simple and effective management methods that can improve soybean production in Bangladesh; CIMMYT: El Batan, Mexico, pp. 1–19.

Jackson, M.L., 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd. New Delhi, India: pp. 10-44.

Jaybhay, S.A., Varghese, P. and Taware, S.P. 2021. Influence of foliar application of nutrient on growth, yield, economics, soil nutritional status and nutrient uptake of soybean. *Legume Research,* 44(11), pp. 1322-1327. https://doi.org/10.18805/LR-4218

Jha, S., Anwar, M.P., Rashid, M.H. and Paul, S.K., 2023. Maximizing yield of mustard through zinc and boron fertilization. *Fundamental and Applied Agriculture*, 8(1&2), 475–482. https://doi.org/10.5455/faa.156450

Khan, M.S.A., Karim, M.A., Haque, M.M., Karim, A.J.M.S. and Mian, M.A.K., 2015. Growth and dry matter partitioning in selected soybean (*Glycine max* L.) genotypes. *Bangladesh Journal of Agricultural Research,* 40(3), pp. 333-345. https://doi.org/10.3329/bjar.v40i3.25409

Khanam, M., Islam, M.S., Ali, M.H., Chowdhury, I.F. and Masum, S.M., 2016. Performance of soybean under different levels of phosphorus and potassium. *Bangladesh Agronomy Journal*, 19(1), 99-108.

Krueger, K., Goggi, A.S., Mallarino, A.P. and Mullen, R.E. 2013. Phosphorus and potassium fertilization effects on soybean seed quality and composition. *Crop Science*, 53, pp. 602–610. https://doi.org/10.2135/cropsci2012.06.0372

Kumaga, F.K. and Ofori, K., 2004. Response of soybean to *Bradirhizobia* inoculation and phosphorus application. *International Journal of Agriculture and Biology*, 6(2), pp. 324-327.

Mahanty, T. Bhattacharjee, S. Goswami, M. Bhattacharyya, P. Das, B. Ghosh, A. and Tribedi, P., 2017. Biofertilizers: A potential approach for sustainable agriculture development. *Environmental Science and Pollution Research*, 24, pp. 3315–3335. https://doi.org/10.1007/s11356-016-8104-0

Majid, M.T., Kaleem, A., Nasir, R., Abdul, K. and Mushtaq, H.K., 2009. Effect of Rhizobium inoculation and NP fertilization on growth, yield and nodulation of soybean (*Glycine max* L.) in the sub-humid hilly region of Rawalakot Azad Jammu and Kashmir, Pakistan. *African Journal of Biotechnology*, 8(22), pp. 6191- 6200. https://doi.org/10.5897/AJB09.1039

Matusso, M.J.M. and Cabo, D.F.G., 2015. Response of soybean [Glycine max (L.) Merrill] to phosphorus fertilizer rates in Ferralsols.

Academic Research Journal of Agricultural Science and Research. 3(10), pp. 281-288. https://doi.org/10.14662/ARJASR2015.057

Mottalib, M.A. 2009. Comparative study on the effects of Bradyrhizobium and urea-N on the growth and yield of soybean (*Glycine max*). M.S. Thesis, Department of Soil Science, Bangladesh Agricultural University (BAU), Mymensingh.

Ndakidemi, P.A., Dakora, F.D., Nkonya, E.M., Ringo, D. and Mansoor, H., 2006. Yield and economic benefits of common bean (*Phaseolus vulgaris*) and soybean (*Glycine max* L) inoculation in northern Tanzania. *Australian Journal of Experimental Agriculture*, 46(4), pp. 571-577. http://dx.doi.org/10.1071/EA03157

Nimu, S.F., Paul, S.K., Salam, M.A. and Sarkar, S.K., 2020. Influence of weed free periods on the growth, yield and quality of soybean (*Glycine max* L.). *Fundamental and Applied Agriculture*, 5(1), pp. 99–107. https://doi.org./10.5455/faa.80967

Pal, S., Paul, S.K., Sarkar, M.A.R. and Gupta, D.R., 2016. Response on yield and protein content of fine aromatic rice varieties to integrated use of cowdung and inorganic fertilizers. *Journal of Crop and Weed,* 12 (1), 1-6.

Paul, S.K., Khatun, M.M. and Sarkar, M.A.R., 2019. Effect of sulphur on the seed yield and oil content of sesame. *Journal of the Bangladesh Agricultural University,* 17(1), 33-38. https://doi.org/10.3329/jbau.v17i1.40660

Paul, S.K., Paul, U., Sarkar, M.A.R. and Hossain, M.S., 2018. Yield and quality of tropical sugarbeet as influenced by variety, spacing and fertilizer application. *Sugar Tech*, 20(2):175-181. https://doi.org/10.1007/s12355-017-0545-3.

Pauline, M.M., John, B.O.O., Jude, J.O.O., Anthony, W. and John, H., 2010. Effect of phosphorus fertilizer rates on growth and yield of three soybean (*Glycine max*) cultivars in Limpopo Province. *African Journal of Agricultural Research,* 5(19), pp. 2653-2660. http://www.academicjournals.org/AJAR

Purwaningsih, O., Indradewa, D., Kabirun, S. and Siddiq, D. 2015. Tanggap tanaman terhadap inokulasi *Rhizobium*, *Agrotop*, 1(1), pp. 33-39.

Rabbani, M.G., Salam, M.A., Paul, S.K. and Kheya, S.A., 2023. Effects of *Rhizobium* Inoculum on Growth, Yield and Quality of Eight Selected Soybean (*Glycine Max*) Varieties. *Journal of Bangladesh Agricultural University,* 21(1): 1–11. https://doi.org/10.5455/JBAU.141905

Rashid, M.H, Akther S, Paul, S.K., Afroz, N., Jahan, I. and Arafat, Y., 2023. Effect of foliar application of nitrogen and zinc on the performance of soybean. *Fundamental and Applied Agriculture,* 8(1&2): 490–496. https://doi.org/10.5455/faa.159807

Russel, D.G., 1986. MSTAT-C Package Program. Crop and Soil Science Department, Michigan State University, USA.

Salam M.A, and Kamruzzaman, M., 2015. Comparative and competitive advantage of soy bean cultivation in Noakhali and Laxmipur District of Bangladesh. *Journal of Bangladesh Agricultural University*, 13(2):265-272. http://dx.doi.org/10.3329/jbau.v13i2.28798

Sindhu, S.S., Sharma, R., Sindhu, S. and Sehawat, A., 2019. Soil fertility improvement by symbiotic rhizobia for sustainable agriculture. In Soil Fertility Management for Sustainable Development; Panpatte, D.G., Jhala, V.K., Eds.; Springer Nature: Singapore; Pte Ltd.: Singapore; pp. 101–166.

Singh, M. Kumar, N. Kumar, S. and Lal, M., 2015. Effect of co-inoculation of *B. Japonicum*, PSB and AM fungi on microbial biomass carbon, nutrient uptake and yield of soybean (*Glycine max* L. merril). *Agriways,* 3, pp. 14–18.

Taj, F.H., Khan, M.H. and Khan, M.K., 1986. Emergence, 100 grain weight and total yield of soybean (*Glycine max* L.) as affected by inoculation and phosphorus application. An approach to some problems in Plants. Proc 1st Res Conf, Plant Scientists (April 24-26, 1982) Univ. Peshawar, Pakistan.

Tomar, S.S., Singh, R. and Singh, P.S., 2004. Response of phosphorus, sulphur and Rhizobium inoculation on growth, yield and quality of soybean. *Progressive Agriculture*, 4(1), pp. 72-73.

Uchida, R., 2000. Essential nutrients for plant growth: Nutrient functions and deficiency symptoms.

Plant nutrient management in Hawaii's soils. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, pp. 31-55.

Wahhab, D.M., Mondal, M.R.I., Akbar, A.M., Alam, S.M., Ahmed U.M. and Begam F., 2001. Status of oil crop production in Bangladesh. Oil Res. Center Bangladesh Agric. Res. Inst. Joydebpur, Gazipur. pp. 1-5.

Xiang, D. B., Yong, T. W., Yang, W. Y., Wan, Y., Gong, W. Z., Cui, L. and Lei, T., 2012. Effect of phosphorus and potassium nutrition on growth and yield of soybean in relay strip intercropping system. *Science Research and Essays*, 7(3), pp. 342-351. https://doi.org/10.5897/SRE11.1086

Yasmin, W., Paul, S.K. and Anwar, M.P. (2020). Growth, yield and quality of faba bean (*Vicia faba* L.) in response to sowing date and phosphorus fertilization. *Archives of Agriculture and Environmental Science*, 5(1), pp. 11-17. https://dx.doi.org/10.26832/24566632.2020.050102

Yi X., Bellaloui, N., MaClure, A.M., Tyler, D.D. and Mengistu, A., 2016. Phosphorus fertilization differentially influences fatty acids, protein, and oil in soybean. *American Journal of Plant Science,* 7, pp. 1975–1992. http://dx.doi.org/10.4236/ajps.2016.714180