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Effect of genotypes-*Rhizobium*-environment interaction on nodulation and productivity of common bean (*Phaseolus vulgaris* L.) in eastern Ethiopia

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Abstract

Background: Effectiveness of *Rhizobium* inoculation is determined by common bean genotypes. Environmental factors also affect common bean genotypes-*Rhizobium*-symbiosis. The effect of common bean genotypes-*Rhizobium* strains-environment interaction on nodulation and common bean production is not well studied. Three genotypes (Dursitu, Gofta, and Kufanzik) and eight selected isolates of common bean nodulating-rhizobia with N-fertilized and control check were used for field experiments at four locations (Babile, Fedis, Haramaya, and Hirna) to evaluate the effect of genotypes-*Rhizobium* strains-environment interaction on the nodulation, yield and yield traits of common bean. The treatments were laid out in a randomized complete block design with three replications.

Results: This study revealed that *Rhizobium* inoculation, the genotypes, environment and their interaction significantly ($P \leq 0.05$) affected all investigated traits of common bean. Common bean genotypes *Rhizobium* inoculation and experimental locations significantly affected nodule number (NN) and nodule dry weight (NDW). The highest NN and NDW as compared to the uninoculated control across locations were recorded with the genotype Dursitu in all inoculation treatments. However, the result revealed the lowest mean total biomass (TBY) and grain yield (GY) over locations with the same genotype Dursitu. The highest mean grain yields of 3358.89, 3257.82, 1499.25 and 2204.82 kg ha^{-1} across the treatments were recorded at Haramaya, Hirna, Babile and Fedis sites, respectively, with the genotype Gofta, thereby implying that there was none specificity between common bean genotypes × locations in the study locations of eastern Ethiopia with tested common bean genotypes. None of the tested isolates produced statistically better NN, NDW, TBY, GY and total plant N accumulation consistently in all locations with all tested common bean genotypes, indicating the presence of *Rhizobium* strains × location specificity.

Conclusion: Therefore, the result showed the need for a specific strain of *Rhizobium* development for common bean production in different locations.

Keywords: Common bean, Ethiopia, Genotype, Locations, *Rhizobium*, Specificity

Background

Symbiotic N_2 fixation (SNF), a biological process of transforming the atmospheric N_2 by mutual interaction of the host plant with soil bacteria is an essential environmentally and economically sustainable sources of N to the soil (Silva and Uchida 2000), thereby reducing the use of chemical N fertilizer. Different rhizobial species belonging to the genera *Rhizobium*, *Agrobacterium*, *Ensifer*, *Bradyrhizobium,* and *Ochrobactrum* are able to produce nodules with common bean plants (Wang et al. 2016). Inoculation is a key biological input to improve crop productivity and soil fertility through increasing the rhizobia in the plant rhizosphere (Keyser and Li 1992;

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Remans et al. 2008), thereby improving nodulation and N_2-fixation (Peoples et al. 1995) and it can also fix to exceed 200 kg N ha year^{-1} (Giller 2001). The symbiotic N_2relationship between common bean and *Rhizobium* contributed up to 90 kg N ha^{-1} which was 40–50% of the total N near physiological maturity (Westermann et al. 1981). Several studies indicated the promising potential of common bean to fix N_2 derived from the atmosphere (Asadi Rahmani et al. 2005; García et al. 2004; Remans et al. 2008).

The efficacy of rhizobial strains in nodulating and fixing atmospheric N with common bean varies with both the host genotypes and the *Bacterium* strains (Aguilar et al. 1998; Caballero-Mellado and Martinez-Romero 1999; Farid and Navabi 2015; Michiels et al. 1998; Moawad et al. 1998). The prevailing environmental conditions significantly shape the diversity and distribution of indigenous rhizobia nodulating common bean (Wang et al. 2016). Deficiency of different essential nutrients have also been reported as legume-*Rhizobium* symbiosis limiting environmental factors, which may limit the nodulation and N_2 derived from the atmosphere (Divito and Sadras 2014). Soil water availability, which is one of the major environmental factors, also influences the N_2 fixation derived from the atmosphere by common bean (Devi et al. 2013) and soybean (Collino et al. 2015). This variability often limits the nitrogen-fixing performance of soil native rhizobia or use of commercially available inocula. Strains of rhizobia widely differed in their abilities to survive, nodulate and fix Nin soil environments (Slattery et al. 2001). Considering the high level of adaptation by native rhizobia to local soil conditions, it is important to characterize the indigenous rhizobial collection for use in inoculant production.

Many research reports indicated that host genotypic factors affect nodulation and nodule activity in *Phaseolus vulgaris* (Graham and Temple 1984; Rennie and Kemp 1983). Nleya et al. (2001) also illustrated the different response of common bean genotypes to the application of *Rhizobium* inoculant. Hardarson et al. (1993) also found that N derived from the atmosphere (% Ndfa) varied from 35 to 70% among different common bean genotypes. Usually, bushy growth habit of common bean has the lowest N fixation efficiency among all legume crops (Bliss 1993; Hardarson et al. 1993; Isoi and Yoshida 1991; Martinez-Romero 2003). Indeterminate genotypes generally can fix more nitrogen than determinate genotypes due to the greater "sink" in the indeterminate variety (Ofori and Stern 1987). Bliss (1993) identified common bean genotypes capable of fixing enough atmospheric N_2 to support the grain yield of 1000–2000 kg ha^{-1}. Therefore, improvement of bean BNF requires a multidisciplinary approach that will increase the host capacity to fix N (Giller 2001) and selection of effective *Rhizobium* strains that can compete for nodulation with native populations of bacteria present in most soils. So far, the effect of environmental condition on *Rhizobium*-common bean genotypes is not well known. Almost no attempt has also been made on effective bushy type common bean genotypes (with variable maturity time)-*Rhizobium* symbiosis, which can give higher responses in different environment conditions. Hence, the objective of this work was to evaluate the effect of bushy type common bean genotypes, *Rhizobium* strains and environment interaction on the nodulation, yield and yield traits of common bean in soils of eastern Ethiopia.

Methods

Description of experimental sites

Field experiments were conducted at four locations, including Hirna (09°13.157′N and 041°06.488′E at an altitude of 1779.6 m above sea level [m.a.s.l.]), Fedis (09°06.941′N and 042°04.835′E at an altitude of 1642.8 m.a.s.l.), Babile (09°13.234′N and 042°19.407′E 1643.4 m.a.s.l.) and Haramaya (09°24.954′N and 042°02.037′E at an altitude of 1999.4 m.a.s.l.) agricultural research centers representing the major common bean cultivating areas of Ethiopia in 2013. The fields were located in the eastern parts of Ethiopia where common bean had long been grown intercropped with sorghum and maize without inoculation. The location map of the study site was previously indicated in Argaw (2016).

Soil sampling

The initial soil samples were collected from the top 0–20 cm for analysis of the soil physico-chemical properties. A composite soil comprising 20 auguring sampling points from each experimental site was taken and transported back to the laboratory within a day. Representative subsamples of 1 kg each were prepared for most probable number (MPN) assay and stored in a refrigerator at 4 °C until used for enumerating indigenous rhizobial population. The soil physico-chemical properties were analyzed using standard procedures employed by Sahlemedhin and Taye (2000).

Soil properties

The soils of the study sites had clay, sandy loam, sandy clay loam and silty clay loam in Hirna, Babile, Haramaya and Fedis sites, respectively. The pH(H_2O) of the study sites ranged from 6.66 to 7.84 which is within the suitable pH ranges for *Rhizobium* species. All experiment sites had the electric conductivity less than 0.14 ms cm^{-1}. The soil organic carbon and total N content were 1.65 and 0.06%, 0.56 and 0.06%, 1.96 and 0.12%; and 1.32 and 0.12% in Hirna, Babile, Haramaya and Fedis sites,

respectively. The soil had the CEC ranging from 6.59 cmol(+) kg^{-1} in Babile to 39.88 cmol(+) kg^{-1} in Hirna site. The soil of the study sites had exchangeable Ca^{+2}, Mg^{+2}, Na^{+1} and K^{+1} with ranges of 39.88–4.18, 12.87–3.5, 0.33–0.12 and 1.09–0.14 cmol(+) kg^{-1}, respectively.

Source of the isolates and common bean seed genotypes

Eight isolates of *Rhizobium* spp. were obtained from Biofertilizer Research and Production Project (BRPP), Haramaya University (Haramaya, Ethiopia). The isolates were designated as HUCBR-1, HUCBR-2, HUCBR-3, HUCBR-4, HUCBR-5, HUCBR-6, HUCBR-7, and HUCBR-8. All isolates used in this study were obtained from Ethiopian soils. All isolates were previously characterized as superior isolates in nodule formation and shoot biomass production of common bean under greenhouse conditions (Argaw 2007).

Seeds of *Phaseolus vulgaris* genotypes used in this study were obtained from Lowland Pulse Research Program, Haramaya University, Haramaya, Ethiopia. The selected genotypes were characterized as highly productive genotypes in the study sites. Beside this, maturity time was also considered for selection of genotypes for this experiment. Accordingly, Gofta, Kufanzik and Dursitu genotypes belong to early, medium and late maturing categories, respectively.

Preparation of inocula

The pure cultures of *Rhizobium* isolates were obtained from the laboratory in slant culture. The bacteria were purified by culturing in YEM (Yeast extract mannitol) agar medium and then single pure colony was transferred into YEM broth medium and kept at 30 °C for 7 days on a rotary shaker at 120 rpm. About 400 ml of culture liquid medium containing appropriate *Rhizobium* sp. were added to 1 kg of the carrier (sterile fine filter mud) and mixed thoroughly and then packed in plastic bags. Filtermud-base inoculum was incubated at 26–28 °C for 15 days. At the time of inoculation, the number of rhizobia in the inoculum was estimated using plate count method. One ml samples of serially diluted inocula from 10^{-6} dilution were plated in YEMA medium. Colonies that developed after incubation at 28 °C for 5–7 days were recorded. This test indicated that the number of rhizobia was more than 1×10^9 g^{-1} inocula.

Experimental layout and treatments

The experimental fields were plowed thoroughly twice with a tractor and divided into sub-plots in accordance with the treatments. The net size of each experimental sub-plot was 3×2 m^2. There were five rows per plot and the spacing was 1 m between plots, 40 cm between rows and 10 cm between plants. Ten levels of inoculation containing eight *Rhizobium* isolates (NSCBR-14, NSCBR-$(25)_2$, NSCBR-59, NSCBR-31, NSCBR-16, NSCBR-18, NSCBR-57 and NSCBR-25) with uninoculated and N-fertilized (20 kg N ha^{-1}) control and three common bean genotypes were factorially combined. Before sowing, 20 kg P ha^{-1} as tri superphosphate for all experimental plots were applied in furrows. Identical field experiments were carried out in four locations.

Common bean seeds were sterilized using 70% ethanol for 1 min and NaClO solution (0.25% as available Cl) for 3 min. The seeds were then washed carefully in sterilized deionized water five times before sowing. Then, 20 g of the different rhizobia inoculants was added to different polyethylene bags containing 200 g of common bean seeds. A 10% (w/v) sucrose solution to increase adherence was added to each bag to enhance proper mixing and adhesion of the rhizobia carrier material to the common bean seeds. After mixing, seeds were allowed to air-dry in the shade for 15 min and sown field layout. Two seeds were planted by hand per hole and later thinned down to one per hole 1 week after germination. A total of 30 treatment combinations were used in the experiment. The experiments were designed as two-factor experiments in a randomized complete block design (RCBD). There were three replications of each treatment. All standard local cultural practices were accomplished throughout the growth period. Manual weeding was done whenever required.

Nodulation, yield and yield attributes

At late flowering and early pod setting stage, five plants were randomly chosen from central three rows for the evaluation of nodulation and plant growth. Adhered soil on the sampled plants were loosen by placing into plastic buckets filled with water. Thereafter, nodules from roots were picked and following data were recorded: (1) Nodule number $plant^{-1}$, and (2) nodule dry weight $plant^{-1}$. Shoot dry weight was also measured after drying the samples at 70 °C in the electrical oven until the weight of the samples became constant. Shoots of the plants were later ground to pass through a 0.5 cm sieve. Total N determinations were done by the Kjeldahl method of Bremner (1965). At full maturity stage, numbers of pods $plant^{-1}$, the number of seed pod^{-1}, plant height at harvest and total biomass were recorded. Grain yield was corrected for 13% moisture content after determining humidity level with a grain moisture tester.

Data analysis

Data were subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS Institute Inc 1999). Statistically significant differences between treatment means were also determined using the least significant

difference (LSD) test at 5% probability level of significance (SAS Institute Inc 1999). Figures were prepared using excel Microsoft of version 10.

Results

Nodule number

Analysis of variance (ANOVA) showed that *Rhizobium* inoculation, experimental location, the genotypes and their interaction significantly affected the nodule number (NN) at $P \leq 0.05$ (Table 1). The effect of *Rhizobium* inoculation treatments on NN varied due to different varieties and experimental locations (Table 2). At Haramaya site, most isolates, except NSCBR-59 and NSCBR-31 inoculations, resulted in significant increase in NN with Dursitu. With Gofta variety, all tested isolates with the exception of isolate NSCBR-59, significantly increased the NN. With exception of NSCBR-31, all isolates resulted in significant increase in NN with Kufanzik genotype.

At Hirna site, NSCBR-59, NSCBR-31, and NSCBR-57 inoculations had significantly higher NN than the control check with Dursitu genotype. However, most isolates, except NSCBR-59, NSCBR-18, and NSCBR-57, increased the NN significantly with Gofta. With Kufanzik genotype, a significant increase in NN was recorded in NSCBR-14, NSCBR-16, and NSCBR-18 treatments.

At Babile site, significantly higher NN was recorded with inoculation of NSCBR-(25) and NSCBR-18 with Dursitu than the uninoculated control. Significant increase in NN of Gofta was recorded with NSCBR-14, NSCBR-$(25)_2$, NSCBR-59 and NSCBR-31 treatments. However, NSCBR-$(25)_2$ isolate significantly increased the NN of Kufanzik. At Fedis site, a significant increase in NN of Dursitu inoculated with all isolates with the exception of NSCBR-31 and NSCBR-18 was recorded while NSCBR-14, NSCBR-$(25)_2$, NSCBR-59 and NSCBR-31 isolates inoculated Gofta resulted in an increase in NN.

In general, Dursitu inoculated with all isolates except NSCBR-31, produced the highest number of nodules increase over the uninoculated control while this highest increase with Kufanzik was recorded at NSCBR-31 inoculation (Fig. 1a). However, the highest increase in NN of Gofta over the control check was obtained from NSCBR-59. The highest means of NN (216.17, 221.93, 106.27 and 152.37) were induced with Dursitu at Haramaya, Hirna, Babile and Fedis sites, respectively, over other treatments while the lowest were recorded from uninoculated control at all sites.

Nodule dry weight

The effect of *Rhizobium* inoculation, the genotypes, experimental locations and their interaction was significant on nodule dry weight (NDW) (Table 1). The effect of inoculated isolates on NDW varied with different genotypes and in the different experimental sites similar to the result obtained in NN (Table 3). At Haramaya site, Dursitu inoculated with all *Rhizobium* inoculation treatments, except NSCBR-$(25)_2$, NSCBR-59 and NSCBR-18, produced significantly higher NDW than the control check. Inoculating NSCBR-14, NSCBR-$(25)_2$ and NSCBR-16 on the genotype Gofta increased significantly the NDW. However, only NSCBR-59 inoculated with Kufanzik significantly increased NDW when compared to the control check.

At Hirna site, NSCBR-$(25)_2$, NSCBR-59, NSCBR-31 and NSCBR-57 isolates significantly increased the NDW of Dursitu genotype. All, except NSCBR-$(25)_2$ and NSCBR-18 isolates, significantly increased more NDW with Gofta than with the uninoculated control. With Kufanzik, inoculating NSCBR-16, NSCBR-18 and NSCBR-57 more significantly increased NDW than uninoculated control. At Babile site, none of the isolates with Dursitu and Kufanzik significantly affected the NDW when compared to the control. However, only NSCBR-$(25)_2$ inoculated to Gofta significantly increased the NDW.

At Fedis site, most of the isolates excluding NSCBR-31 and NSCBR-18, significantly improved NDW with Gofta. A significant increase in NDW of Gofta was observed with NSCBR-14, NSCBR-59, NSCBR-31 and NSCBR-16. InoculatingNSCBR-14, NSCBR-59, and NSCBR-16 with Kufanzik were significantly ($P \leq 0.05$) enhanced the NDW. With Dursitu, all isolates with the exception of NSCBR-59, NSCBR-31, and NSCBR-18, resulted in the highest increase in NDW over the control check, while better NDW of Kufanzik was obtained with NSCBR-59 and NSCBR-18 (Fig. 1b). Only NSCBR-31 inoculated with Gofta recorded the highest NDW over the control check. The highest NDW across the inoculation treatments was produced with Dursitu.

Total biomass yield

ANOVA revealed that the main effect of *Rhizobium* inoculation, the genotypes, experimental locations and their interaction were significant ($P \leq 0.05$) on total biomass yield (TBY) (Table 1). At Haramaya site, NSCBR-16, NSCBR-57, and NSCBR-25 inoculated to Dursitu significantly increased in the TBY(Table 4). Isolate NSCBR-14 inoculated to Gofta and none of the isolates with Kufanzik resulted in a significant increase in the TBY. At Hirna site, significantly higher TBY of Dursitu was recorded in response to NSCBR-14, NSCBR-59, and NSCBR-31 inoculation than that of the control, while NSCBR-59 and NSCBR-18 inoculations significantly increased TBY of Kufanzik. However, the data exhibited the non-significant effect of inoculation on TBY of Gofta.

Table 1 Summary of ANOVA results for all investigated traits of common *bean affected by Rhizobium inoculation*, locations and common bean genotypes and their interaction, in Haramaya, eastern Ethiopia, during 2012/2013 main cropping season

Sources of variation	df	Mean of squares								
		NN	NDW	SDW	NPP	NSP	100 seeds weight	GY	TBY	Tot N
Inoculation (I)	9	57820.21***	1.3474***	390.95***	36.19***	0.8309***	5.97***	689219.2***	1901478.7***	0.3843***
Error a	18	6.93	0.0272	1.419	0.436	0.1307	0.2717	36.32	73.8	0.0438
Location (L)	3	162712.69***	12.0138***	18507.05***	24000.08***	8.8561***	222.18***	50871117.8***	303516204.1***	14.8800***
Genotypes (G)	2	99133.02***	4.9526***	1336.97***	192.52***	13.0149***	7713.64***	27841004.6***	13380537.9***	13.9593***
Error b	40	3.45	0.0118	0.903	0.354	0.0669	0.1485	27.32	43.6	0.0195
L × I	27	7791.62***	0.6423***	214.30***	23.12***	0.5278**	3.01***	224350.6***	1314309.9***	0.3052***
G × I	18	6338.46***	0.3683***	369.16***	11.66**	0.5495**	3.00**	1366719.0***	795260.8***	0.2897***
L × G	6	21688.09***	0.2510***	1273.77***	29.85***	1.7977***	74.17***	1234231.0***	2163372.5***	1.8200***
L × G × I	54	9120.29***	0.4940***	309.04***	13.97***	0.4452***	2.90***	208208.5***	639905.5***	0.2491***
Total	359	–	–	–	–	–	–	–	–	–

NN nodule number, *NDW* nodule dry weight, *SDW* shoot dry weight, *NPP* number of pods per plant, *NSP* number of seeds per pod, *GY* grain yield, *TBY* total biomass yield, *PH* plant height, *Tot N* total nitrogen

** Significant at 0.01

*** Significant at 0.001

Table 2 Nodule number of common bean investigated from three genotypes (Dursitu, Kufanzik and Gofta) over four experimental locations (Babile, Fedis, Haramaya and Hirna), in eastern Ethiopia, in 2012/2013 main cropping season

Inoculation	Nodule number											
	Dursitu				Kufanzik				Gofta			
	Haramaya	Hirna	Babile	Fedis	Haramaya	Hirna	Babile	Fedis	Haramaya	Hirna	Babile	Fedis
NSCBR-14	226.67bcd	236.67bcd	101.33c	179.33ab	136.00abc	231.67bc	122.33a	140.67a	95.33 cd	210.00ab	76.00abc	110.00bcd
NSCBR-$(25)_2$	290.00bc	235.00bcd	248.00a	166.67abc	135.33abc	280.00b	119.33ab	152.67a	130.67bc	153.33a-d	92.67a	160.00abc
NSCBR-59	117.00de	363.33a	85.67c	223.33a	96.67c	177.67 cd	112.33abc	176.67a	268.00 a	160.33abc	75.00abc	213.33a
NSCBR-31	178.00cde	269.33abc	80.00c	139.67bcd	116.67bc	366.67a	110.33abc	130.00a	76.00de	110.67bcd	91.67ab	107.00bcd
NSCBR-16	463.33a	201.67 cd	96.33c	171.67abc	145.00ab	246.00bc	98.33a-d	155.00a	93.67 cd	215.00a	85.67ab	189.33ab
NSCBR-18	138.00e	148.33 cd	162.00b	115.00cde	151.00ab	149.33de	90.33bcd	67.33b	100.33 cd	198.33ab	89.33ab	106.87bcd
NSCBR-57	281.67bc	345.00ab	75.00c	151.67bc	143.67ab	199.33 cd	86.00 cd	166.00a	119.67bc	136.67a-d	79.67ab	89.33 cd
NSCBR-25	333.00b	166.67 cd	92.00c	213.33a	160.33a	284.33b	102.33a-d	73.67b	151.67b	183.33abc	86.00ab	132.33a-d
−VE Control	79.33e	140.00d	61.67c	89.33de	47.33de	150.00de	73.00de	70.00b	49.67e	88.33 cd	68.00bc	97.67 cd
+VE Control	54.67e	113.33d	60.33c	73.67e	38.33e	93.00e	53.00e	72.00b	42.67e	55.67d	52.67c	54.67 cd
Mean	216.17	221.93	106.27	152.37	117.03	217.80	96.77	120.00	112.77	151.17	79.67	126.03
LSD (0.05)	126.39	124.57	50.57	60.55	42.8	80.27	30.65	48.51	39.55	103.74	23.72	83.97d
CV (%)	20.22	19.41	16.46	13.74	12.65	12.74	10.95	13.93	12.13	23.74	10.30	23.04
P value	***	***	***	***	***	***	***	***	***	***	***	***
F value	25.61	11.70	32.37	16.55	25.37	25.20	12.55	21.16	66.02	6.68	6.85	8.32

Means within the same column followed by the same letter are not significantly different at the 5% probability level by Tukey's test

−VE-negative control (no inoculation and N application), +VE control −20 kg N ha^{-1}; *NSCBR* National Soil Common Bean Rhizobium

*** Significant at 0.001

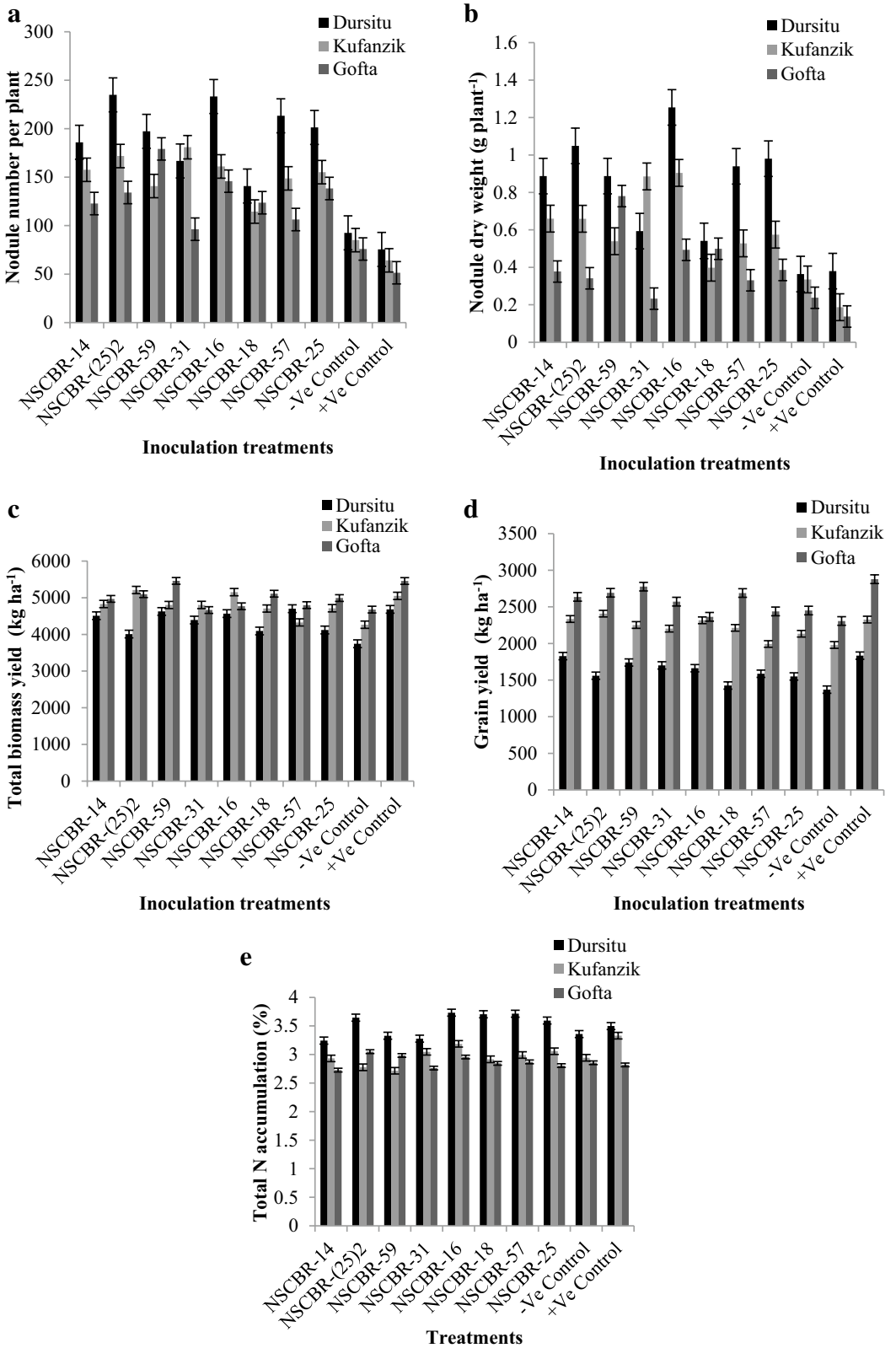

Fig. 1 The effect of *Rhizobium* isolates inoculation on **a** Nodule number, **b** Nodule dry weight, **c** Total biomass yield, **d** Grain yield and **e** Total N accumulation of three varieties of common bean, in eastern Ethiopia, 2012/2013 cropping season

At Babile site, a significant increase in TBY of Dursitu inoculated with NSCBR-14 was obtained. With Gofta, better TBY than from the uninoculated control was recorded with NSCBR-$(25)_2$ and NSCBR-(16). Kufanzik inoculated with NSCBR-$(25)_2$ gave significantly better TBY than that of the control. Inorganic N application with all genotypes at Babile site produced the highest TBY over the other treatments.

At Fedis site, NSCBR-59, NSCBR-16, and NSCBR-57 inoculated to Dursitu produced significantly higher TBY than the control. Gofta inoculated with NSCBR-$(25)_2$, NSCBR-31 and NSCBR-16 gave significantly higher TBY than the uninoculated control. Inoculating NSCBR-$(25)_2$ resulted in a significant increase in TBY with Kufanzik. In contrast to nodulation, the highest TBY (2589.44 and 5036.48 kg ha^{-1}) across the treatments were produced with Gofta at Babile and Fedis sites. At Haramaya and Hirna sites, all genotypes produced almost similar amount of TBY. With control check, Gofta recorded the highest TBY in all sites. Across locations, Gofta when compared to the other varieties recorded the highest TBY with all treatments (Fig. 1c).

Grain yields

The grain yield (GY) of common bean was significantly ($P \leq 0.05$) affected by *Rhizobium* inoculation, the genotypes, experimental sites and their interaction (Table 1). The effects of isolates on GY were significantly variable among the different genotypes and experimental locations (Table 5). At Haramaya site, Dursitu inoculated with NSCBR-14, NSCBR-16 and NSCBR-57 produced significantly higher GY than the uninoculated control. With Gofta, applying NSCBR-14 resulted in a significant increase in GY compared with the uninoculated control. The response of Kufanzik to inoculation with NSCBR-14, NSCBR-59, NSCBR-16 and NSCBR-18 significantly affected GY.

At Hirna site, all isolates, except NSCBR-18, NSCBR-57, and NSCBR-25 with Dursitu, resulted in a significant increase in GY while none of the isolates significantly affected the GY of Gofta. Kufanzik inoculated with NSCBR-14, NSCBR-16 and NSCBR-18 significantly increased the GY. At Babile site, NSCBR-14 with Dursitu gave significantly higher GY than the uninoculated control. With Gofta, NSCBR-$(25)_2$ and NSCBR-16 inoculation increased GY significantly. However, the data revealed the non-significant effect of inoculation on the GY of Kufanzik.

At Fedis site, a significant improvement of GY for Dursitu was obtained from inoculation with NSCBR-59, while *Rhizobium* inoculations did not affect the GY of Gofta and Kufanzik. The highest mean GY of 2932.3, 2739.4, 1490.0 and 2065.6 kg ha^{-1} were recorded with Gofta in Haramaya, Hirna, Babile and Fedis sites, respectively. In all experimental sites with all treatments including uninoculated control, Gofta produced the highest GY of 3498.4, 3257.82, 1499.25 and 2204.82 kg ha^{-1} at Haramaya, Hirna, Babile and Fedis over Kufanzik and Dursitu (Fig. 1d).

Total plant N accumulation

ANOVA showed significant ($P \leq 0.05$) effect due to *Rhizobium* inoculation, the genotype, experimental locations and their interaction on total plant N accumulation (TPNA) (Table 1). The effect of *Rhizobium* inoculation was non-significant on plant N accumulation in Dursitu at Haramaya site (Table 6). At this experimental site, inoculation with NSCBR-16, NSCBR-57 and NSCBR-25 to Gofta significantly improved the plant N accumulation, while this trait was higher in Kufanzik inoculated with NSCBR-59, NSCBR-31, and NSCBR-16 than uninoculated control.

At Hirna site, a significant increase in plant N accumulation by NSCBR-$(25)_2$, NSCBR-59, NSCBR-57 and NSCBR-25 inoculated with Dursitu was recorded. None of the *Rhizobium* inoculations significantly affected the plant N accumulation with Gofta and Kufanzik. At Babile site, all *Rhizobium* inoculations did not improve the TPNA of all the tested genotypes. At Fedis site, all isolates, excluding NSCBR-14 and NSCBR-59 with Dursitu were significantly higher in plant N accumulation than the uninoculated control. However, this trait did not significantly affect when isolates were inoculated to Gofta and Kufanzik. The highest mean total plant N accumulation values of 3.6257, 3.9950, 2.8543 and 3.5637% were recorded with Dursitu in Haramaya, Hirna, Babile and Fedis sites, respectively. Like nodulation, the highest plant tissue N accumulation in all treatments including uninoculated control was recorded with Dursitu genotype (Fig. 1e).

Discussion

Utilizing *Rhizobium* inoculation for pulses production is a common practice in different part of the world including some countries in sub-Saharan Africa (SSA). However, the success of this inoculant technology in common bean is variable from location to location. Besides, it depends on common bean genotypes. Due to different rhizobia population size and its competitiveness in different locations and presence of specificity between *Rhizobium* strain-common bean genotypes (Aouani et al. 1997), we need to develop genotype and location specific *Rhizobium* inoculant. Hence, this study was initiated to evaluate the effect of genotypes, *Rhizobium* inoculation and environmental locations on nodulation and productivity of common bean in major common bean growing areas of eastern Ethiopia.

Table 3 Nodule dry weight of common bean investigated from three genotypes (Dursitu, Kufanzik and Gofta) over four experimental locations (Babile, Fedis, Haramaya and Hirna), in eastern Ethiopian, in 2012/2013 main cropping season

Inoculation	Nodule dry weight (g plant^{-1})											
	Dursitu				Kufanzik				Gofta			
	Haramaya	Hirna	Babile	Fedis	Haramaya	Hirna	Babile	Fedis	Haramaya	Hirna	Babile	Fedis
NSCBR-14	1.9527bc	0.9591b	0.1557b	0.4807b	0.8001ab	1.1745 cd	0.1263bcd	0.5393c	0.2401b	0.2401ef	0.0661bc	0.6500bc
NSCBR-$(25)_2$	1.3644 cd	1.8193a	0.1396b	0.8717a	0.5716bc	1.5471bc	0.2061a	0.3117de	0.3697b	0.5116 cd	0.0876ab	0.3970de
NSCBR-59	0.7400e	1.7659a	0.1451b	0.8983a	0.4329cde	0.5869e	0.1025cde	1.0351a	1.5093a	0.4133de	0.0830ab	1.1167a
NSCBR-31	0.5533e	1.5782a	0.1105b	0.1320c	0.3429cde	2.4817a	0.1670ab	0.5503c	0.2070b	0.4300d	0.0980ab	0.1965ef
NSCBR-16	3.6583a	0.7725bc	0.1449b	0.4413b	1.0363a	1.7070b	0.1107 cd	0.7637b	0.2398b	0.8381b	0.0772ab	0.8187b
NSCBR-18	0.8420de	0.6835bc	0.3122ab	0.3270bc	0.5450 cd	0.7108de	0.0850de	0.2520def	0.5243b	1.1180a	0.1072ab	0.2473def
NSCBR-57	1.3562 cd	1.7729a	0.1380b	0.4897b	0.3997cde	1.2241bc	0.0623ef	0.4250 cd	0.4911b	0.6549bc	0.0630a	0.1145f
NSCBR-25	2.0594b	0.9970b	0.1028b	0.7607a	0.3843cde	1.6599bc	0.1423bc	0.1106f	0.4867b	0.4978 cd	0.0859bc	0.4743 cd
−VE Control	0.4963e	0.6788bc	0.1164b	0.1654c	0.3033de	0.6581e	0.1301bc	0.2500def	0.2405b	0.3342de	0.0640ab	0.3125def
+VE Control	0.3183e	0.5108c	0.5703a	0.1210c	0.2317e	0.3532e	0.0217f	0.1410ef	0.1233b	0.1262f	0.0340bc	0.2661def
Mean	1.3341	1.1538	0.1935	0.4688	0.5048	1.2103	0.1154	0.4379	0.4746	0.5164	0.0766	0.4594
LSD (0.05)	0.606	0.3691	0.3740	0.2659	0.2491	0.5016	0.0435	0.1948	0.4763	0.1896	0.0404c	0.2403
CV (%)	15.71	11.06	66.83	19.62	16.86	14.33	13.03	15.38	34.71	12.70	18.25	18.09
P value	***	***	**	***	***	***	***	***	***	***	***	***
F value	70.19	50.09	3.77	30.73	25.20	42.73	36.36	56.34	17.14	59.30	6.67	43.12

Means within the same column followed by the same letter are not significantly different at the 5% probability level by Tukey's test

−VE-negative control (no inoculation and N application), +VE control −20 kg N ha^{-1}; *NSCBR* National soil Common Bean Rhizobium

** Significant at 0.01

*** Significant at 0.001

Table 4 Total biomass yield of common bean investigated from three genotypes (Dursitu, Kufanzik and Gofta) over four experimental locations (Babile, Fedis, Haramaya and Hirna), in eastern Ethiopian, in 2012/2013 main cropping season

Inoculation	Total biomass yield (kg ha^{-1})											
	Dursitu				Kufanzik				Gofta			
	Haramaya	Hirna	Babile	Fedis	Haramaya	Hirna	Babile	Fedis	Haramaya	Hirna	Babile	Fedis
NSCBR-14	5157.4cde	7370.1a	2095.4ab	3414.8 cd	6870.4a	6500.0a	1722.2b	4222.2 cd	6018.5ab	6944.4abc	2342.6 cde	4568.5b
NSCBR-(25)$_2$	5000.0cde	5981.5bcd	1185.2d	3870.4abc	6473.1ab	6270.4a	3301.9a	4796.3ab	5859.3ab	5592.6d	2824.1bc	6111.1a
NSCBR-59	5240.7cde	7388.9a	1555.6bcd	4318.5a	6154.6ab	6740.7a	2591.6ab	3722.2e	6322.2ab	7611.1a	2722.2bcd	5185.2b
NSCBR-31	5101.9cde	6844.4ab	1975.9abc	3648.1bcd	5898.1ab	6837.0a	2000.0b	4481.5abc	5025.9b	6129.6cd	2705.6bcd	4800.0b
NSCBR-16	6388.9b	6314.8bc	1385.2 cd	4179.6ab	5693.5b	6659.3a	3355.6a	4905.6a	5546.3ab	6414.8bcd	1888.9e	5222.2ab
NSCBR-18	4772.4de	5925.9bcd	1946.3bcd	3731.5a-d	5740.7b	6851.9a	2074.1b	4157.4cde	5450.0ab	7348.1ab	2220.4de	5422.2ab
NSCBR-57	7518.5a	5442.6 cd	1694.3bcd	4148.1ab	5497.2b	5840.7a	2063.9b	3907.4de	6495.5a	5787.0d	2351.9cde	4557.4b
NSCBR-25	6064.8bc	5259.3d	1966.7abc	3190.7d	5713.0b	6533.3a	2527.8b	4083.3cde	5685.2ab	6263.0bcd	2948.1b	5074.1b
−VE Control	4685.2e	5463.0 cd	1407.4 cd	3425.9 cd	5675.9b	5492.6a	2037.0b	3851.9de	5954.6ab	5835.2 cd	2294.4cde	4627.8b
+VE Control	5851.9 cd	6537.0ab	2534.7a	3805.6a-d	6023.1ab	6805.6a	3052.8a	4322.2bcd	6101.9ab	7333.3ab	3596.3a	4796.3b
Mean	5578.17	6252.78	1774.66	3773.3	5973.98	6453.15	2472.78	4245.0	5845.94	6525.93	2589.44	5036.48
LSD	1093.4	1002.8	617.77	648.73	1061.1	1421.3	918.92	487.25	1359.4	1143.8	579.93	9.9.78
CV (%)	6.78	5.55	12.04	5.95	6.14	7.62	12.85	3.97	8.04	6.06	7.75	6.25
P value	***	***	***	***	**	*	***	***	*	***	***	***
F value	16.39	15.02	10.78	8.07	3.99	2.61	10.31	16.18	2.56	10.25	17.07	7.04

Means within the same column followed by the same letter are not significantly different at the 5% probability level by Tukey's test

−VE-negative control (no inoculation and N application), +VE control −20 kg N ha^{-1}; *NSCBR* National Soil Common Bean Rhizobium

* Significant at 0.05

** Significant at 0.01

*** Significant at 0.001

Table 5 Grain yield of common bean investigated from three genotypes (Dursitu, Kufanzik and Gofta) over four experimental locations (Babile, Fedis, Haramaya and Hirna), in eastern Ethiopian, in 2012/2013 cropping season

Inoculation	Grain yield (kg ha^{-1})											
	Dursitu				Kufanzik				Gofta			
	Haramaya	Hirna	Babile	Fedis	Haramaya	Hirna	Babile	Fedis	Haramaya	Hirna	Babile	Fedis
NSCBR-14	2323.1a	2554.35a	1340.6ab	1093.3b	3800.1a	2829.3ab	1098.6d	1607.0abc	3735.6a	3470.6ab	954.0e	2384.4ab
NSCBR-(25)$_2$	2192.9ab	2107.69bcd	653.7c	1285.6ab	3206.5bc	2634.3ab	1987.1a	1801.3ab	3339.8abc	3201.4abc	1657.8abc	2570.0a
NSCBR-59	2059.8abc	2486.94a	796.5c	1616.8a	3105.8bc	2565.6ab	1619.8abc	1716.7abc	3608.7ab	3625.7a	1913.1a	1956.3abc
NSCBR-31	2239.1ab	2132.96bc	1101.2abc	1328.1ab	2915.8bc	2910.8a	1046.6d	1938.8a	3062.1bc	3092.9bc	1631.9abc	2497.4ab
NSCBR-16	2454.9a	2122.41bcd	786.9c	1285.2ab	2983.8bc	2657.0ab	1932.4ab	1693.1abc	3265.8ab	3334.4ab	1080.1de	1776.4bc
NSCBR-18	1683.9c	1803.06de	1054.2bc	1162.4ab	3007.3bc	2817.5ab	1411.9 cd	1615.7abc	3215.7a	3648.0a	1232.8cde	2659.6a
NSCBR-57	2441.9a	1615.56e	892.7bc	1396.7ab	2761.6c	2433.8b	1442.5bcd	1333.8bc	3688.4bc	3096.4bc	1390.0b-e	1577.2c
NSCBR-25	2139.1ab	1918.89 cde	1043.5bc	1097.6b	3195.3bc	2611.5ab	1474.8bcd	1248.6c	3241.9c	2759.7c	1774.9ab	2024.3abc
−VE Control	1873.0bc	1750.93e	790.6c	1063.8b	2727.0c	2534.2ab	1221.9cd	1432.4abc	2932.3c	2739.8c	1490.0a-d	2065.6abc
+VE Control	2263.1ab	2292.59ab	1543.0a	1238.9ab	3375.9ab	2776.4ab	1501.0a-d	1652.2abc	3498.4a	3609.4a	1868.1ab	2537.0a
Mean	2167.07	2078.54	1000.28	1256.83	3107.92	2677.03	1473.66	1603.96	3358.89	3257.82	1499.25	2204.82
LSD	408.32	325.07	473.22	517.43	537.01	452.72	500.47	529.87	582.44	502.05	484.42	734.04
CV (%)	6.51	5.40	16.36	14.24	5.98	5.85	11.75	11.43	6.00	5.33	11.18	11.51
P value	***	***	***	*	***	*	***	**	***	***	***	***
F value	8.86	22.88	8.56	2.65	8.66	2.80	9.87	4.00	5.30	11.44	11.66	6.51

Means within the same column followed by the same letter are not significantly different at the 5% probability level by Tukey's test

−VE-negative control (no inoculation and N application), +VE control −20 kg N ha^{-1}; *NSCBR* National soil Common Bean Rhizobium

* Significant at 0.05

** Significant at 0.01

*** Significant at 0.001

Table 6 Total N accumulation of common bean investigated from three genotypes (Dursitu, Kufanzik and Gofta) over four experimental locations (Babile, Fedis, Haramaya and Hirna), in eastern Ethiopian, in 2012/2013 main cropping season

Inoculation	Total N accumulation (%)											
	Dursitu				Kufanzik				Gofta			
	Haramaya	Hirna	Babile	Fedis	Haramaya	Hirna	Babile	Fedis	Haramaya	Hirna	Babile	Fedis
NSCBR-14	3.4633c	4.0600a-e	2.2967b	3.1533d	2.5300c	4.0300a	2.8933a	2.2733b	2.2567de	3.6667ab	2.2300d	2.7533abc
NSCBR-$(25)_2$	3.3000c	4.3667ab	3.1367abc	3.7767ab	2.3400c	3.3367bcd	2.3567b	3.0700a	2.5900bcd	3.8067ab	2.8800ab	2.9233a
NSCBR-59	3.6433bc	4.0933a-d	2.2700d	3.3067 cd	2.7600bc	2.6667e	2.3600b	3.0733a	2.7400ab	3.8733a	2.5267a-d	2.7933ab
NSCBR-31	3.5267bc	3.4167f	2.5233 cd	3.6433bc	2.5633c	3.5967abc	2.8733ab	3.1533a	2.7167abc	3.4300b	2.4667bcd	2.4367bc
NSCBR-16	3.9367ab	4.0333b-e	3.2400ab	3.7200ab	3.1633ab	3.3433bcd	3.1933a	3.0467a	3.0300a	3.6167ab	2.5567a-d	2.6200abc
NSCBR-18	4.1367a	3.7433def	3.3600a	3.5800bc	2.4333c	3.0567de	3.0967a	3.0767a	2.1567e	3.5967ab	2.6767ab	2.9533a
NSCBR-57	3.5800bc	4.4233a	3.0233abc	3.8300ab	3.1033ab	3.3000bcd	2.8567ab	2.7067ab	2.3267de	3.9200a	2.6667abc	2.5700abc
NSCBR-25	3.6033bc	4.1367abc	3.0233abc	3.6133bc	3.1533ab	3.2100 cd	2.8333ab	3.0333a	2.5233cde	3.6533ab	2.6567abc	2.3867c
−VE Control	3.7400abc	3.7033ef	3.0767abc	2.9133d	2.3100c	3.7500ab	3.7167ab	2.9933a	2.3400de	3.5600ab	2.8933a	2.6300abc
+VE Control	3.3267c	3.9733cde	2.5933bcd	4.1000a	3.5767a	3.8567a	3.0300a	2.8567a	2.3467 cde	3.7667ab	2.2467cd	2.9167a
Mean	3.6257	3.9950	2.8543	3.5637	2.7933	3.4147	2.8210	2.9283	2.5027	3.6890	2.5800	2.6983
LSD	0.4527	0.3881	0.6467	0.4105	0.4878	00.5133	0.5198	0.5252	0.3751	0.4025	0.4235	0.4047
CV (%)	4.32	3.36	7.84	3.98	6.04	5.20	6.37	6.20	5.18	3.77	5.68	5.19
P value	***	***	***	***	***	***	***	***	***	**	***	***
F value	8.23	15.55	9.47	18.10	19.54	15.58	7.29	6.33	12.88	3.55	7.16	6.26

Means within the same column followed by the same letter are not significantly different at the 5% probability level by Tukey's test

−VE-negative control (no inoculation and N application), +VE control −20 kg N ha^{-1}; *NSCBR* National Soil Common Bean Rhizobium

** Significant at 0.01

*** Significant at 0.001

In general, the *Rhizobium* inoculation, the locations, the common bean genotypes and their interaction effect was significant ($P \leq 0.05$) on nodulation, yield and yield traits of common bean (Table 1). This indicates the need for specific *Rhizobium* isolate development for each of common bean genotype when cultivating in different locations. Similar findings were previously reported on common bean (Handley et al. 1998; Mostasso et al. 2002; Popescu 1998; Remans et al. 2008). This specificity could be due to the fact that the exchanges of chemical signals between the two partners are present. The legume roots exude organic compounds (flavonoids) (Hungria et al. 1997; Long 2001), which differ between plant species and genotypes. Then after, rhizobial bacteria respond with lipo-chitin oligosaccharides, known as Nod factors, which act as specific morphogenetic signal molecules to induce the roots nodule formation (Oldroyd and Downie 2008). In addition, the result of the current study revealed the need for location specific *Rhizobium* development.

The present study revealed that isolates performed better in improving NN, NDW, TBY, GY and TPNA with one of the tested genotypes did not consistently exhibit with other genotypes, indicating the presence of specificity of *Rhizobium* isolates and common bean genotypes. Similarly, Bouhmouch et al. (2005) reported the common bean genotypes-*Rhizobium* specificity. This indicates the presence different infectivity potential of *Rhizobium* isolates with different common bean genotypes (Neila et al. 2014).

We found that relatively more number of inoculated *Rhizobium* performed better in NN than the background rhizobia in the Haramaya site than in the other study sites. This indicates the presence of less competitive background rhizobia in infectiveness at Haramaya site than the other study sites. The current study showed that those isolates that performed better in improving NN did not perform similarly in NDW enhancement in all study sites, suggesting that better in infectiveness is not always good in effectiveness. The present work indicated that all isolates including the uninoculated control produced the lowest mean NN and NDW in all genotypes at Babile. This was probably due to low rhizobial population in this site (Ojo et al. 2015) and this consequently reduced the nodule formation. Low nodulation formation might be also attributed to the prevailed adverse environmental condition at Babile site (Hungria et al. 2003). Elias and Herridge (2015) found that rhizobial population was positively correlated with soil moisture. Besides, the soil textural class of Babile soil was sand and had low SOM (Table 1), which could reduce the survival of inoculated *Rhizobium* in the soil (Hagedorn 1978; Mahler and Wollum 1981). However, Bliss (1993) suggested that the limitation of N_2 fixation imposed by environmental factors could be resolved through the selection and breeding of improved common bean cultivars.

The highest NN and NDW in the control without inoculation were produced with Dursitu at Haramaya and Hirna sites and Kufanzik at Babile and Gofta at Fedis site. This suggests the presence of appropriate indigenous rhizobia, which could be different in infectiveness and effectiveness in different soils. Rodiño et al. (2011) determined common bean variety and variety × environment interaction effect on nodulation. A similar finding was reported in common bean in Canadian Prairie by Nleya et al. (2009) who found that common bean genotypes differed in nodulation formation. In addition, Ikeda (1999) found that the number of nodules was directly controlled by host genotype. This preference could have a major significance in resolving strain competition problem in *Phaseolus vulgaris* (Raposeiras et al. 2006).

The result of the present work indicated that those isolates induced the highest nodulation with one genotype was not consistently performed with the other genotypes. Similarly, Bonish and MacFarlane (1987) demonstrated that isolates mean effectiveness of 12% with 'Tamar' variety was recorded and 87% mean effectiveness with Huia variety. Differences in host variety among clover lines influence the effectiveness of the symbiosis (Hagedorn and Caldwell 1981; Sherwood and Masterson 1974).

The highest mean NN and NDW across locations and with all treatments including uninoculated control were produced in Dursitu. Dursitu at Haramaya, Babile and Fedis sites and Kufanzik at Hirna site induced the highest mean NDW across the treatments. This indicates the presence of more infectiveness by inoculated *Rhizobium* and background rhizobia with Dursitu rather than other tested genotypes. This might be attributed to the high promiscuity of Dursitu with several rhizobial species (Cardoso et al. 2012) apparently resulting from the capacity of the host plant to perceive a genotype of rhizobial molecular signals (Michiels et al. 1998). Significant environment by inoculant interaction effect on nodule dry weight was reported by Nleya et al. (2009). Therefore, the current work found the presence of *Rhizobium* isolate-genotype specificity in nodule production in a different location.

The result of the present study indicated the highest mean total plant N accumulation across treatments including uninoculated control was recorded in Dursitu as it was found in nodulation. Similar results have been previously reported by lentil and pea (Abi-Ghanem et al. 2011). This implies that improving nodulation is important traits to enhance the total N in plant tissue. Variation in plant N accumulation among genotypes could be due to the presence of variability in SNF among common bean genotypes (Hardarson et al. 1993; Nleya et al. 2002).

Yadegari et al. (2010) found that Cultivar 'Akhtar' demonstrated the highest potential for nodulation, nitrogen fixation, and seed yield production compared to cultivars 'Sayyad' and 'Goli'. Buttery et al. (1997) also compared 17 common bean genotypes inoculated with various *Rhizobium* strains for N fixation and they found differences among genotypes in acetylene reduction activity and seed N content.

In contrast to the finding in nodulation, the mean TBY and GY across locations were the highest in Gofta. This genotype also produced the highest mean TBY and GY across treatments including uninoculated control. The highest biomass and grain production in all experimental locations was also recorded with Gofta. This finding is consistent with the observation of Tsai et al. (1993) who found that Mexico-309 was superior for nodulation parameters but poor for seed yield, while Preto Caruaru produced high seed yield, but was inferior in nodulation traits. The yield advantage of Gofta could be attributed to its delayed maturity when compared to other tested common bean genotypes. Due to genetic makeup difference among common bean genotypes, it may record high production though induced low nodulation (Pereira et al. 1984). Conversely, Rodiño et al. (2011) found that genotypes with a big nodule phenotype showed a good plant response and more beneficial for plant growth and seed yield. In contrast to the current study, Farid and Navabi (2015) found the common bean genotypes × environment interaction for grain yield production.

Regardless of the tested genotypes, the highest TBY at Babile site was recorded with inorganic N treatment. Similarly, Hungria et al. (2003) found further increase of common bean production on average by 132 kg ha^{-1} with a supplement of 15 kg N ha^{-1} over the inoculated plants. In other experimental sites, a significant increase in TBY was obtained with *Rhizobium* inoculation. Similarly, Huntington et al. (1986) found that *Rhizobium* inoculation increased the yield by 30–80% in common bean using when compared to N fertilizer plant. In contrast to the current finding, Ruiz Diaz et al. (2009) found that the non-significant effect of inorganic N application with and without inoculation on the yield of soybean n though plant N accumulation was improved. This result could be attributed to high N_2 derived from the atmosphere by soybean when compared to common bean.

It has been shown that none of the inoculated *Rhizobium* significantly improved the plant accumulated N at Babile when compared to the uninoculated control. This result could be attributed to dry condition and low soil moisture availability in Babile (Saito et al. 1984; Smith et al. 1985, 1988) and this cause early nodules senescence and decline in nitrogenase activity (Becana and Sprent 1987) and low N_2 fixation. On the other hand, the *Rhizobium* inoculation at other experimental locations significantly increased plant N accumulation. This result could be attributed to the fact that more than 50% of its plant N accumulated was derived from biological N_2 fixation when inoculated with effective *Rhizobium* under favorable condition (Pena-cabriales et al. 1993).

Some of the isolates inoculated to Dursitu accumulated significantly higher plant N than the uninoculated control but this result was not observed with the remaining genotypes. Previously investigations under field conditions (Hobbs and Mahon 1982; Rengel 2002; Young et al. 1982) have shown that some *Rhizobium* isolates are more efficient when inoculated on some genotypes than on others. Huntington et al. (1986) concluded from their greenhouse study that the host/endophyte combination forms a relatively ineffective symbiotic association being primarily inherent in the host plant rather than the endophyte or the environment. The current result is also consistent with the findings of Hungria and Neves (1987); Hardarson et al. (1993) and Neves et al. (1987) who found that plant N concentration in different pulse crops is influenced by the host plant cultivar as well as by *Rhizobium* strain. Graham (1981) and Amarger (1986) found that nitrogen fixation depends on rhizobia × line interaction and that the process of selection of efficient rhizobia should be developed with adequate lines.

Conclusion

The result of this experiment showed the presence of *Rhizobium* strain × locations specificity. Besides, the result exhibited the need for different *Rhizobium* isolate for tested common bean genotypes. The result indicated the similar performance of all common beans varieties in most of the investigated traits, except nodulation, regardless of the experimental locations. This suggests the need for specific *Rhizobium* strain development for biofertilizer production for different locations. Hence, we recommend the development of location-based *Rhizobium* isolates for inoculants production.

Authors' contributions

AA planned, designed and conducted the field experiment; AA and DM analyzed the data using appropriate software and prepared the manuscript. Both authors read and approved the final manuscript.

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