Journal of Chemical, Environmental and Biological Engineering
2024; Vol. 8, No. 2, pp. 66-76
https://doi.org/10.11648/j.jcebe.20240802.13

Research Article

Validation Trial of Rhizobium Strains Inoculation on Chickpea (*Cicer arietinum* L.) Varieties in the Central Highlands of Ethiopia

Desalegn Regassa*

Planning And Scaling Expert, Capacity Building for Scaling Up Evidence Based Best Practices in Agricultural Production in Ethiopia Project, College of Development Studies, Addis Ababa University, Addis Ababa, Ethiopia

Abstract

The sustainability of agriculture has become a major global concern due to the adverse environmental impacts of intensive chemical input use. The application of biofertilizers, such as rhizobium, can mitigate the reliance on chemical fertilizers, reduce production costs, and lessen environmental harm. This study evaluates the benefits of rhizobial inoculation in enhancing chickpea productivity and its implications for broader adoption. Conducted in the Becho and Seya-Debrna Wayu districts of Ethiopia during the 2019 cropping season, the experiment utilized two chickpea varieties (Habru and Natoli) and three rhizobium strains (cp-11, cp-17, and cp-29) in a factorial randomized complete block design with unfertilized controls. Data on grain yield, above-ground biomass yield, yield components, and nodule scores were collected and analyzed using ANOVA in SAS. Results indicated significant differences among treatments in nodulation, grain yield, and yield components. The combination of the recommended NPS boron blend (100 kg/ha) with the CP-29 strain yielded the highest grain yield (4.52 ton/ha), the most pods per plant (39.88), and the tallest plants (112.6 cm). This treatment increased grain yield by 55.22% and 26.41% over the uninoculated and unfertilized control and the uninoculated but phosphorus-fertilized control, respectively, demonstrating the potential of inoculant technology to enhance chickpea productivity. The Habru variety consistently outperformed at both sites, warranting its recommendation for further promotion in the study districts and similar agro-ecological zones in Ethiopia.

Keywords

Biofertilizer, Chickpea, Nodulation, Productivity, Rhizobium

1. Introduction

Chickpea (Cicer arietinum L.) ranks as the third most important food legume globally, following common beans and soybeans [25]. The top producers include India, Australia, Ethiopia, and several others [15]. Approximately 14.80 million hectares are dedicated to chickpea production, yielding 14.24 million tons, resulting in an average productivity of 0.96 tons/ha [15].

Ethiopia, recognized as a secondary center of origin [2, 21], is Africa's leading chickpea producer. The crop thrives in the central, northern, and eastern highlands at altitudes of 1400-2300 m.a.s.l., with annual rainfall between 500 and 2000 mm [4, 2].

*Corresponding author: amensisa.regassa@gmail.com (Desalegn Regassa)

Received: 24 October 2024; **Accepted:** 20 November 2024; **Published:** 30 December 2024

Chickpeas are among the important legumes accounting for over 15.25% (0.46 million MT) of Ethiopian pulses production (3.01 million MT) and 14.80% (0.24 million hectares) of total area allotted to pulses (1.62 million hectares [9], with desi varieties grown mainly for the local market and the larger seeded, kabuli varieties, largely for export. The crop is known for soil nitrogen enrichment, rotational advantages, and lower cost of production. It is used as a disease cycle breaker and helps to reduce pesticide and herbicide usage [10]. Chickpea occupies an important position amongst the pulse crops grown in Ethiopia because of its multiple functions. It is a key component of the daily diet, and thus an important protein source for Ethiopian households who cannot afford animal products. It is an important dietary crop consumed in different preparations like snacks, curry, blends, green peas, and salads, to mention a few. It also plays an important role in Ethiopia's foreign exchange earnings through exports to Asia and Europe [32]. Despite this, the level of productivity of the crop is still low as compared to its potential, and the sustainably of the production system is also in question given the country's increasing reliance on inorganic fertilizer.

In the present scenario, the sustainability of agriculture, in general, has become a major issue of global concern as the intensive use of chemical inputs harms the environment. Current trends in agriculture are therefore focused on the reduction of the use of pesticides and inorganic fertilizers, forcing the search for alternative ways to improve crop yield in sustainable agriculture. The use of biofertilizers such as rhizobium can reduce the need for chemical fertilizers, decrease adverse environmental effects, and also reduce the cost of production for farmers. Today, biofertilizers have emerged as a highly potent alternative to chemical fertilizers due to their eco-friendly, easy-to-apply, non-toxic, and cost-effective nature.

Biofertilizers are carrier-based preparations containing beneficial microorganisms in a viable state intended for seed or soil application to improve soil fertility and plant growth by increasing the number and biological activity of beneficial microorganisms in the rhizosphere. They improve soil fertility levels by fixing atmospheric nitrogen, solubilizing insoluble soil phosphates, and releasing plant growth substances in the soil [35]. Some important inoculants are rhizobium inoculants, Azotobacter inoculants, Arbuscular mycorrhiza (AM), blue-green algae inoculants, azolla, and phosphate solubilizing bacterial (PSB) inoculants. Rhizobium inoculants are widely used as biofertilizers to enhance legume crop growth and yield as they fix atmospheric nitrogen symbiotically.

There is increasing evidence to suggest that inoculation enhances plant growth, grain and biomass yield in chickpeas [7, 17, 22, 33]. Chickpea can meet a significant portion (4–85%) of its N requirement through the symbiotic N2 fixation process when grown in association with effective and compatible rhizobium strains [34]. The inoculation of seeds with rhizobium is known to increase nodulation, N uptake, growth and yield parameters of legume crops [26]. [3] reported that inoculation of seed with its own specific and suitable rhizobium strain before planting is crucial to fully benefit from grain legume crop in terms of maximum yield and soil improvement. A given legume cultivar modulated by different strains of the same species of rhizobium would fix different amounts of nitrogen. It is also true that a given strain of rhizobium will nodulate and fix different amounts of N in symbiosis with a range of cultivars of the same plant species [24, 28].

In combination with P-fertilizer (90 kg/ha), grain yields in Pakistan increased from 1600 to 3100 kg/ha and Stover yields from 4350 to 7500 kg/ha [1]. [12] reported that inoculation with rhizobium and mycorrhiza improved both grain and Stover yields by about 60% in Turkey. [8] also reported that rhizobium inoculation increased nodulation and seed yield of chickpeas by up to 35% in Japan. In Ethiopia, previous studies conducted in three regions (Oromia, Amhara, and South Nations, Nationalities and People Region) show some strong responses to inoculation for chickpeas [29].

Even though chickpea productivity in Ethiopia is better than the average global productivity of 0.96 tons ha-1 [15], productivity in the country remains low, with a national average yield of 1.92 t ha^{-1} [9], far below the potential yield of 4–5 t ha^{-1} reported on experimental stations [5, 16, 6]. This yield gap between the average and potential yield of chickpeas could be due to many factors like the use of local variety, poor agronomic practices, low soil nutrients, absence of compatible strains, low population numbers of rhizobia, lack of effectiveness, inappropriate method of inoculation due to lack of knowledge and skill about the technology and poor survival rate of rhizobia in the soil or competition amongst strains of rhizobia. So there is a need to alleviate such chickpea productivity constraints by identifying specific and compatible elite rhizobia strains that proved to be compatible with establishing effective symbiosis with chickpea and eventually increase yield and sustained soil fertility. Generally, the knowledge of effective rhizobia strains for efficient symbiosis with chickpea varieties and the efforts to test and recommend rhizobia inoculums on fire is very limited in the country.

This study aims to investigate the effects of rhizobium inoculation on chickpea growth and productivity, providing insights for promoting inoculant technology among farmers in Ethiopia.

2. Methods and Materials

2.1. Experimental Area

The experiment was conducted in Becho (Awash Bune Peasant Association) and Seya-Debrna Wayu (Rome Peasant Association) districts during the 2019 cropping season. Both districts feature mixed farming systems and moderately fertile lands. Seya-Debrna Wayu district is found in the North Shewa zone of the Amhara region at a distance of 47 km West of Debre-Berhan town, the zonal capital, and 125 km East of Addis Ababa, the capital city of the country. The district is located between 90 42' to 90 53' N latitude and 390 08' to 390 17' E longitude. Its average altitude is about 2,600 meters above sea level (masl) and the average rainfall is 900 mm per annum. About 83% of the district has highland agroecology, 10% mid-highland, 2% lowland, and others constitute 5%. Eighty-five percent of the district's soil type is clay soil. Loam and silt soils constitute 10% and 5%, respectively. Cereals like bread wheat and teff; pulse crops like lentil, faba-bean, field pea, chick-pea, and grass-pea and horticultural crops like potato, carrot, garlic, onion, and cabbage are cultivated in the district.

Becho is one of the districts located in the South-West Shewa zone of Oromia region. The major town in Becho is Tulu Bolo. Geographically, the district lies at 8035'0'' latitude and 38015' 0'' E longitude; and is located about 80 km southwest of Addis Ababa, the capital city of Ethiopia. Agro-ecologically, 95% of the district is covered by highland and the rest is covered by mid-highland. The district lies between 2106 m to 2600 masl, and experiences mean annual rainfall of about 1300 mm: with June to September as the main rainy season. The mean annual temperature ranges between 16 ℃ to 25 ℃. In terms of soil, about 85% of the area is characterized by black soil (vertosol), 10% by red soil and the rest is covered by other kinds of soil. The topography is dominated by plains with undulating and hilly lands. The major crops grown in the district are teff, wheat, and chickpea for both home consumption and for sale. Cattle, sheep and goats are the major types of livestock owned by different households.

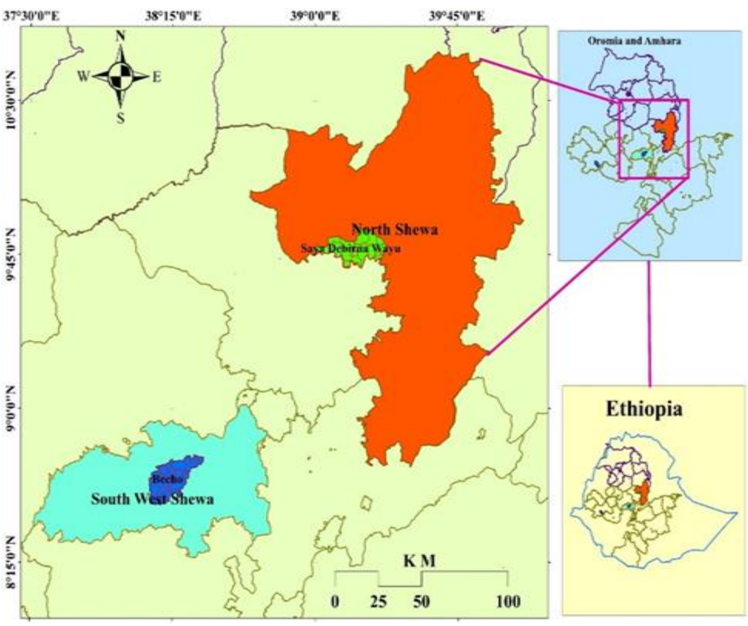

Figure 1. *Study area map.*

2.2. Experimental Design of the Study

Locally adapted and validated varieties, Habru (kabuli type) and Natoli (desi type) obtained from Debrezeit Agricultural Research Center and three inoculants (rhizobium strains), cp-11, cp-17 and cp-29 obtained from Holeta Biotechnology Research Center were used for the experiment on three farmer fields in each of the two districts. In the Becho district, a pesticide called Farate was applied to control pod borers but in the Seya-Debrna Wayu district no pesticide was applied as the insect pest was not observed in the district. Although chickpea rust disease was observed in both districts no chemical was applied to control the disease. At Seya-Debrna Wayu district all three farmers used bread wheat as a previous season crop on experimental farmland and all the three farmers at Becho used tef.

Table 1. *Factors and treatments used for the experiment.*

Factors/treatment	Remark
chickpea varieties	
Natoli	
Habru	
Fertilizers (Biofertilizer strains + Inorganic fertilizer NPSB)	
CP-11+ 100 kg NPSB/ha	
CP-17+ 100 kg NPSB/ha	

Factors/treatment	Remark
CP-29+ 100 kg NPSB/ha	
No strain but 100 kg NPSB/ha	Control 1
No strain and no NPSB	Control 2

The two varieties and three rhizobium strains were arranged in RCBD in factorial arrangement with three replications in each farmer's field with two check/control plots which form ten treatment combinations (table 1): NPS boron blend (18.1%N, 36.1 %P_2O_5, 0.0 %K_2O, 6.7 %S, 0.0 %Zn, and 0.71% B) was the source of P at 36.1% P_2O_5 kg ha−1 rate and applied at sowing. Seeds were inoculated at a rate of 5 g of inoculants per kg of seed using sugar solution as a sticker. Inoculation was done under shade and the inoculated seeds were kept for a few minutes until air dry before planting. The seed was broadcasted in a plot size of 3m x 10m plot, 0.5m between plots at a seed rate of 140kg ha-1. Farmers were used as replication in each district. 100kgNPSB/ha is the blanket fertilizer rate recommended for Becho and similar areas by MoA.

2.3. Data Collection and Data Analysis

Composite soil samples were collected before planting at a depth of 20 cm, sampled at 10 even intervals per experimental plot. Examination Methods: PH-H_2O=ES ISO 10390:2014 (1:2.5); Texture= Bouyoucos Hydrometer Method; OC=Walkey Black; TN= ES ISO 11261:2015 (kjeldahl Method); CEC=Ammonium Acetate Method; P ES ISO 11263:2015 (olsens Method) and Ca, K, Mg and S= Mehlich-3.

Agronomic data like Nodule scores (total, active, and inactive nodule numbers), yield (grain and biomass), and yield components (plant height, number of pods per plant, and stand count) data were also collected.

ANOVA was performed for all collected traits (both soil and plant-based data) as per the methods described by Gomez and [18] using SAS computer software [31] for randomized complete block design. The significance of the treatment effect was determined using F-test. When ANOVA indicated that there was a significant value, multiple comparisons of mean value were performed using the least significant difference method (LSD).

3. Results and Discussion

3.1. Physical and Chemical Properties of Soil of the Experimental Site Before Planting

The soil of the experimental sites was clay. The average analysis result of the two experimental sites showed that the soil at both sites is characterized as clay with a pH of 7.04 at Becho district and 7.8 at Seya-Debrna Wayu district (Table 2). The detailed soil properties are presented in Table 2.

Table 2. Soil physical and chemical properties of the experimental sites (Becho district Awash Bune Peasant association and Seya-Debrna Wayu district Rome peasant association) before planting in 2019 sampled from top 20cm depth.

site	Properties	Value	Ratings	References
Becho district awash bune peasant association	Chemical properties			
	CEC (cmol(+)/kg soil)	34.43	High	[13]
	PH	7.04	Neutral	[23, 14, 13]
	Organic carbon (%)	0.60	Very low	[23]
	Total nitrogen (%)	0.05	Very low	[10, 13]
	C: N ratio	12.46	low	[27]
	Available P (Mg/kg)	12.09	Medium	[20, 14]
	S (Mg/Kg)	7.44	Low	[13]
	Ca(Cmol(+)/kg soil)	21.37	Very high	[20,14, 13]
	Mg(Cmol(+)/kg soil)	7.34	High	[20, 13]
	K(Cmol(+)/kg soil)	3.47	Very high	[20]
	Na(Cmol(+)/kg soil)	0.28	Low	[14, 10, 13]
	Physical properties (%)			

site	Properties	Value	Ratings	References
	Sand	18.67		
	Silt	22.00		
	Clay	59.33		
	Texture class		Clay	
Seya-Debrna Wayu district Rome Peasant Association	Chemical properties			
	CEC (cmol(+)/kg soil)	45.99	Very high	[13]
	PH	7.80	Slightly alkaline	[23, 14, 13]
	Organic carbon (%)	0.68	Very low	[23]
	Total nitrogen (%)	0.07	low	[10, 13]
	C: N ratio	10.27	low	[27]
	Available P (Mg/kg)	16.69	Medium	[20, 14]
	S (Mg/Kg)	9.60	Medium	[13]
	Ca(Cmol(+)/kg soil)	36.88	Very high	[20, 14, 13]
	Mg(Cmol(+)/kg soil)	5.49	High	[20, 14, 13]
	K(Cmol(+)/kg soil)	2.00	Very high	[20, 14]
	Na(Cmol(+)/kg soil)	0.07	Very low	[14, 10, 13]
	Physical properties (%)			
	Sand	12.00		
	Silt	20.67		
	Clay	67.33		
	Texture class		Clay	

3.2. Yield and Its Components

ANOVA analysis over location showed that there was a significant difference among the treatments in affecting yield, some yield components, and nodule scores (table 3). The result showed that the Habru variety is a high yielder at both experimental sites even though the yield difference is not significant in the Becho district (table 3). The effect of strains on grain yield is not significantly different at the Seya-Debrna Wayu district but significantly different at the Becho district and when combined in over location.

Table 3. *Mean squares of collected parameters at both districts and combined over the location.*

	Experimental sites					
	Seya-Debrna Wayu		Becho		Combined (over location)	
	Df =4	Df=1	Df =4	Df=22	Df =4	Df=1
Traits	Fertilizer	variety	Fertilizer	variety	Fertilizer	variety
Tnod	88.03**	11.38ns	635.67*	1684.05**	528.58*	709.26*
Anod	97.42**	9.79ns	482.61*	1330.40**	459.68*	555.96ns

	Experimental sites					
	Seya-Debrna Wayu		Becho		Combined (over location)	
	Df =4	Df=1	Df =4	Df=22	Df =4	Df=1
Traits	**Fertilizer**	**variety**	**Fertilizer**	**variety**	**Fertilizer**	**variety**
Inod	6.29ns	0.39ns	20.98ns	8.60ns	13.15ns	2.67ns
SC	11.50ns	12.55ns	48.96n***	3.17ns	48.64**	14.16ns
NPP	26.42ns	357.49*	259.97*	100.87ns	175.28ns	419.03*
PH	142.15***	75.11**	248.96***	205.41***	378.31***	264.5***
BmY	3.25ns	30.44**	17.58**	15.21*	17.54*	44.34**
GY	0.58ns	6.06**	4.69***	1.98ns	3.93**	7.48**
HI	0.02*	0.01ns	0.02*	0.01ns	0.04***	0.00ns

Tnod= total nodulation; Anod= Active nodule; Inod= Inactive nodule; SC= Stand count, Npp= number pod per plant; PH= Plant height; HI= Harvest index; BmY=biamas yield (ton ha-1); GY=Grain yield (ton ha-1); ns= non-significant; *= significant at 0.05; **= significant at 0.01 and ***= significant at 0.001

The treatment with the recommended NPSB rate and with CP-29 gave the highest grain yield (4.52ton ha-1) in over locations analysis. On average, this treatment increased grain yield by 55.22% and 26.41% over the check which was neither inoculated with rhizobium nor fertilized with phosphorus fertilizer (local control) and the check which is uninoculated but with phosphorus fertilizer (standard control) respectively, indicating the possibility of boosting chickpea productivity for farmers with inoculant technology. Similar to the experiment, the use of rhizobium had shown an advantage in enhancing chickpea productivity in India [30, 11, 19]. When locations were compared, a higher grain yield (4.23 ton ha-1) was obtained at the Becho district than Seya-Debrna Wayu district (2.93 ton ha-1), and in contrast to this, biomass yield was higher (9.41 ton ha-1) at Seya-Debrna Wayu district than at Becho district (8,89 ton ha-1) (Tables 6 and 7).

The results of individual location analysis for nodule score and yield components showed that in the Seya-Debrna Wayu district, there is a significant difference among rhizobium strains in affecting nodule score and plant height, but there was no significant difference between varieties in affecting nodulation. At Becho district, there was a significant difference among strains and between varieties in affecting nodule score. Nodule scores over location also showed significant ($P \leq 0.05$) variation between varieties and among rhizobium strains in affecting nodulation (Table 4).

Table 4. *Mean values of grain yield (ton ha-1) of 2 chickpea varieties and 5 fertilizers/strains tested at two locations in 2019 cropping season.*

Variety	Experimental sites		Treatment means
	Seya-Debrna Wayu	Becho	
Natoli	2.48b	3.98a	3.23b
Habru	3.38a	4.49a	3.93a
Site means	2.93	4.23	3.58
CV (%)	30.00	17.93	27.50
LSD (0.05)	0.67	ns	0.51
Fertilizer/strain			
T1(NPSB +CP-11)	3.04a	3.76b	3.40b
T2(NPSB +Cp-17)	2.75a	4.12b	3.43b

Variety	Experimental sites		Treatment means
	Seya-Debrna Wayu	Becho	
T3(NPSB +CP-29)	3.31a	5.72a	4.52a
T4(NPSB)- standard control	3.04a	4.11b	3.57b
T5 -local control	2.50a	3.43b	2.97b
Site means	2.93	4.23	3.58
CV (%)	30.00	17.93	27.50
LSD (0.05)	ns	0.92	0.81

*ns= non-significant

Besides increasing grain and biomass yield, the treatment with the recommended NPS boron blend rate (100kg ha-1) and with CP-29 rhizobium strain gave the highest total nodule score per plant (34.57), active nodule score per plant (29.37), number of pod per plant (39.88) and tallest height (112.6cm) in over locations analysis (Table 5). In the Becho district, the Natoli variety performed better concerning symbiotic parameters including total nodule number and active nodule score than the Habru variety even though the effect is non-significant in the Seya-Debrna Wayu district and over-location analysis.

Table 5. *Effect of Biofertilizer strains on collected nodule score, yield and yield components in over-location.*

Treatments	Tnod	Anod	Inod	SC	NPP	PH	BmY	GY	HI
Fertilizer/strain									
T1(NPSB +CP-11)	19.82b	16.69a	3.01a	14.33ab	29.38a	51.44b	8.67b	3.40b	0.47ab
T2(NPSB +Cp-17)	23.48b	20.79ab	2.74a	14.00ab	32.85a	87.33b	8.73b	3.43b	0.46b
T3(NPSB +CP-29)	34.57a	29.37a	4.79a	15.00a	39.88a	112.60a	11.26a	4.52a	0.53a
T4(NPSB)	18.88b	13.92b	4.94a	12.33b	33.15a	89.00b	8.90b	3.57b	0.47ab
T5 (control)	19.11b	15.57b	3.19a	9.99c	34.69a	81.88b	8.19b	2.97b	0.37c
LSD (5%)	11.05	10.13	ns	2.18	ns	3.69	2.06	0.81	0.07
Variety									
1 (Natoli)	9.96b	6.82a	3.11a	13.61a	31.35b	48.53b	8.29b	3.23b	0.46a
2 (Habru)	36.39a	31.71a	3.36a	12.64a	36.63a	52.73a	10.01a	3.93a	0.46a
LSD (5%)	6.99	ns	ns	ns	4.94	2.33	1.3	0.51	ns
Mean	23.17	19.27	3.73	13.13	33.99	50.63	9.05	3.58	0.46
CV(%)	57.71	63.6	76.27	20.05	27.78	8.81	27.17	27.5	18.23
Fert/Strain*var	ns	ns	ns	ns	ns	ns	ns	ns	ns

Tnod= total nodulation; Anod= Active nodule; Inod= Inactive nodule; SC= stand count; PH=plant height; NPP=no of pod per plant; BmY=biamas yield; GY=Grain yield; ns= non-significant

***Table 6**. Effect of Biofertilizer strains on collected yield components in Seya-Debrna Wayu district.*

Treatments	Tnod	Anod	Inod	SC	NPP	PH	BmY	GY	HI
Fertilizer/strain									
T1(NPSB +CP-11)	7.31bc	4.44b	2.63a	14.50a	35.79a	53.75b	9.27a	3.04a	0.37a
T2(NPSB +Cp-17)	9.19bc	6.47b	2.81a	13.67a	38.50a	52.04b	8.87a	2.75a	0.35ab
T3(NPSB +CP-29)	15.81a	13.56a	2.25a	15.40a	40.05a	59.10a	10.68a	3.31a	0.42a
T4(NPSB)	11.38ab	6.50b	4.88a	12.33a	37.96a	51.71b	9.27a	3.04a	0.38a
T5 (control)	6.11c	3.14b	2.98a	12.18a	34.85a	45.51b	8.95a	2.50a	0.26b
LSD (5%)	4.48	5.20	ns	ns	ns	3.71	ns	ns	0.10
Variety									
1 (Natoli)	9.35a	6.25a	2.99a	14.26a	33.98b	50.84b	8.40b	2.48b	0.34a
2 (Habru)	10.58a	7.39a	3.22a	12.97a	40.88a	54.01a	10.42a	3.38a	0.37a
LSD (5%)	ns	ns	ns	ns	5.86	2.34	1.41	0.67	ns
Mean	9.96	6.82	3.11	13.62	37.43	52.42	9.41	2.93	0.36
CV (%)	40.41	62.88	56.49	20.13	20.42	5.83	19.59	30.00	23.76
Fert/Strain*var	ns	ns	*	ns	ns	ns	ns	ns	ns

Tnod= total nodulation; Anod= Active nodule; Inod= Inactive nodule; SC= stand count; PH=plant height; NPP=no of pod per plant; BmY=biamas yield; GY=Grain yield; ns= non-significant

***Table 7**. Effect of Biofertilizer strains on collected yield components in Becho district.*

Treatments	Tnod	Anod	Inod	SC	NPP	PH	BmY	GY	HI
Fertilizer/strain									
T1(NPSB +CP-11)	32.33b	28.95b	3.39a	14.17a	22.96c	49.13b	8.07b	3.76b	0.56ab
T2(NPSB +Cp-17)	37.78ab	35.11ab	2.67a	14.33a	27.21bc	46.79b	8.60b	4.12b	0.57a
T3(NPSB CP-29)	53.33a	45.17a	7.33a	14.60a	39.7a	59.10a	11.84a	5.73a	0.64a
T4(NPSB)	26.39b	21.33b	5.00a	12.33a	28.33bc	47.79b	8.53b	4.11b	0.57a
T5 (control)	32.11b	28.00b	3.40a	7.79b	34.55ab	41.40c	7.42b	3.43b	0.48b
LSD (5%)	16.31	15.88	ns	2.97	9.92	3.54	2.26	0.92	0.09
Variety									
1 (Natoli)	43.88a	38.37a	4.90a	12.97a	28.1a	46.23b	8.18a	3.97a	0.58a
2 (Habru)	28.90b	25.05b	3.82a	12.32a	32.38a	51.46a	9.60b	4.49a	0.55a
LSD (5%)	10.32	10.05	ns	ns	ns	2.24	1.43	ns	ns
Mean	36.39	31.71	4.36	12.65	30.55	48.84	8.89	4.23	0.57
CV(%)	36.95	41.3	67.52	19.35	26.78	5.98	20.98	17.93	13.08
Fert/Strain*var	ns	ns	ns	ns	ns	ns	ns	ns	ns

Tnod= total nodulation; Anod= Active nodule; Inod= Inactive nodule; SC= stand count; PH=plant height; NPP=no of pod per plant; BmY=biomass yield; GY=Grain yield; ns= non-significant

4. Conclusion and Recommendations

As the result showed, Habru variety and treatment with NPS boron blend rate (100kg ha-1) and with CP-29 rhizobium strain gave significantly the highest grain yield, biomass, and collected yield components. On average, this treatment increased grain yield by 55.22% and 26.41% over the check which was neither inoculated with rhizobium nor fertilized with Phosphorus fertilizer and the check, which is uninoculated but with Phosphorus fertilizer respectively, indicating the possibility of boosting chickpea productivity for farmers with inoculant technology. Therefore, Habru variety with recommended NPS boron blend rate (100kg ha-1) and with CP-29 rhizobium strain can be recommended for further popularization in Seya-Debrna Wayu district, Becho district and areas with similar agro-ecologies in the country. The findings are based on two locations and one cropping season. Further studies using a combination of locations and seasons are required to generate more reliable information and wider recommendations.

Abbreviations

ANOVA	Analysis of Variance
AM	Arbuscular Mycorrhiza
BmY	Biomass Yield
CDS	College of Development Studies
CEC	Cation Exchange Capacity
CP	Chickpea
CSA	Central Statistical Authority
FAO	Food and Agriculture Organization
GY	Grain Yield
HI	Harvest Index
ILRI	International Livestock Research Institute
IPMS	Improving Productivity and Market Success
K2O	Potassium Oxide
LSD	Least Significant Difference
m.a.s.l.	Meters Above Sea Level
Mg	Milligram
MoA	Ministry of Agriculture
N	Nitrogen
N2	Nitrogen Gas
NPSB	Nitrogen, Phosphorus, Sulfur, Boron
OC	Organic Carbon
P	Phosphorus
PH	Plant Height
PROTA	Plant Resources of Tropical Africa
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
SC	Stand Count
TN	Total Nitrogen
Zn	Zinc

Acknowledgments

This work was supported by the Addis Ababa University Cluster CASCAPE project, a project under the Bilateral Ethiopian Netherlands Effort for Food Income & Trade (BENEFIT). Holeta Biotechnology Research Center also deserves special thanks for supplying elite rhizobium strains for free. The agriculture extension staff of the Becho and Seya-Debrna Wayu districts are also acknowledged for their unreserved support in fieldwork and data collection.

Author Contributions

Desalegn Regassa is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

References

[1] Ali, H., Khan, M. A., and Randhawa, S. A. (2004). Interactive effect of seed inoculation and Phosphorus application on growth and yield of chickpea (Cicer arietinum L.). International Journal of Agriculture and Biology, 6(1), 110-112.

[2] Anbessa, Y., and Bejiga, G. (2002). Evaluation of Ethiopian chickpea landraces for tolerance to drought. Genetic Resources and Crop Evolution, 49(6), 557-564.

[3] Ayaz, M., Ahmad, E., Sagoo, A. G., Ullah, I., Hussain, A., And Manzoor, M. (2010). Nodulation, grain yield and grain protein contents as affected by rhizobium inoculation and fertilizer placement in chickpea cultivar little-98.

[4] Bejiga, G., and van der Maesen, L. J. G. (2006). Cicer arietinum L. Plant Resources of Tropical Africa, 1, 42-46.

[5] Bejiga, G., van der Maesen, L. J. G., 2006. In: Brink, M., Belay, G. (Eds.), Cicer arietinum L. PROTA (Plant Resources of Tropical Africa/Ressources végétales de l’Afrique tropicale), Wageningen, Netherlands Accessed 27 November 2016.

[6] Belay, G. (2006). Cereals and pulses (Vol. 1). PROTA Foundation, Wageningen, Netherlands.

[7] Ben Romdhane, S., Aouani, M., Trabelsi, M., De Lajudie, P., Mhamdi, R., 2008. Selection of high nitrogen-fixing rhizobia nodulating chickpea (Cicer arietinum L.) for semi-arid Tunisia. J. Agron. Crop Sci. 194(6), 413–420.

[8] Bhuiyan, M. A. H., Khanam, D., Khatun, M. R. and Hassan, M. S., (1998). Effect of molybdenum, boron and Rhizobium on nodulation, growth and yield of chickpea. Bull. Inst. Trop. Agric., Kyushu Univ. 21: 1-7.

[9] CSA (Central Statistical Authority). Agricultural Sample Survey 2018/2019 (2011 E. C.), Volume I Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season). Statistical Bulletin 584, April 2017, Addis Ababa, Ethiopia, p. 14.

[10] Damiani, L., Marinski, J., Branca, T., Mali, M., Floqi, T., and Stylios, C. (2013). Environmental management strategy for improving the ecological status of SEE ports. In Proceedings of 2013 IAHR Congress. Tsinghua University Press, Beijing.

[11] D. L. Rudresh, M. K. Shivaprakash, and R. D. Prasad, "Effect of combined application of Rhizobium, Phosphate solubilizing bacterium and Trichoderma spp. on growth, nutrient uptake and yield of chickpea (Cicer parthenium L.)," Applied Soil Ecology, vol. 28, no. 2, pp. 139–146, 2005.

[12] Erman, M., Demir, S., Ocak, E., Tufenkci, S., Oguz, F. and Akkopru, A. (2011). Effects of Rhizobium, arbuscular mycorrhiza and whey applications on some properties in chickpea (Cicer arietinum L.) under irrigated and rainfed conditions 1-Yield, yield components, nodulation and AMF colonization. Field Crops Research. Vol. 122(1): 14-24.

[13] Eyasu Elias, 2016. Soils of the Ethiopian Highlands: Geomorphology and Properties. CASCAPE Project, ALTERA, Wageningen University and Research Centre (Wageningen UR). The Netherlands. 385pp.

[14] FAO, 2006a. Guideline for Soil Description. Fourth Edition. Food and Agriculture Organization of the United Nations. Rome, Italy. 110pp. FAO, 2006b. Fertilizer and Plant Nutrition Bulletin No 16. Food and Agriculture Organization of the United Nations, Rome, Italy.

[15] FAOSTAT. (2015). Retrieved May 21, 2016, from http://faostat3.fao.org/download/Q/QC/E

[16] Fikre, A., 2016. Progresses of chickpea research and development in Ethiopia. In: Korbu, L., Damte, T., Fikre, A. (Eds.), Harnessing Chickpea Value Chain for Nutrition Security and Commercialization of Smallholder Agriculture in Africa, Proceedings of a Workshop. 30th January–1st February 2014, Debre Zeit, Ethiopia. pp. 25–39. http://oar.icrisat.org/id/eprint/9977

[17] Funga, A., Chris, O., Ojiewo, O. C., Turoop, L., Githiri Stephen Mwangi, S. G., 2016. Symbiotic effectiveness of elite rhizobia strains nodulating Desi type chickpea (Cicer arietinum L.) varieties. J. Plant Sci. 4(4), 88–94. http://www.Sciencepublishinggroup.com/j/jps

[18] Gomez, K. A. and A. A. Gomez. 1984. Statistical Procedures for Agricultural Research. 2nd edition. John Willey & Sons Ltd., New York, USA. 680pp.

[19] Gupta, S. C. and Namdeo S. L., (1996). Effect of Rhizobium strains on symbiotic traits and grain yield of chickpea. Indian J. Pulses Res. 9(1): 94-95.

[20] Hazelton P. and B. Murphy, 2007. Interpreting Soil Test Results: What do all those Numbers Mean? CSIRO. Department of Natural Resources. 169 pp.

[21] ICARDA (2009). Project 4: Food legume improvement in Medium-term plan 2010–2012, pp. 98–128. Available at website: http://www.cgiar.org/our-research/crop-factsheets/chickpea/

[22] Khaitov, B., Kurbonov, A., Abdiev, A., Adilov, M., 2016. Effect of chickpea in association with Rhizobium to crop productivity and soil fertility. Eurasian J. Soil Sci. 5(2), 105–112.

[23] Landon J. R., 1991. Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Sub-tropics. Longman Scientific and Technical, 474pp.

[24] Mulongoy, K. (1995). Technical paper 2: Biological nitrogen fixation. Food and Agriculture Organization of the United Nations (FAO) Corporate Document Repository, ILRI Training Manual, 2.

[25] Namvar, A., Sharifi, R. S., 2011. Phenological and morphological response of chickpea (Cicer arietinum L.) to symbiotic and mineral nitrogen fertilization. Žemdirbystė (Agric.) 98(2), 121–130. https://www.cabdirect.org/cabdirect/abstract/ 20113272755

[26] Namvar A., Sharifi R. S., Sedghi M., Zakaria R. A., Khandan T. and Eskandarpour B., (2011). Study on the effects of organic and inorganic nitrogen fertilizer on yield, yield components and nodulation state of chickpea (Cicer arietinum L.). Communications in Soil Science and Plant Analysis. Vol. 42(9): 1097-1109.

[27] Newey, A. (2006). Litter carbon turnover with depth. Ph.D. Thesis, Australian National University, Canberra.

[28] P. C. Jain, P. S. Kushawaha, U. S. Dhakal, H. Khan, and S. M. Trivedi, "Response of chickpea (Cicer arietinum L.) to Phosphorus and biofertilizer," Legume Research, vol. 22, pp. 241–244, 1999.

[29] Ronner, E. and Giller, K. E. 2012. Background information on agronomy, farming systems, and ongoing projects on grain legumes in Ethiopia, www.N2Africa.org, 33 pp.

[30] Rudresh, D., Shivaprakash, M., & Prasad, R. (2005). "Effect of Combined Application of Rhizobium, Phosphate Solubilizing Bacterium and Trichoderma spp. on Growth, Nutrient Uptake and Yield of Chickpea (Cicer arietinum L.)". Applied Soil Ecology, 28(2), 139-146. https://doi.org/10.1016/j.apsoil.2004.07.005

[31] SAS (Statistical Analysis System) Software. 2009. Version 9.2. Inc. Carry, North Carolina, USA.

[32] Shiferaw, B., Teklewold, H., 2007. Structure and Functioning of Chickpea Markets in Ethiopia: Evidence Based on Analyses of Value Chains Linking Smallholders and Markets. Improving Productivity and Market Success (IPMS) of Ethiopian Farmers Project Working paper 6. ILRI (International Livestock Research Institute), Nairobi, Kenya 63 pp.

[33] Tena, W., Wolde-Meskel, E., Walley, F., 2016. Response of chickpea (Cicer arietinum L.) to inoculation with native and exotic Mesorhizobium strains in Southern Ethiopia. Afr. J. Biotechnol. 15(35), 1920–1929. http://dx.doi.org/10.5897/AJB2015.15060

[34] Togay, N., Togay, Y., Cimrin, K. M. and Turan, M. (2008). Effect of Rhizobium inoculation, sulfur and Phosphorus application on yield, yield components and nutrient uptake in chickpea (Cicer aretinum L.).

[35] Venkatachalam, B., (2008). Role of bio-fertilizers in organic farming: Organic farming in rain-fed agriculture: Central institute for dry land agriculture. Hyderabad. 85-95 Vol. 4(8).

Biography

Desalegn Regassa is an expert in agricultural development, landscape restoration, and environmental conservation, with extensive experience in plant breeding, seed technology, and sustainable agriculture. He has held senior roles in agronomy and field coordination, leading multi-stakeholder projects to advance smallholder farmers' welfare and promote sustainable practices, particularly in wetlands and rural economies. His research focuses on agroforestry, vermicompost production, and organic farming, and he has successfully developed and implemented large-scale projects that support resilient agricultural systems.