Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Evaluation of Different Rhizobial Strains of Faba Bean (V. Faba) for Yield and Yield Components in Acid-Prone Areas: South Gondar Zone, Northwest Ethiopia

Getachew Yilma

getachewmk@gmail.com

Ethiopian Institute of Agricultural Research https://orcid.org/0009-0003-4738-6940

Banchamilak Bitew

Tesema Minale

Research Article

Keywords: Acid soil, Biological nitrogen fixation, Faba bean, Lime, Nodulation, Rhizobium, Symbiotic efficiency, Sustainable agriculture

Posted Date: November 3rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10574542/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Abstract

Aims

Soil acidity constrains faba bean (Vicia faba L.) productivity in the Ethiopian highlands by increasing aluminum toxicity and suppressing biological nitrogen fixation. Although liming is a well-established amendment, its interaction with elite rhizobial inoculants under farmers' field conditions remains poorly documented. This study aimed to evaluate the performance of nine rhizobial strains under limed and unlimed conditions on nodulation, growth, biomass, and grain yield of faba bean.

Methods

A split-plot trial with three replications was conducted over three cropping seasons in Farta and Guna Begemidir districts, South Gondar Zone, Ethiopia. Lime served as the main-plot factor and rhizobial inoculation as the subplot factor.

Results

Lime application significantly increased grain yield by 17.6% (2329 vs. 1980 kg ha^{-1}), along with biomass yield, plant height, nodule number, and nodule dry weight. Rhizobial strains differed significantly in symbiotic effectiveness, with strain FB-15 giving the highest grain yield (2467 kg ha^{-1}), biomass yield (6846 kg ha^{-1}), nodule number (51.9 plant^{-1}), and nodule dry weight (1.90 g plant^{-1}). Significant lime × strain interactions for grain yield, plant height, nodulation, and nodule dry weight indicated that inoculant performance depended on soil acidity status: FB-15 performed best under limed conditions (2889 kg ha^{-1}), while FB NS-03 outperformed other strains without lime (2536 kg ha^{-1}). The negative control consistently gave the lowest values across all parameters.

Conclusions

Combining lime with efficient rhizobial inoculation substantially enhances biological nitrogen fixation and faba bean productivity in acidic soils. FB NS-03 offers farmers a viable alternative where lime is unavailable.

INTRODUCTION

Faba bean (*Vicia faba* L.) is one of the most important protein-rich cool-season grain legumes cultivated in the Ethiopian highlands and other temperate and Mediterranean agroecosystems. Ethiopia is the largest producer of faba bean in Africa and consistently ranks among the world's leading producers, second only to China in recent years[1, 2]

The crop contributes to household food security, income generation, livestock feed, and sustainable cropping systems due to its high-quality protein content and its ability to establish an efficient symbiotic association with nitrogen- fixing rhizobia [3, 4].

Through biological nitrogen fixation (BNF), faba bean can meet a large proportion of its nitrogen requirement, thereby reducing the dependence on synthetic nitrogen fertilizers, improving soil fertility, and contributing residual nitrogen to subsequent cereal crops in rotation [3, 5, 6].

Ethiopia accounts for a major share of African faba bean production, highlighting the crop's strategic importance for food security and sustainable agricultural development in the region.

Despite its importance, national average productivity remains considerably lower than the attainable yield [7]. One of the principal causes is strong soil acidity in Ethiopian highlands. About 43% of the Ethiopian cultivated land is estimated to be affected by soil acidity, particularly in humid and subhumid regions which receive high annual rainfall [8].

Soil acidity reduces crop yield and productivity by inducing aluminum (Al^{3+}) and manganese toxicity while decreasing the availability of essential nutrients including phosphorus, calcium, magnesium, and molybdenum. These constraints adversely affect root development, microbial activity, nodulation, and nitrogen fixation in legume crops like faba bean[9].

Biological nitrogen fixation is particularly sensitive to acidic soil conditions. Low soil pH inhibits rhizobial survival, infection, and nodule development, ultimately reducing nitrogenase activity[10, 11]. Aluminum toxicity can damage root hairs, preventing successful rhizobial infection[10, 12], while phosphorus deficiency limits the energy required for nitrogen fixation. Consequently, indigenous rhizobial populations in acidic soils often exhibit poor symbiotic effectiveness, resulting in reduced crop performance.

Liming is regarded as one of the most effective strategies for ameliorating acidic soils. The application of agricultural lime neutralizes soil acidity, decreases exchangeable aluminum, enhances nutrient availability, stimulates microbial activity, and creates favorable conditions for effective nodulation[12, 13]. Numerous studies have demonstrated that liming significantly improves legume growth and nitrogen fixation; however, responses vary depending on soil characteristics, environmental conditions, and rhizobial strain compatibility[13–15].

Rhizobial inoculation has emerged as an environmentally friendly and cost-effective technology for enhancing biological nitrogen fixation[11, 16]. Modern elite strains differ considerably in competitiveness, survival, infectivity, and nitrogen-fixing efficiency. Selecting strains that perform well under acidic conditions, particularly when integrated with lime application, is therefore essential for maximizing productivity[17, 18]. Although several rhizobial strains have been developed for faba bean in Ethiopia, comparative evaluations under limed and unlimed acidic soils remain limited, particularly under multi-location and multi-year field conditions[15, 19].

The interaction between soil amendment and microbial inoculation is increasingly recognized as an important component of climate-smart and sustainable agriculture. Integrating lime with highly efficient rhizobial inoculants may provide synergistic benefits by simultaneously correcting soil acidity and improving biological nitrogen fixation. However, information regarding the consistency of strain performance across contrasting acidity conditions is still inadequate.

Therefore, the present study aimed to evaluate the performance of different rhizobial strains under limed and unlimed soil conditions in acidic highland environments of northwestern Ethiopia. Specifically, the study sought to (i). determine the effects of lime on nodulation, growth, biomass production, and grain yield of faba bean; (ii). compare the symbiotic effectiveness of selected rhizobial strains; and (iii) assess the interaction between lime application and rhizobial inoculation for improving faba bean productivity under acidic soil conditions.

Materials and Methods

Description of the Study Area

The study was conducted in Farta and Guna Begemidir districts of south Gondar zone, Amhara region, northwestern Ethiopia. The experiments were established at Debre Tabor Sub-station and selected farmers field representing the major faba bean-growing areas affected by soil acidity. The study area is 665 km from the capital city Addis Ababa at an altitude ranging from 2584 to 2853 masl.

The geographical coordinate of south Gondar zone extend between $37^{o}45'0"$-$38^{o}50'0"$ E and $11^{o}16'0"$ to $12^{o}18'0"$ N (Fig. 1). It is characterized by cool subhumid highland with a unimodal rainfall pattern extending from June to September. The long-term annual rainfall ranges between 900 and 1600 mm with an average of 1300 mm.

The dominant soil type of the experiment is Nitisol, which is characterized by strong acidity, moderate organic matter content and high phosphorus fixation capacity. Soil acidity is one of the principal limiting constraints of faba bean productivity because of aluminum toxicity, reduced phosphorus availability, and impaired biological nitrogen fixation.

Experimental Materials

We used an improved faba bean variety (*Wolki*) and 7 faba bean rhizobial strains including negative and positive controls. The negative control is without any input while, the positive control is a treatment with chemical fertilizers for N and P sources (Table 1). Agricultural lime (CaCO3) was used to ameliorate soil acidity. The rhizobial strains were collected from Holeta Agricultural Research Center. Rhizobial inoculants were peat-based formulation containing approximately $1.4*10^{8}$ viable cells per gram. Lime was added using the formula below.

Experimental Design

The experiment was laid out as a split-plot arrangement in a randomized complete block design with three replications. Lime was considered as a main plot, while strains were assigned as subplots. Lime levels were with and without lime, which were denoted L_1 and $L_{0,}$ respectively.

In the subplot treatments, nine rhizobial strains were included as shown in Table 1.

Table 1
Treatment arrangement

Main plot	Sub plots								
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**
Lime 0	-ve Control	FB-1018	FB-1017	FB-NS-03	FB-04	FB-15	FB-EM-11	FB-1035	+ve control
Lime 1	-ve Control	FB-1018	FB-1017	FB-NS-03	FB-04	FB-15	FB-EM-11	FB-1035	+ve control

Individual subplot size was 2.5m *2.8 m, a row spacing of 40cm and 10cm between plants. The harvesting area excluded border rows at each side of the plot to minimize edge effects. Each treatment was replicated three times.

Lime Application

Agricultural lime calcium carbonate was applied to each plot based on the formula stated by [20]

$$LR\ (CaCO3) = \frac{EA\ (cmol/kg\ of soil * 0.15m * 10000m2 * BD(g/cm3) * 1000}{2000} * 1.5$$

where LR=Lime requirement, EA= Exchangeable acidity, BD=Bulk density g/cm^3, 1.5 a crop factor (CF), 0.15 m is the soil depth.

Seed Inoculation and Planting

The selected faba bean variety was coated with the corresponding rhizobial inoculant by using table sugar as an adhesive agent to ensure uniform distribution of inoculants on the seed surface. Immediately after inoculation, the seeds were sown on the prepared rows and covered with soil to avoid direct sunlight contact of the rhizobia. The spacing between each seed was 10 cm.

Crop Management

Phosphorus fertilizer was added uniformly based on the national blanket recommendation of 100 kg DAP/ha, which contains 46 kg of P2O5 and 18 kg of N for all treatments except the negative control. 18 kg of N from DAP is used as a starter nitrogen for nodulation and N fixation. Weed management was done by hand weeding throughout the growing season to avoid weed competition.

Data Collection

Plant height, nodule number, and nodule dry weight, pod number and seed per pod were collected by randomly selecting 5 plants per each plot. Seed yield and above ground biomass was measured by fully harvesting the plot except the two border rows.

Statistical Analysis

The trial was conducted as a split-plot arrangement within a randomized complete block design at each of the two locations (Farta and Guna Begemidir) over three consecutive cropping seasons, with lime application as the main-plot factor and rhizobial strain as the subplot factor. Because data were generated across multiple seasons and locations, a combined analysis of variance was performed with season-location combination (hereafter "environment") treated as a random effect, and replications treated as random and nested within environment. Homogeneity of error variances across environments was checked (Levene's test) prior to combining the data; where a significant environment interaction was detected, results are reported and interpreted with this interaction in mind rather than as a single pooled mean. Treatment means were separated using Tukey's Honestly Significant Difference (HSD) test at the 1% probability level.

The statistical model of the experiment is:

$$Y_{ijkl} = \mu + E_i + R_{j(i)} + L_k + (EL)_{ik} + \delta_{ij(k)} + S_l + (ES)_{il} + (LS)_{kl} + (ELS)_{ikl} + \varepsilon_{ijkl}$$

where: Y_{ijkl} = observed value, μ = overall mean, E_i = effect of environment (season-location combination, random), $R_{j(i)}$ = effect of replication nested within environment (random), L_k = effect of lime, $(EL)_{ik}$ = environment × lime interaction, $\delta_{ij(k)}$ = main-plot error, S_l = effect of rhizobial strain, $(ES)_{il}$ = environment × strain interaction, $(LS)_{kl}$ = lime × strain interaction, $(ELS)_{ikl}$ = environment × lime × strain interaction, and ε_{ijkl} = subplot (residual) error.

All statistical analyses were performed using Statistical Analysis Software (SAS Institute Inc., Cary, NC, USA) version 9.4, with the combined analysis of variance across environments carried out using PROC MIXED, treating environment and replication (nested within environment) as random effects and lime, strain, and their interactions as fixed effects. Statistical significance were declared at $P \leq 0.05$ while mean separation was done at $P \leq 0.01$.

Results

Main Effect of Lime Application on Growth, Nodulation and Yield of Faba Bean

Table 2
Separate effects of lime and rhizobia on faba bean yield and yield components.

Lime	Grain Yield kg ha^{-1}	Biomass kg ha^{-1}	Plant height (cm)	Nodule Number /plant	Nodule Dry weight (g plant^{-1})
L1	2329a	5810a	108.4a	47.9a	1.7a
L0	1980b	5229b	99.8b	43.2b	1.6b
CV	3.1	3.83	2.04	3.04	3.2
MSD	19.34	61.106	0.6136	0.3994	0.0155
Treatments					
-ve Control	1586g	4147g	101.4c	33.4g	1.24g
FB-1018	2411ab	6391b	108.4a	51.0ab	1.87ab
FB-1017	1962e	4943e	101.3c	41.7e	1.53e
FB-NS-03	2283c	4790ef	105.6b	48.4c	1.8c
FB-04	2362b	6054c	105.3b	50.0b	1.83bc
FB-15	2467a	6846a	105.4b	51.9a	1.9a
FB-EM-11	2079d	5938cd	102.3c	43.7d	1.6d
FB-1035	2370b	5840d	105.7b	50.1b	1.84bc
+ve control	1872f	4729f	101.7c	39.7f	1.44f
CV	3.1	3.83	2.04	3.04	3.2
MSD	57.546	181.82	1.8258	1.1886	0.0461

CV=Coefficient of variance, MSD=Minimum significant difference. Means with similar letter within the same column did not show significant difference.

Lime application significantly ($P \leq 0.01$) improved all measured agronomic and nodulation parameters of faba bean compared with the unlimed treatment (Table 2). Grain yield increased from 1,980 kg ha^{-1} under unlimed conditions to 2,329 kg ha^{-1} following lime application, representing a yield improvement of approximately 17.6%. Similarly, biomass yield increased by about 11.1%, while plant height increased by approximately 8.6%. Nodulation also responded positively to liming, with nodule number increasing from 43.2 to 47.9 nodules plant^{-1}, accompanied by a significant increase in nodule dry weight (Table 2).

Performance of Rhizobial Strains

Highly significant differences ($P \leq 0.01$) were observed among the rhizobial strains for grain yield, biomass yield, plant height, nodule number, and nodule dry weight, indicating considerable variation in symbiotic effectiveness among inoculants.

Among the evaluated inoculants, FB-15 produced the highest grain yield (2,467 kg ha^{-1}), followed by FB-1018 and FB-04. In contrast, the uninoculated negative control recorded the lowest grain yield (1,586 kg ha^{-1}). Biomass yield exhibited a similar trend, with FB-15 producing the greatest above-ground biomass (6,846 kg ha^{-1}), whereas the negative control produced only 4,147 kg ha^{-1}.

Rhizobial strains also differed significantly in their ability to induce nodulation. FB-15 recorded the highest number of nodules (51.9 nodules $plant^{-1}$) together with the greatest nodule dry weight (1.90 g $plant^{-1}$). The negative control consistently produced the fewest nodules and the lowest nodule dry weight.

Interaction Between Lime and Rhizobial Strains

Table 3
Interaction effect of lime and rhizobial strains on faba bean yield and yield components.

Lime Level	Strain	Grain Yield kg ha^{-1}	Biomass kg ha^{-1}	Plant height (cm)	Nodule Number/plant	Nodule Dry weight (g plant^{-1})
L0	-ve Control	1429 ± 150.9h	3929 ± 513.9	97.1 ± 2.5g	31 ± 3.1i	1.20 ± 0.11h
	FB-1018	2127 ± 12.4ef	6055 ± 507.1	101.1 ± 3.3f	47 ± 0.5ef	1.80 ± 0.05de
	FB-1017	1836 ± 45.8fg	4683 ± 452.8	97.6 ± 1.2g	40 ± 0.9gh	1.50 ± 0.06fg
	FB-NS-03	2536 ± 157.5c	4538 ± 293.0	103.8 ± 2.9e	55 ± 3.5b	2.10 ± 0.13b
	FB-04	2173 ± 16.4de	5735 ± 314.5	99.2 ± 1.9fg	48 ± 0.5e	1.80 ± 0.00d
	FB-15	2045 ± 49.8f	6486 ± 516.9	100.4 ± 3.6fg	45 ± 1.3f	1.70 ± 0.05e
	FB-EM-11	1653 ± 39.7g	5626 ± 172.0	98.1 ± 1.3g	36 ± 1.1h	1.30 ± 0.05g
	FB-1035	2277 ± 47.7d	5533 ± 305.2	102.9 ± 3.5e	50 ± 0.6d	1.90 ± 0.05c
	+ve control	1744 ± 25.6g	4480 ± 275.3	97.7 ± 1.4g	38 ± 0.8gh	1.40 ± 0.00fg
L1	-ve Control	1743 ± 212.1g	4366 ± 571.0	105.6 ± 2.3de	36 ± 4.2h	1.30 ± 0.16g
	FB-1018	2695 ± 223.7b	6728 ± 563.4	115.7 ± 2.5a	55 ± 4.6b	2.00 ± 0.16bc
	FB-1017	2088 ± 199.3f	5203 ± 503.1	105.1 ± 1.8de	43 ± 4.1g	1.50 ± 0.15f
	FB-NS-03	2031 ± 116.5f	5042 ± 325.5	107.3 ± 1.2cd	42 ± 2.4g	1.50 ± 0.08f
	FB-04	2551 ± 136.5c	6372 ± 349.5	111.4 ± 1.8b	53 ± 2.9c	1.90 ± 0.12c
	FB-15	2889 ± 225.5a	7206 ± 574.3	110.3 ± 1.2bc	59 ± 4.6a	2.10 ± 0.16a
	FB-EM-11	2504 ± 72.2c	6251 ± 191.1	106.4 ± 1.5cd	51 ± 1.4d	1.90 ± 0.06c
	FB-1035	2464 ± 135.3c	6148 ± 339.2	108.4 ± 1.8c	51 ± 2.7d	1.80 ± 0.09d

Lime Level	Strain	Grain Yield kg ha⁻¹	Biomass kg ha⁻¹	Plant height (cm)	Nodule Number/plant	Nodule Dry weight (g plant⁻¹)
	+ve control	2000 ± 123.5f	4978 ± 305.9	105.7 ± 1.9de	41 ± 2.5g	1.50 ± 0.08f
CV (%)		3.11	3.83	2.04	3.04	3.21
MSD (P ≤ 0.01)		124.5	ns	2.15	2.8	0.12

Means followed by the same lowercase letter within a column for each variable are not significantly different (P ≤ 0.01) based on Tukey's HSD test. CV: Coefficient of Variation; MSD: Minimum Significant Difference; ns: not significant (Biomass Yield interaction was not significant, P = 0.079).

The interaction between lime application and rhizobial inoculation significantly affected grain yield, plant height, nodule number, and nodule dry weight, whereas biomass yield was not significantly influenced by the interaction (P = 0.079).

Among all treatment combinations, lime + FB-15 achieved the highest grain yield (2,889 kg ha⁻¹), highest biomass yield (7,206 kg ha⁻¹), greatest nodule number (59 nodules plant⁻¹), and one of the highest nodule dry weights (2.10 g plant⁻¹). Under unlimed conditions, FB-NS-03 gave the highest grain yield (2,536 kg ha⁻¹) among the non-limed treatments. The unlimed negative control produced the lowest grain yield of all treatment combinations (1,429 kg ha⁻¹).

Relationship Between Nodulation and Grain Yield

Treatments that produced larger nodule numbers and greater nodule dry weight generally also achieved higher grain yields, indicating a positive association between nodulation parameters and grain yield across treatments

Effect of Lime on Growth, Nodulation and Yield of Faba Bean

Similarly [15] reported that lime application can significantly increase faba bean biomass and grain yield. [21]also summarized that application of lime can improve faba bean yield from 29–53%. The improvement in grain yield under limed conditions is primarily attributable to the amelioration of soil acidity. Acidic soils are characterized by high concentrations of exchangeable aluminum (Al^{3+}) and manganese (Mn^{2+}), which inhibit root elongation and restrict nutrient uptake. Lime application neutralizes exchangeable acidity, reduces aluminum toxicity, and increases soil pH, thereby improving the availability of essential nutrients such as phosphorus, calcium, magnesium, and molybdenum. These changes promote healthier root systems, greater nutrient acquisition, and enhanced plant growth[22].

Improved nodulation observed under limed conditions further explains the increased productivity. Rhizobial survival and infection are highly sensitive to acidic environments. Increasing soil pH creates a

more favorable environment for rhizobial multiplication, root hair infection, and nodule development. Enhanced nodulation ultimately improves biological nitrogen fixation, supplying additional nitrogen for vegetative growth and grain filling.

The present findings are consistent with previous reports demonstrating that liming acidic soils substantially improves legume productivity through enhanced nutrient availability and biological nitrogen fixation. Similar positive responses have been reported for faba bean, soybean, chickpea, and common bean cultivated in acidic tropical soils[23, 24].

Performance of Rhizobial Strains

Several research results also support this result, showing that inoculation of faba bean with different rhizobial strains can improve nodulation and grain yield[25–29]

The observed variability among strains likely reflects differences in rhizobial competitiveness, survival under acidic conditions, root colonization efficiency, infection success, nitrogenase activity, and compatibility with the host genotype. Elite strains generally possess greater tolerance to environmental stresses and exhibit superior nitrogen-fixing capacity compared with native rhizobial populations. This is consistent with the poor performance of the negative control, which indicates that indigenous rhizobial populations alone were insufficient to maximize nitrogen fixation and crop productivity under the experimental conditions.

Interaction Between Lime and Rhizobial Strains

These results demonstrate the synergistic effect of integrating soil acidity amelioration with biological nitrogen fixation. Liming improves the soil environment, while elite rhizobial strains exploit the improved conditions to establish more effective symbioses. Enhanced nodulation increases atmospheric nitrogen fixation, providing additional nitrogen to support biomass accumulation and grain production.

Similarly [28]reported that FB-15 can give significantly higher yield than the positive and negative controls. In the absence of lime, strain FB-NS-03 also gave significantly higher grain yield than other non-lime-treated treatments; a similar result was reported by[27]

The absence of a significant interaction for biomass yield suggests that biomass production was influenced primarily by the independent effects of lime and rhizobial inoculation rather than by their combined interaction. Nevertheless, the numerical increases observed under the combined treatments indicate clear agronomic advantages.

Relationship Between Nodulation and Grain Yield

The positive association between nodule number, nodule dry weight, and grain yield observed in this study suggests that improved biological nitrogen fixation contributed substantially to enhanced crop productivity. Nodule dry weight is often considered a more reliable indicator of nitrogen fixation potential than nodule number because larger nodules usually contain more active nitrogen-fixing tissue. The

superior performance of FB-15 under limed conditions therefore reflects both increased nodulation and improved nodule functionality.

Improved nitrogen availability resulting from effective symbiosis likely enhanced chlorophyll synthesis, photosynthetic activity, protein accumulation, and assimilate translocation during reproductive growth, ultimately increasing grain yield [30–32]

Agronomic Implications

The findings demonstrate that correcting soil acidity alone can substantially improve faba bean productivity; however, combining lime application with elite rhizobial inoculation provides considerably greater benefits[33]. In the acidic highlands of Ethiopia, where aluminum toxicity and phosphorus fixation severely constrain biological nitrogen fixation, integrated soil fertility management should include both chemical amelioration and microbial inoculation[34]. However, in situations where agricultural lime is not available, some rhizobial strains can tolerate soil acidity and give significant nodulation and better grain yield than other isolates[34]. Therefore, faba bean producer farmers can have an alternative rhizobial strain in the case of lime unaffordability.

Among the tested inoculants, FB-15 consistently exhibited superior performance across measured traits, indicating strong adaptation to the experimental environments and high symbiotic efficiency under liming. FB-NS-03 was also a moderately effective rhizobial strain that gave a competitive grain yield without lime. These strains therefore represent promising candidates for large-scale dissemination in acid-prone faba bean-growing areas following further multi-environment validation.

Study Limitations

The limitation of the present study should be noted. First, baseline soil chemical properties (Total nitrogen, organic carbon, and available phosphorus) for the experimental sites were not characterized in this study; reporting these values would have strengthened the interpretation of the acidity-amelioration effects observed and is recommended for future trials at these sites. Second, the trial was conducted using a single improved faba bean variety (Wolki), so the generalizability of strain performance to other faba bean varieties grown in the region remains to be confirmed through further multi-variety testing.

Conclusion

Collectively, the results indicate that both lime application and rhizobial inoculation independently enhanced faba bean growth, nodulation, biomass accumulation, and grain yield. Their combined application generated the greatest agronomic benefits, emphasizing the importance of integrating soil acidity management with biological nitrogen fixation technologies. These findings support the development of integrated soil fertility management strategies aimed at improving productivity while reducing dependence on mineral nitrogen fertilizers in the Ethiopian highlands.

Declarations

Conflict of interest

Authors of this paper declare that they have no conflict of interest between them.

Funding

This research was conducted by the financial support of the Ethiopian Institute of Agricultural Research.

Authors contribution

Getachew Yilma wrote the first draft of the manuscript and conducted data collection and analysis. Banchamlak Bitew and Tesema Minale also reviewed the draft and added valuable comments. Both authors conducted the research together with the corresponding author.

Acknowledgement

We gratefully acknowledge the Ethiopian Institute of Agricultural Research for the financial support of this research. We also want to express our gratitude to the Fogera National Rice Research and Training Center for allowing the facilities to carry out this research work.

Availability of data

The data generated and analyzed during the current study are available from the corresponding author on reasonable request.

References

1. Zewide I, Ademe A (2025) Unlocking faba bean (Vicia faba L.) potential: How cattle manure and fertilizer boost yields in Kaffa Zone, South-Western Ethiopia. Heliyon 11
2. Crépon K et al (2010) Nutritional value of faba bean (Vicia faba L.) seeds for feed and food. Field crops Res 115:329–339
3. Jithesh T et al (2024) Recent progress and potential future directions to enhance biological nitrogen fixation in faba bean (Vicia faba L). Plant-Environment Interact 5:e10145
4. Merga B, Egigu MC, Wakgari (2019) M Reconsidering the economic and nutritional importance of faba bean in Ethiopian context. Cogent Food Agric 5:1683938

5. Jensen ES et al (2012) Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review. Agron Sustain Dev 32:329–364
6. Peoples Má et al (2009) The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. Symbiosis 48:1–17
7. Keneni G, Fikre A, Eshete M (2016) Reflections on highland pulses improvement research in Ethiopia. Ethiop J Agric Sci, 17–50
8. Yirga C, Erkossa T, Agegnehu G (2019) (Ethiopian Institute of Agricultural Research, Addis Ababa, Ethipia
9. Agegnehu G, Yirga C, Erkossa T (2019) Soil acidity management
10. Wood M, Cooper J, Holding A (1984) Aluminium toxicity and nodulation of Trifolium repens. Plant Soil 78:381–391
11. Kebede E (2021) Competency of rhizobial inoculation in sustainable agricultural production and biocontrol of plant diseases. Front Sustainable Food Syst 5:728014
12. Jaiswal SK, Naamala J, Dakora FD (2018) Nature and mechanisms of aluminium toxicity, tolerance and amelioration in symbiotic legumes and rhizobia. Biol Fertil Soils 54:309–318
13. Fekadu E, Kibret K, Melese A, Bedadi B (2018) Yield of faba bean (Vicia faba L.) as affected by lime, mineral P, farmyard manure, compost and rhizobium in acid soil of Lay Gayint District, northwestern highlands of Ethiopia. Agric Food Secur 7:16
14. Gedamu SA, Tsegaye EA, Beyene TF (2021) Effect of rhizobial inoculants on yield and yield components of faba bean (Vicia fabae L.) on vertisol of Wereillu District, South Wollo, Ethiopia. CABI Agric Bioscience 2:8
15. Geleta D, Bekele G (2022) Yield response of Faba bean to lime, NPSB, and rhizobium inoculation in Kiremu District, Western Ethiopia. *Applied and Environmental Soil Science* 3208922 (2022)
16. Prasad B, Kumar P, Dubey RC (2026) Advances in rhizobial technology: driving sustainable agriculture in the 21 st century. Arch Microbiol 208:81
17. Mendoza-Suárez MA et al (2020) Optimizing Rhizobium-legume symbioses by simultaneous measurement of rhizobial competitiveness and N2 fixation in nodules. *Proceedings of the National Academy of Sciences* 117, 9822–9831
18. Checcucci A, DiCenzo GC, Bazzicalupo M, Mengoni A (2017) Trade, diplomacy, and warfare: the quest for elite rhizobia inoculant strains. Front Microbiol 8:2207
19. Geremu T, Abera G, Lemma B, Rasche F (2025) Abundance and symbiotic efficiency of indigenous rhizobia nodulating faba bean and common bean in southern Ethiopia. Front Soil Sci 5:1568292
20. Agumas B et al (2016) Effect of lime and Phosphorus on soil health and bread wheat productivity on acidic soils of South Gonder. Amhara Reg Agricultural Res Inst (ARARI)
21. Agegnehu G et al (2021) Extent and management of acid soils for sustainable crop production system in the tropical agroecosystems: a review. Acta Agriculturae Scand Sect B—Soil Plant Sci 71:852–869

22. Enesi RO et al (2023) Liming remediates soil acidity and improves crop yield and profitability-a meta-analysis. Front Agron 5:1194896
23. Fekadu E, Kibret K, Melese A (2019) Integrated acid soil management for growth, nodulation, and nutrient uptake of faba bean (Vicia faba L.) in Lay Gayint District, Northwestern Highlands of Ethiopia. *International Journal of Agronomy* 7498518 (2019)
24. Tadesse N, Yoseph T, Demrew Z (2025) Agronomic performances of Faba bean (Vicia faba L.) varieties to Rhizobial inoculation, biochar and lime applications under acidic soil conditions in Ethiopia. Food Energy Secur 14:e70091
25. Habetamu Getinet KA (2024) Evaluating Yield response of fababean (Vicia faba L.) through integrated use of Rhizobium strains and lime on acidic soils of Anded district northwestern Ethiopia. Afr J Agric Res 12:72–78
26. Eshetu M, Chimdessa C, Sebboka S, Bedaso N, Chibsa T (2018) Evaluation of Best Performing Indigenous Rhizobium Inoculants for Faba Bean Production at Goba and Sinana District of Bale Highland South Eastern Ethiopia
27. Bekele M, Yilma G (2019) Evaluation of Rhizobial Strain of Faba Bean for Symbiotic Performance Grown in Acid-Prone Areas. Guagusa Shekudad District
28. Negash S, Elema R, Tolosa A (2023) in Reg Rev Workshop Completed Res Activities 151
29. Mebrahtu S (2024) Evaluation of the Effects of Rhizobia on Nodulation, Yield and Yield Components of Faba Bean. Asian Soil Res J 8:104–110
30. Dwivedi SL et al (2015) Advances in host plant and rhizobium genomics to enhance symbiotic nitrogen fixation in grain legumes. Adv Agron 129:1–116
31. Zayed O et al (2023) Nitrogen journey in plants: From uptake to metabolism, stress response, and microbe interaction. Biomolecules 13:1443
32. Jaiswal SK, Mohammed M, Ibny FY, Dakora FD (2021) Rhizobia as a source of plant growth-promoting molecules: potential applications and possible operational mechanisms. Front Sustainable Food Syst 4:619676
33. Agegnehu G, Nelson PN, Bird MI (2016) Crop yield, plant nutrient uptake and soil physicochemical properties under organic soil amendments and nitrogen fertilization on Nitisols. Soil Tillage Res 160:1–13
34. Alemayehu D, Dechassa N (2022) Inoculating faba bean seed with rhizobium bacteria increases the yield of the crop and saves farmers from the cost of applying phosphorus fertilizer. Int J Plant Prod 16:261–273

Figures

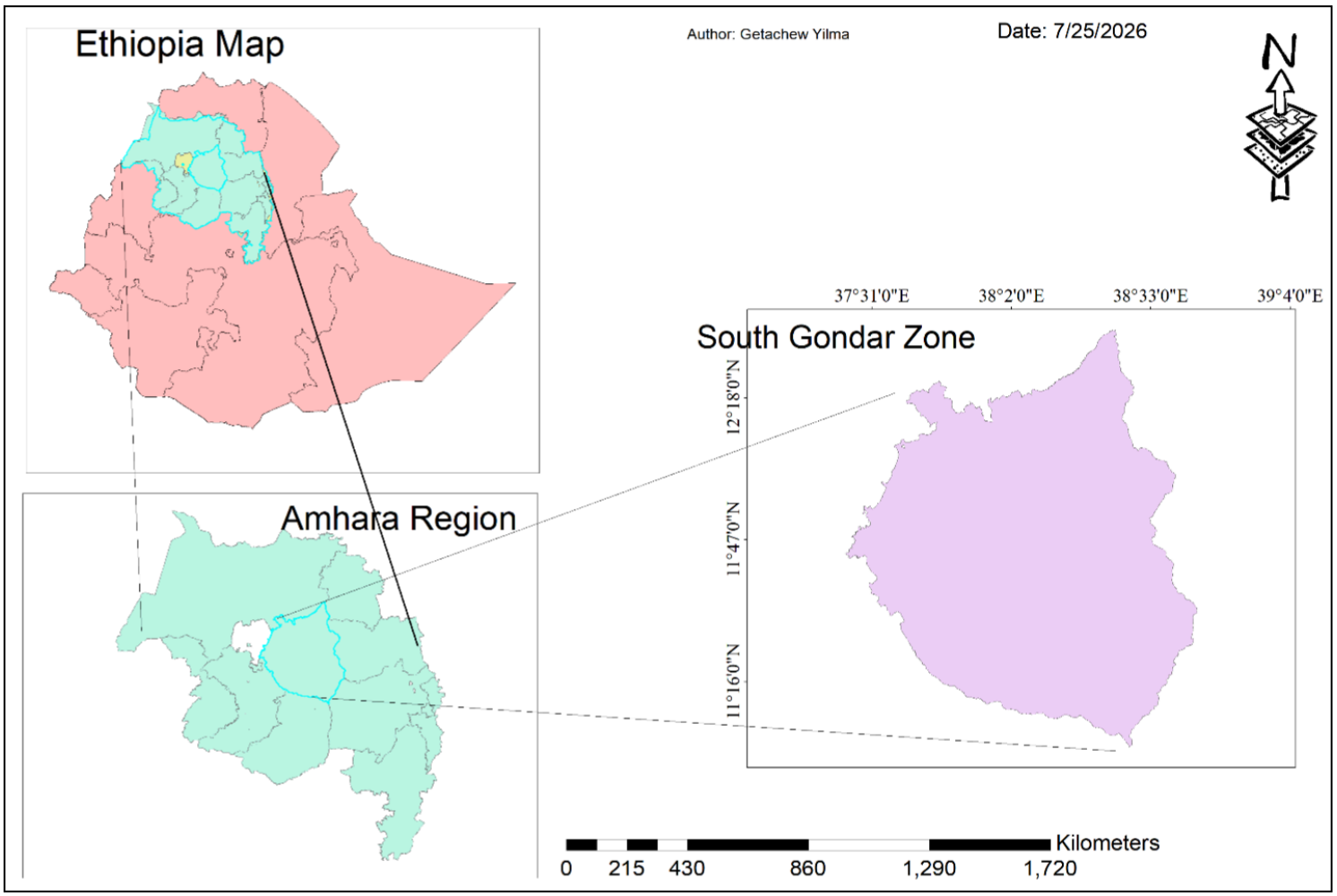


Figure 1

Location map of the study area developed by the author using ArcGIS.