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Application of rhizobia boosts the growth and yield of faba bean (*Vicia faba* L.) under field condition

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ABSTRACT

An experiment was conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh from November 2019 to March 2020 to study the effect of rhizobium strains on the growth and yield of faba bean (*Vicia faba* L.). The experiment consisted of two local varieties of faba bean, *viz*. black seeded faba bean and brown seeded faba bean and five rhizobium strains, *viz*. FM-1a, Faba-2, Faba-10, Mix-1 (1a, 2, 10), Mix-2 (153, 129, 640), and urea, and control. The experiment was laid out in a randomized complete block design with three replications. Results revealed that rhizobia exerted a significant influence on the growth and yield of faba bean varieties. In case of variety, brown seeded faba bean produced the highest number of nodules plant^{-1} (69.90), nodule dry weight plant^{-1} (7.26 mg), dry weight plant^{-1} (166 g), number of pods plant^{-1} (41.08), number of seeds pod^{-1} (2.87), 100-seed weight (22.71 g), seed yield (2.21 t ha^{-1}) and stover yield (3.28 t ha^{-1}) than black seeded faba bean. On the other hand, the highest SPAD value (40.06), number of nodules plant^{-1} (75.50), nodule dry weight plant^{-1} (7.143 mg), pod length (4.38 cm), number of pods plant^{-1} (41.83) and seed yield (2.22 t ha^{-1}) of faba bean were recorded from rhizobium strain FM-1a. Again, in case of interaction, the highest number of nodules plant^{-1} (85.67), nodule dry weight plant^{-1} (8.27 mg), dry weight plant^{-1} (198 g), number of pods plant^{-1} (47.33) and 100-seed weight (23.48 g) were recorded in brown seeded faba bean with rhizobial strain FM-1a. The highest seed yield (2.66 t ha^{-1}) and stover yield (3.26 t ha^{-1}) which was also recorded in brown seeded faba bean with rhizobial strain FM-1a. Based on this result it can be concluded that brown seeded faba bean with rhizobial strain FM-1a could be a promising combination for faba bean cultivation.

Keywords: Faba bean, rhizobial strains, growth, yield

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1 Introduction

Legume crop plays a significant role in the human diet and animal feed which can fix atmospheric N through symbiosis, but only a few species of this group are currently exploited in agriculture (Cernay et al., 2016; Mouradi et al., 2018). Faba bean (*Vicia faba* L.) is a unique legume crop because of its rich nutrient content which also serves as an outstanding source of proteins, complex carbohydrates, dietary fibre, choline, lecithin, minerals and secondary metabolites (Ansevica et al., 2009; Cazzato et al., 2012; Paul and Gupta, 2021; Roy et al., 2022). It covers more than 66 countries over the world where Asia is the world's leading continent covering 41% of production followed by Africa and Europe production (Merga et al., 2019; Paul and Gupta, 2021). It is a good source

of L-dopa, a precursor of dopamine used as a drug to treat Parkinson's disease (Singh et al., 2013; Ramírez-Moreno et al., 2015). Locally known as Kalimator/ Baklakalai/ Bhograkalai grown in some limited areas of Central and Northern parts of Bangladesh under *rabi* season after transplanted *aman* rice harvest (Biswas, 1988; Yasmin et al., 2020; Sheikh et al., 2020; Paul et al., 2022).

The lower productivity of this legumes is due to the low soil fertility. During the past few decades, it was observed that the extensive use of inorganic fertilizers to supply N and P has had a huge influence on soil fertility and food quality resulting in a reduction in the quantity and quality of the produce (Pereira et al., 2019). These limitations can be overcome through inoculation of compliant effective rhizobial strain (Jida and Assefa, 2014; Yohannes et al., 2015). Faba bean's ability to fix atmospheric N depends on effective rhizobia populations and the inoculation of its seed with bacterial strains before sowing (Jensen et al., 2011; Siczek and Lipiec, 2016). Again, soil microbial processes and community in the rhizosphere are greatly influenced by the inoculation of rhizobium (Siczek and Lipiec, 2016), which supplies nitrogen to agro-ecosystems and reduce the content of environmental pollution that has numerous positive effects on subsequent crop production (Laranjo et al., 2014). Even though an increase in growth, yield, and soil fertility are observed due to the inoculation of rhizobia on legumes crops, and a correlation between legume variety and rhizobial strain is vital for successful nitrogen fixation (Emam and Luckow, 2014; Allito et al., 2015).

Bangladesh Institute of Nuclear Agriculture has isolated some *Rhizobium/ Bradyrhizobium* strains as a substitute for nitrogenous fertilizers but is not recommended for faba bean (Sheikh et al., 2020). Recently, the Department of Biotechnology, BINA, and the Department of Agronomy, BAU jointly isolated some rhizobium stains from faba bean root nodules at the Biotechnology Laboratory, BINA (Yesmin et al., 2021). Some stains performed well in the pot culture previously (Yesmin et al., 2022) but were not yet tested under field conditions. So, the field performance of rhizobium strains isolated from faba bean root nodules is needed to be tested. Therefore, considering the above point of view, the present study was undertaken to check the effectiveness of rhizobium strains and variety on the performance of faba bean.

2 Materials and Methods

2.1 Experimental site

The experiment was conducted at Agronomy Field Laboratory of Bangladesh Agricultural University, Mymensingh located at 24°43′11.1″N, 90°25′42.2″E and altitude of 18 m during the period from November 2019 to March 2020. The soil belongs to the Old Brahmaputra Alluvium Soil under Agro-ecological Zone 9 (AEZ-9). The land was medium-high with a silty-loam texture having pH 6.9, EC 0.4 dS m^{-1}, OC 1.00%, N 0.09%, P 1.60 ppm, K 0.10% meq per 100 g soil, Ca 8.30 meq per 100 g soil, Mg 3.29 meq per 100 g soil, S 2.98 ppm, Zn 0.21 ppm and B 0.23 ppm (Bithy et al., 2020; Das et al., 2022).

2.2 Experimental design and treatments

The experiment consisted of two local varieties of faba bean, *viz*. black seeded faba bean and brown seeded faba bean, and five rhizobial strains, *viz*. FM-1a (T1), Faba-2 (T2), Faba-10 (T3), Mix-1 (1a, 2, 10) (T4), Mix-2 (153, 129, 640) (T5), and Urea (T6) with control (T7) treatments. The experiment was laid out in a randomized complete block design (RCBD) with three replications. There were 14 treatment combinations and 3 replications with a total of 42-unit plots. The unit plot size was 2.25 m^2 (1.5 m × 1.5 m).

2.3 Plant materials and land preparation

Two indigenous varieties' of faba bean *viz*. Black seeded faba bean and brown seeded faba bean were used in this study. The black seeded faba bean was collected from Sadullapur (Gaibandha District), and the brown seeded one was collected from Mithapukur (Rangpur District), Bangladesh. The experimental land was opened with a power tiller on 20 November 2019. Ploughing and cross ploughing was done with a power tiller followed by laddering. Land preparation was completed on 25 November 2019 and was ready for sowing seeds. P_2O_5, K_2O and S @ 60, 60 and 46 kg ha^{-1} were applied as Triple Super Phosphate (TSP), Muriate of Potash (MoP), and Gypsum, respectively. All fertilizers except urea were applied as basal doses at final land preparation.. The fertilizers were broadcasted and thoroughly mixed with the soil. Rhizobial strains were mixed with the seed before sowing.

2.4 Crop husbandry

The rhizobium strains were collected from the Biotechnology Laboratory of Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh.. The collected faba bean seeds were mixed with specific rhizobial strains maintaining proper sanitation. The seeds are sown in the furrow maintaining 30 cm × 20 cm spacing on 25 November 2019. All intercultural operations were done as and when necessary.

2.5 Harvesting and data collection

At harvest, five hills were randomly selected excluding border rows and were marked using bamboo

sticks in each plot for determining growth parameters *viz*. plant height (cm), the number of branches plant^{-1}, SPAD value, nodules plant^{-1}, nodule dry weight plant^{-1} and dry weight plant^{-1} at 60 days after sowing (DAS), respectively. The crop was harvested plot-wise when about 90% of the pods became matured. The black seeded faba bean was harvested at 115 DAS (21 March 2020) and the brown seeded faba bean was harvested at 120 DAS (26 March 2020) from 1.5 m $\times$ 1.5 m area in each plot respectively. Before harvest five plants were selected randomly from each plot excluding borders rows and a central 1.0 m $\times$ 1.0 m area and uprooted to record data on crop characters and yield components. The rest of the prefixed central 1.0 m2 area was harvested plot-wise and bundled separately and tagged. The bundles of this crop were sun-dried for three days by placing them on the open threshing floor. The dried seeds and straw were cleaned and weighed. The seeds were dried to a constant level. The dried seeds and straw were cleaned and weighed.

2.6 Statistical analysis

The collected data were compiled and analyzed statistically using the analysis of variance (ANOVA) technique with the help of a computer package program MSTAT-C. The significant difference among the treatment means was estimated by Duncan Multiple Range Test (DMRT) (Gomez and Gomez, 1984).

3 Results and Discussion

3.1 Growth parameters

Variety and Rhizobial strains exerted a significant effect on plant height at 60 DAS (Table 1). Brown seeded faba bean produced taller plants (41.59 cm) compared with black seeded faba bean (31.10 cm) (Table 1). This result could be linked with Mitiku and Wolde (2015) who found that Degaga variety was able to increase plant height to 135 cm. Rhizobial strain FM-1a produced the tallest plant (38.22 cm) followed by Mix-1 (1a, 2, 10) (38 cm) and Faba-2 (37.20 cm), and the shortest plant (33.33 cm) was obtained in rhizobial strain Mix-2 (153, 129, 640) (Table 1). This could be attributed to the favorable effect of rhizobial strain on plant height. Rhizobial inoculation in legumes increased plant height was reported elsewhere (Zarina et al., 2017; Mouradi et al., 2018; Mitiku and Mnalku, 2019; Sheikh et al., 2020; Yesmin et al., 2022).

The number of branches plant^{-1} was significantly influenced by variety at 60 DAS (Table 1). The higher number of branches plant^{-1} (6.19) was obtained from black seeded faba bean .This variation is mostly due to the genetic variation between the varieties. A similar observation was reported by Mitiku and Wolde (2015) who reported that growth attributed differed among varieties.

Variety, rhizobial strain, and interaction of variety and rhizobial strains exerted a significant influence on chlorophyll content (SPAD value) plant^{-1} at 60 DAS (Table 1). It was observed that black seeded faba bean showed a higher SPAD value (39.30) compared to brown seeded faba bean (38.57). These differences are mostly due to the genetic variation between the varieties. Similar observation was reported by Limantara et al. (2015) and Jiang et al. (2017) who found strong positive correlation of leaf chlorophyll content with SPAD value in vegetable crops. Therefore, SPAD value (relative greenness) is often considered as an indirect measure of leaf chlorophyll content in plants. Cillis et al. (2019) also stated that plant chlorophyll content varies with different varieties. Besides, the highest SPAD value (40.06) was obtained from rhizobial strain FM-1a which was at par with Mix-1 (1a, 2, 10), while the lowest SPAD value (38.02) was obtained from Mix-2 (153, 129, 640) (Table 1). These results are consistent to those of Yesmin et al. (2022) who noticed that rhizobial inoculation increases plant chlorophyll content (SPAD value). Rhizobial strains increased plant chlorophyll content up to 1.3 mg g^{-1} as reported by Sara (2013). Among the interaction, the highest SPAD value (40.93) was recorded in black seeded faba bean along with rhizobial strain FM-1a which was at par with brown seeded faba bean along with Mix-1 (1a, 2, 10)(Table 1).

Nodule numbers varied significantly due to varieties, rhizobial strains, and the interaction effect between variety and rhizobial strains at 60 DAS (Table 1). The brown seeded faba bean produced a higher number of nodules plant^{-1} (69.90) compared with black seeded faba bean (63.76) (Table 1). The variation in the number of nodules plant^{-1} as assessed might be due to varietal characteristics. Among rhizobial strains, Faba-10 produced a significantly higher number of nodules plant^{-1} (79.33) followed by Faba-2 (78) and FM-1a (75.50), while control treatment showed the lowest value (46.67) (Table 1). The findings of the present study were in close agreement with the observations of El-Akhdar (2020) and Yesmin et al. (2021) who reported that rhizobial inoculation increase nodules plant^{-1} in faba bean. Among the interaction, the highest number of nodules plant^{-1} was obtained from brown seeded faba bean along with rhizobial strain FM-1a (85.67) which was statistically identical to black seeded faba bean along with rhizobial strain Faba-10, while the lowest number of nodules plant^{-1} (40.67) was found in black seeded faba bean along with control (Table 1). The weight of nodules were varied significantly due to varieties, rhizobial strains and their interactions at 60 DAS (Table 1). The highest nodule dry weight plant^{-1} (7.26 mg plant^{-1}) was recorded from brown seeded faba bean than black seeded faba bean (5.74 mg plant^{-1}) (Table 1). The

Table 1. Effect of variety, rhizobial strains and their interactions on growth attributes of faba bean at 60 DAS

Treatment	Plant height (cm)	Branches plant^{-1} (no.)	SPAD value	Nodules plant^{-1} (no.)	Nodule DW plant^{-1} (mg)	DW plant^{-1} (g)
Variety (V)						
Black seeded (V1)	31.10b	6.19a	39.30a	63.76b	5.74b	148b
Brown seeded (V2)	41.59a	5.71b	38.57b	69.90a	7.26a	166a
Sig. level	**	**	**	**	**	**
Rhizobial strains						
FM-1a (T1)	38.22a	6.33	40.06 a	75.50a	7.143a	179.3b
Faba-2 (T2)	37.20ab	6	38.21 c	78.00a	6.969ab	173.2c
Faba-10 (T3)	36.23ab	6.16	38.51bc	79.33a	6.846abc	182.5a
Mix-1 (T4)	38.00a	6	39.74a	67.17b	6.405bcd	162.5d
Mix-2 (T5)	33.33c	5.66	38.02 c	63.17bc	5.755e	150.8e
Urea (T6)	35.19bc	6	38.78bc	58.00 c	6.282cde	145.5f
Control (T7)	36.25ab	5.5	39.26ab	46.67d	6.140de	106.5g
Sig. level	**	NS	**	**	**	**
V×T						
V1×T1	33.23	6.33	40.93a	65.33cde	6.01e	160g
V1×T2	31.9	6.33	38.68bcd	75.67abc	6.43de	166f
V1×T3	29.7	6.66	38.29cde	84.00a	6.44de	191b
V1×T4	32.33	6.33	39.51bc	65.00cde	5.86e	153h
V1×T5	29.78	6	38.87bcd	64.67cde	4.86f	158g
V1×T6	30.21	6	39.33bc	51.00fg	4.78f	120k
V1×T7	30.55	5.66	39.49bc	40.67g	5.80e	88l
V2×T1	43.2	6.33	39.19bc	85.67a	8.27a	198a
V2×T2	42.5	5.66	37.74de	80.33ab	7.50abc	179c
V2×T3	42.77	5.66	38.72bcd	74.67abcd	7.24bcd	173d
V2×T4	43.67	5.66	39.96ab	69.33bcd	6.94bcd	171de
V2×T5	36.89	5.33	37.17e	61.67def	6.64cde	143i
V2×T6	40.17	6	38.23cde	65.00cde	7.78ab	171e
V2×T7	41.94	5.33	39.02bcd	52.67efg	6.47de	124j
Sig. level	NS	NS	*	**	**	**
CV (%)	4.99	9.65	1.76	10.23	7.6	6.5

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, * = Significant at 5% level of probability, NS = Not significant; DAS = Days after sowing, DW = Dry weight, V1 = Black seeded faba bean, V2 = Brown seeded faba bean, T1 = FM-1a, T2 = Faba-2, T3 = Faba-10, T4 = Mix 1 (1a, 2, 10), T5 = Mix 2 (153, 129, 640), T6 = Urea, T7 = Control

number and size of nodules are responsible for the nodule dry weight of faba bean. Besides, the rhizobial strain FM-1a produced significantly higher nodule dry weight (7.143 mg plant^{-1}), while Mix-2 (153, 129, 640) produced lowest nodule dry weight (5.755 mg plant^{-1}). The findings of the present study were in agreement with the observations of El-Akhdar (2020) who reported that rhizobial inoculation may increase the number of nodules dry weight plant^{-1} from 0.36 g to 1.44 g. Almost similar result was found by Yesmin et al. (2022) who reported that suitable rhizobial strain increases nodule's dry weight plant^{-1}. Further, the highest nodule dry weight (8.27 mg plant^{-1}) was recorded from brown seeded faba bean along with rhizobial strain FM-1a, and the lowest nodule dry weight (4.78 mg plant^{-1}) was found in black seeded faba bean along with urea (Table 1).

Variety, rhizobial strains and their interaction exerted significant influence on plant dry weight (DW) at 60 DAS (Table 1). Brown seeded faba bean showed higher DW plant^{-1} (166 g plant^{-1}) compared to black seeded faba bean (148 g plant^{-1}) (Table 1). This finding is consistent with Dobocha et al. (2019), who reported that different plant varieties vary in plant DW. Among rhizobial strains, Faba-10 showed significantly higher DW (182.5 g plant^{-1}), while control produced lowest DW (106.5 g plant^{-1}) (Table 1). The observations of this study were also in close confor-

Table 2. Effect of variety, rhizobial strains and their interactions on crop characters and yield components of faba bean

Treatment	PH (cm)	Branches (no.)	PL (cm)	Pods plant^{-1} (no.)	Seeds pod^{-1} (no.)	WHS (g)	BY (t ha-1)	HI (%)
Variety (V)								
Black seeded (V1)	43.78b	6.61	4.19	36.61b	2.73b	12.29b	4.21b	42.12a
Brown seeded (V2)	61.25a	6.28	4.25	41.08a	2.87a	22.71a	5.49a	40.18b
Sig. level	**	NS	NS	**	**	**	**	**
Rhizobial strains (T)								
FM-1a (T1)	56.12a	6.83a	4.38a	41.83a	2.83	17.76ab	5.00b	44.25a
Faba-2 (T2)	52.53bc	6.66ab	4.35a	39.90abc	2.81	17.51bc	4.73cd	42.78b
Faba-10 (T3)	52.63bc	6.83a	4.41a	41.30ab	2.86	17.99a	5.23a	42.30b
Mix-1 (T4)	56.15a	6.33ab	4.09bc	37.67cd	2.76	17.24cd	4.89bc	39.07c
Mix-2 (T5)	46.14d	6.00b	4.11bc	37.37cd	2.8	17.23cd	4.64de	39.84c
Urea (T6)	54.02ab	6.50ab	4.25ab	38.80bc	2.83	17.74ab	4.97b	40.58c
Control (T7)	50.06c	6.00b	3.99c	35.10d	2.73	17.06d	4.51e	39.26c
Sig. level	**	*	**	**	NS	**	**	**
V×T								
V1×T1	48.57c	6.66	4.25abc	36.33def	2.73	12.03 c	4.07fg	43.53bc
V1×T2	43.43d	6.66	4.29abc	40.40cd	2.76	12.55 c	4.09fg	45.25b
V1×T3	40.89de	7.33	4.43ab	43.33bc	2.86	12.66 c	4.90e	47.24a
V1×T4	48.11c	6.66	4.18bc	36.13ef	2.66	12.24 c	4.30f	40.56d
V1×T5	38.49 e	6.33	4.16bc	36.07ef	2.73	12.25 c	4.11fg	40.53d
V1×T6	43.97d	6.33	4.04c	32.47fg	2.73	12.23 c	4.15fg	38.37de
V1×T7	43.05d	6.33	4.01c	31.60 g	2.66	12.08c	3.89g	39.42de
V2×T1	63.67a	7	4.50a	47.33a	2.93	23.48a	5.92a	44.98b
V2×T2	61.64a	6.66	4.40ab	39.40de	2.86	22.47b	5.38cd	40.32d
V2×T3	64.19a	6.33	4.40ab	39.27de	2.86	23.32a	5.56bc	37.35e
V2×T4	64.37a	6	4.00 c	39.20de	2.86	22.24b	5.48c	37.58e
V2×T5	53.78 b	5.66	4.05 c	38.67de	2.86	22.22b	5.18d	39.15de
V2×T6	64.07a	6.66	4.46ab	45.13ab	2.93	23.24a	5.79ab	42.79c
V2×T7	57.07 b	5.66	3.98 c	38.60de	2.8	22.03b	5.14de	39.10de
Sig. level	**	NS	*	**	NS	**	**	**
CV (%)	4.41	8.42	3.97	5.55	3.75	1.91	2.95	2.88

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, * = Significant at 5% level of probability, NS = Not significant; PH = plant height, PL = pod length, WHS = weight of 100 seeds, V1 = Black seeded faba bean, V2 = Brown seeded faba bean, T1 = FM-1a, T2 = Faba-2, T3 = Faba-10, T4 = Mix 1 (1a, 2, 10), T5 = Mix 2 (153, 129, 640), T6 = Urea, T7 = Control

mity with the observations of Matkarimov et al. (2019) who noticed that rhizobial inoculation increases dry matter production plant^{-1}. Among the interaction, the highest DW (198 g plant^{-1}) was obtained from brown seeded faba bean along with rhizobial strain FM-1a, and the lowest DW (88 g plant^{-1}) was found in black seeded faba bean along with control (Table 1).

3.2 Crop characters, yield and yield components

The significant effect of variety, rhizobial strains and the interaction of variety and rhizobial strains were found on plant height (Table 2). Brown seeded faba bean produced taller plants (61.25 cm) compared with black seeded faba bean (43.78 cm) (Table 2). This is in line with the findings of Mitiku and Wolde (2015) who found the highest plant height (135 cm) of Degaga variety. The tallest plant (56.15 cm) was obtained with the inoculation of rhizobial strain Mix-1 (1a, 2, 10), which was at par with rhizobial strain FM 1a (56.12 cm), and the shortest plant was observed in rhizobial strain Mix-2 (153, 129, 640) (46.14 cm) (Table 2). This could be attributed to favorable effect of rhizobial strain on plant height. Similar result was observed by Mitiku and Mnalku (2019) who reported that rhizo-

bial inoculation able to increase plant height up to 139 cm that was almost similar with Zarina et al. (2017) and Mouradi et al. (2018). Among the interaction, the tallest plant (64.37 cm) was recorded from brown seeded faba bean along with rhizobial strain Mix-1 (1a, 2, 10). While, black seeded faba bean along with rhizobial strain Mix-2 (153, 129, 640) produced the shortest plant (38.49 cm) (Table 2).

Number of branches plant^{-1} differed significantly by rhizobial strains. Variety and interaction of variety and rhizobial strains were found non-significant (Table 2). Varietal differences regarding number of branches plant^{-1} might be due to their difference in genetic make-up. Table 2 shows that rhizobial strains FM-1a and Faba-10 produced the highest number of branches plant^{-1} (6.83), where lowest number of branches plant^{-1} (6.00) was found in control. This finding was in conformity with the reports of Yesmin et al. (2022) and Youseif et al. (2017) who reported that rhizobial inoculation increased the number of branches plant^{-1}.

Pod length was significantly affected by the effect of rizobial strains and the interaction of variety and rhizobial strains (Table 2). The highest pod length (4.41 cm) was recorded from rhizobial strain Faba-10 which was statistically identical to Faba-2 and FM-1a, while the lowest pod length (3.99 cm) was obtained at control. This finding was probably due to nitrogenase activity of rhizobial bacteria which caused to enhance pod length in faba bean. Among the interaction, the highest pod length (4.50 cm) was obtained from brown seeded faba bean along with rhizobial strain FM-1a which was at par with brown seeded faba bean along with Faba-2 and brown seeded faba bean along with Faba-10, while the lowest pod length (3.98 cm) was found in brown seeded faba bean along with control (Table 2).

Number of pods plant^{-1} was significantly affected due to variety, rhizobial strains and interactions (Table 2). The highest number of pods plant^{-1} (41.08) was obtained from brown seeded faba bean, while lower number of pods plant^{-1} (36.61) was observed in black seeded faba bean (Table 2). This result was supported by Cillis et al. (2019) who reported that number of pods plant^{-1} varied among varieties. The highest number of pods plant^{-1} (41.83) was recorded from FM-1a which was similar with Faba-10 and the lowest number of pods plant^{-1} (35.10) was obtained at control. This finding is in agreement with the findings of Zerihun and Abera (2014) who found that inoculating 10 g rhizobial strains kg^{-1} seed of faba bean produce 13 pods plant^{-1}. Among the interaction, the highest number of pods plant^{-1} (47.33) was obtained from brown seeded faba bean along with rhizobial strain FM-1a, while the lowest number of pods plant^{-1} (31.60) was found in black seeded faba bean along with control (Table 2).

Number of seeds pod^{-1} was significant influenced by variety (Table 2). The highest number of seeds pod^{-1} (2.87) was obtained from brown seeded faba bean, while the lowest number (2.73) of seeds pod^{-1} was obtained at black seeded faba bean (Table 2). The variation in number of seeds pod^{-1} between the varieties were probably due to heredity or varietal characters. Number of seeds pod^{-1} significantly influenced by variety was reported by Cillis et al. (2019) who mentioned that Aguadulce produced higher number of seeds pod^{-1} (5.52).

The influence of variety, rhizobial strain and interaction of variety and rhizobial strains were found significant in respect to 100-seed weight (Table 2). The maximum weight of 100-seeds (22.71 g) was obtained from brown seeded faba bean than black seeded faba bean (12.29 g). The differences in 100-seeds is assessed might be due to the variation in genetic constituents between the variety. Variety has significant influence on 100-seeds weight was reported by Dobocha et al. (2019). The highest 100-seeds weight (17.99 g) was recorded from rhizobial strain Faba-10 which was at par with rhizobial strain FM-1a (17.76 g) and the lowest 100-seeds weight (17.06 g) was obtained at control (Table 2). Further the interaction of variety and rhizobial strains resulted highest 100-seeds weight (23.48 g) of brown seeded faba bean along with rhizobial strain FM-1a which is similar with brown seeded faba bean along with rhizobial strain Faba-10, while the lowest 100-seeds weight (12.03 g) was found in black seeded faba bean along with rhizobial strain FM-1a (Table 2).

The seed yield was significantly affected by plant variety, rhizobial strain and interaction of variety and rhizobial strains (Fig. 1). The higher seed yield (2.21 t ha^{-1}) was obtained from brown seeded faba bean compared to black seeded faba bean (1.78 t ha^{-1}) (Fig. 1). Significant variation of seed yield among the genotype was reported by Dobocha et al. (2019) who reported that the variety Moti produced higher seed yield (3.59 t ha^{-1}) than others. The highest seed yield (2.22 t ha^{-1}) was recorded from rhizobial strain FM-1a which was similar with rhizobial strain Faba-10 (2.19 t ha^{-1}) and the lowest yield (1.77 t ha^{-1}) was found in control (Fig. 1). Rhizobial strain increased seed yield was reported by Sheikh et al. (2020), who mentioned that application of rhizobium increased faba bean yield over control. Similar trend was confirmed by Youseif et al. (2017) who depicted that rhizobial inoculation can increase seed yield up to 4.29 t ha^{-1}. Among the interaction, brown seeded faba bean along with rhizobial strain FM-1a gave the highest seed yield (2.66 t ha^{-1}) followed by brown seeded faba bean along with urea (2.48 t ha^{-1}), while the lowest seed yield (1.53 t ha^{-1}) was obtained from black seeded faba bean along with control (Fig. 1).

Stover yield differed significantly due to plant variety, rhizobial strain and interaction of variety and rhizobial strains (Fig. 2). Fig. 2 shows that the higher

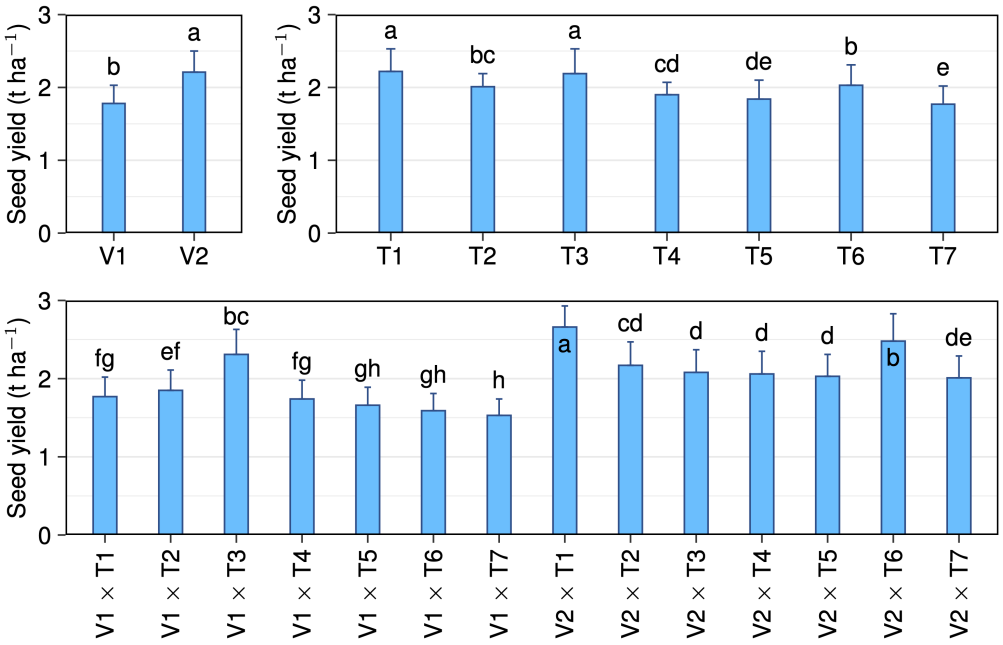

Figure 1. Effect of variety, rhizobial strain and their interactions on seed yield of faba bean (*Vicia faba*). Bars with same letters or without any letter do not differ significantly, whereas the same with dissimilar letters differ significantly at 5% level of probability. V1 = Black seeded faba bean, V2 = Brown seeded faba bean, T1 = FM-1a, T2 = Faba-2, T3 = Faba-10, T4 = Mix 1 (1a, 2, 10), T5 = Mix 2 (153, 129, 640), T6 = Urea, T7 = Control

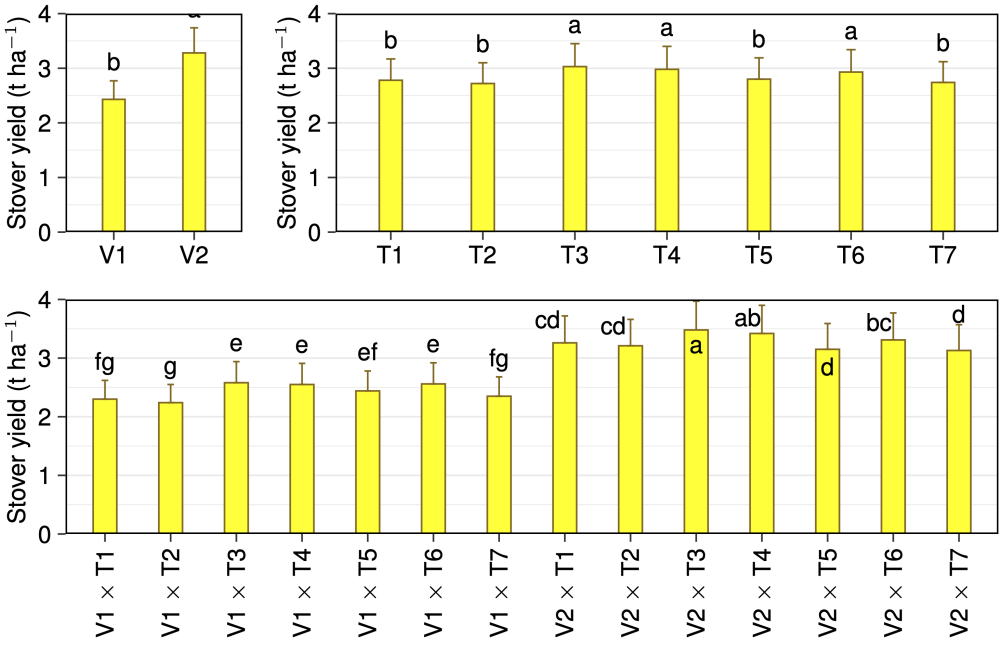

Figure 2. Effect of variety, rhizobial strain and their interactions on stover yield of faba bean (*Vicia faba*). Bars with same letters or without any letter do not differ significantly, whereas the same with dissimilar letters differ significantly at 5% level of probability. V1 = Black seeded faba bean, V2 = Brown seeded faba bean, T1 = FM-1a, T2 = Faba-2, T3 = Faba-10, T4 = Mix 1 (1a, 2, 10), T5 = Mix 2 (153, 129, 640), T6 = Urea, T7 = Control

stover yield (3.28 t ha^{-1}) was produced by brown seeded faba bean than black seeded faba bean (2.43 t ha^{-1}). The highest stover yield (3.03 t ha^{-1}) was obtained from rhizobial strain Faba-10 which was similar with rhizobial strain Mix-1(1a, 2, 10), while the lowest stover yield (2.72 t ha^{-1}) was obtained from rhizobial strain Faba-2 (Fig. 2). This could be linked with Youseif et al. (2017) who reported that rhizobial inoculation can increase stover yield up to 5.9 t ha^{-1}. Among the interaction, brown seeded faba bean along with rhizobial strain Faba-10 gave the highest stover yield (3.48 t ha^{-1}) which was at par with brown seeded faba bean along with rhizobial strain Mix-1 (1a, 2, 10), while the lowest seed yield (2.24 t ha^{-1}) was obtained from black seeded faba bean along with rhizobial strain Faba-2 (Fig. 2).

Variety, rhizobial strain and their interaction had significant effect on biological yield (Table 2). The higher biological yield (5.49 t ha^{-1}) was obtained from brown seeded faba bean than black seeded faba bean (4.21 t ha^{-1}) (Table 2). The biological yield varied significantly due to varietal characteristics was reported by Dobocha et al. (2019) who mentioned that Moti variety produced higher biomass (7.6 t ha^{-1}) compared to others. The highest biological yield (5.23 t ha^{-1}) was recorded from rhizobial strain faba-10 followed by FM-1a, while the lowest biological yield (4.51 t ha^{-1}) was found in control (Table 2). Rhizobial inoculation can increase total biomass up to 12.58 t ha^{-1} (Youseif et al., 2017). Among the interaction, brown seeded faba bean along with rhizobial strain FM-1a gave the highest biological yield (5.92 t ha^{-1}) followed by brown seeded faba bean along with urea, while the lowest biological yield (3.89 t ha^{-1}) was observed in black seeded faba bean along with control (Table 2).

Variety, rhizobial strain and thieir interaction had significant influence on harvest index (Table 2). The higher harvest index (42.12%) was obtained from black seeded faba bean, while the lower harvest index (40.18 %) was recorded from brown seeded faba bean (Table 2). Significant variation of harvest index among the genotypes was reported by Dobocha et al. (2019) who reported that Degaga variety had harvest index 50.3% compared to others. From Table 2, it is revealed that application of FM-1a gave the highest harvest index (44.25 %), while the lowest harvest index (39.07%) was found at Mix-1 (1a, 2, 10). This result was similar with the report of Zarina et al. (2017) who reported that rhizobial inoculation significantly increased harvest index. Among the interaction, the highest harvest index (47.24%) was obtained from black seeded faba bean along with rhizobial strain Faba-10 followed by brown seeded faba bean along with FM-1a, while the lowest harvest index (37.35 %) was found in brown seeded faba bean along with rhizobial strain Faba-10 (Table 2).

4 Conclusion

Results revealed that brown seeded faba bean produced a higher seed yield compared to black seeded faba bean. Rhizobial strain FM-1a performed better than other single and mixed rhizobial strains and also urea treatment in respect of growth and yield performance. All growth attributes, crop characters, and seed yield were recorded in brown seeded faba bean with rhizobial strain FM-1a. Irrespective of the variety the rhizobial strain FM-1a produced a higher seed yield. Therefore, FM-1a appears as the promising strain (as biofertilizer) for faba bean cultivation.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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