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Article

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Posted Date: September 22nd, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10703594/v1>

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Additional Declarations: No competing interests reported.

Integrated Use of Blended NPSB Fertilizer and Biochar Rates for Enhancing Grain Yield of Faba Bean (*Vicia faba* L.) Varieties in Adiyo District, Kaffa Zone, Southwestern Ethiopia

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Abstract

Faba bean is a major pulse in Ethiopia. However, the country as a whole is still producing below potential level due to poor soil fertility and lack of availability of improved varieties. To investigate the impact of integration of organic and inorganic fertilizers along with the use of high, yielding varieties, experiments were set up in Boka Kebele, Adiyo District during the 2023 cropping season. Four faba bean varieties, Dosha, Gebelcho, Tumsa, and a local one, were subjected to tests for yield and yield components. The findings revealed that the varieties differed substantially in most yield and yield components. Adoption of high, yielding varieties such as Dosha and Gebelcho can lead to better productivity and profitability for farmers. These findings are of great significance to the small, scale farmers in Ethiopia who greatly depend on the cultivation of faba bean for their food and income needs. In the case of both limed and unlimed soil, Gebelcho had the highest number of pods per plant and 100, seed weight, whereas the local variety had the lowest. Gebelcho also resulted in the highest grain yield (4184 and 3483.7 kg ha⁻¹) by integrated application of 5 ton CHB + 50 kg NPSB, while the local variety gave the least (1226.3 and 948.7 kg ha⁻¹) on limed and unlimed soil, respectively. Based on these results, Gebelcho variety is an agro, ecologically suitable variety for faba bean growers in the study area. Additional research and extension work should be undertaken to disseminate the use of improved soil fertility management practices and high yielding varieties among Ethiopian farmers. At last, the nation stands to benefit greatly from faba bean production in terms of food security and economic development.

Keywords: Faba bean, Biochar, NPSB, Yields, Varieties, Acidic soils

1. INTRODUCTION

Faba bean (*Vicia faba* L.) remains a major source of food and feed worldwide. The main producers include China, Ethiopia, Australia and Egypt (Dhull et al., 2022). This species has significantly high protein content, with up to 25.4% protein (Adissie et al., 2020; Martineau Ct et al., 2022; Alemu & Wato, 2023). Over 60 countries grow faba beans and China is by far the largest producer, followed by Ethiopia, Egypt and the UK (Merga et al., 2019). Globally, faba bean ranks third in cultivated area and production among pulse crops after soybean and field pea (Adissie et al., 2020). Ethiopia is a secondary center of diversity for faba bean and is one of the top producing nations of this crop (FAO, 2016). The country produces 56% of Africa's faba bean crop and this legume is a major source of protein for many smallholder farmers living in the area

(Hailu et al., 2014; Alemu & Wato, 2023). During the 2020/2021 cropping season, around 4.5 million smallholder farmers produced 1, 078, 265.5 metric tons of faba bean from 518, 466.39 ha according to Hailu et al. (2014). In Ethiopia, this crop is mainly a source of protein but it also plays a role in improving soil fertility and livestock feed (Wondafrash et al., 2019). Faba bean not only gives small, scale farmers a way to earn money but it also brings in foreign currency to the country (Merga et al., 2019; Alemu & Wato, 2023). FAO (2016) states that Ethiopia is the world's fourth, largest exporter of faba bean with the capacity to export more if production increases significantly beyond domestic consumption (Eshetu, 2015). At present, the national average yield is 2.1 t ha⁻¹ (CSA, 2019), which is approximately 76.2 % lower than the average yield of 2.9 t ha⁻¹ in the leading producing countries (FAOSTAT, 2019). On the other hand, the release of faba bean varieties at research stations achieves yields of up to 3.5 t ha⁻¹ (NPC, 2016), demonstrating the large yield gap between farmer, managed and research, managed systems. The main factors that have limited the productivity of faba bean in Ethiopia are climatic conditions, genetic potential, edaphic factors (soil fertility and acidity), and biotic stresses (diseases, pests, and weeds) (Fekadu et al., 2019; Belachew et al., 2018; Wondafrash et al., 2019; Alemu & Wato, 2023). Soil fertility and acidity have been singled out in a number of studies as the main constraints to faba bean production in Ethiopia (Endalkachew et al., 2018; Getachew, 2018; Getahun & Abere, 2019; Alemu & Wato, 2023).

Soil acidity is one of the significant challenges to faba bean cultivation in Ethiopia (Tadele, 2020; Tadele & Shiferaw, 2022). Nearly 40% of the highland soils in the country are extremely low in organic carbon content (ATA, 2019). On the other hand, nitrogen, phosphorus, and potassium are severely depleted in acidic soils (Tsige et al., 2023), since essential nutrient elements such as phosphorus, calcium, magnesium, and molybdenum become less available (Beyene et al., 2023). Basically, soils with a pH level below 5.5 are deficient in macronutrients such as N, P, K, Ca, and Mg (Kaagul et al., 2023). Karkanis et al. (2018) also stated that a lower pH and the resulting nutrient deficiencies will limit the yield of faba beans. Moreover, soil organic matter and nutrient pools that support crop growth are significantly depleted (Wang et al., 2023). Excessive amounts of Al³⁺, Fe, and Mn also play a role in lowering faba bean yields in acidic environments (Huang et al., 2023). These negative impacts occur especially severely in legume plants since the disruption of complex host, microbe interactions plays a big part in it (Daemo et al., 2024). Due to faba bean's sensitivity to soil acidity, the crop has been removed from the production system in some parts of Ethiopia (Genanew et al., 2012). Local faba bean cultivars' genetically determined acidity sensitivity along with the resulting decrease in yield are thus, an additional limiting factor (Temesgen & Sefera, 2013; Alemayehu et al., 2025).

Studies in different locations of Ethiopia have generally found that topsoil in the highlands is very low in macronutrients especially N, P, and K (Abuye et al., 2021). Only about half of the nitrogen fertilizer applied becomes available to the plants, as nitrogen is temporarily immobilized in soil organic matter and lost through leaching, erosion, nitrification, or volatilization (Tsige et al., 2023). Besides this, phosphorus is another major limiting nutrient in Ethiopian soils. The main reason for this is that soils have a high ability to fix phosphorus and parent materials is inherently low in phosphorus, which was also a factor here (Mesfin et al., 2020).

Management practices for faba bean production have been thoroughly discussed in literature (Agegnehu & Yirga, 2009; Getachew, 2018; Mesfin et al., 2020; Alemu & Wato, 2023). Endalkachew et al. (2019) and Negasa et al. (2019) have come up with a report on grain yield increment resulting from the use of organic, inorganic, and biofertilizers. On the other hand, the use of improved varieties, crop rotation, residue management, and fallowing have also been proven to result in increased grain yield (Getnet & Yehizbalem, 2017). Studies conducted in various parts of the world have shown that liming enhances nutrient uptake and increases faba bean yield (Lukas et al., 2015; Zhao et al., 2018), which is in agreement with the findings from Ethiopian studies that have demonstrated growth and yield response of the crop to lime application (Fekadu et al., 2018; Asrat et al., 2020). Besides, applying lime helps in releasing phosphorus, molybdenum, and boron into the soil, provides a conducive environment for microbe activities like nitrogen fixation and nitrification, and in some cases, it corrects soil structure (Daemo et al., 2024). Even with the interventions of extension agencies (BoARD, research institutions, NGOs), farmers in the study area mostly grow local, unimproved faba bean varieties as a monoculture during the rainy season for household consumption and a few market sales. Extension services, including the IPMS program, have not effectively spread improved, potentially higher, yielding varieties among farmers, and research on the best agronomic practices for these varieties in the region is still very limited. The existing recommendations are general and do not specify fertilizer rates, liming, or other practices for improved cultivars. Therefore, a focused approach is highly necessary to raise the yield of improved faba bean varieties through better agronomic practices, which is a must in the local situation. This investigation was mainly oriented towards determining the most effective combination of organic and inorganic fertilizer rates and pinpointing the most productive faba bean varieties in terms of grain yield and yield components.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The investigation was carried out at the Boka Keble Farmers' Training Center (FTC) in the Adiyo district of the Kaffa zone during the principal 2023 cropping season (Meher). This locale is recognized as a principal faba bean production area within the district (Kaffa Zone Agricultural Department, 2023). The center is positioned in southwestern Ethiopia, approximately 474 km from Addis Ababa, at latitude 07°18' N, longitude 36°96' E, and an elevation of 2,511 m above sea level.

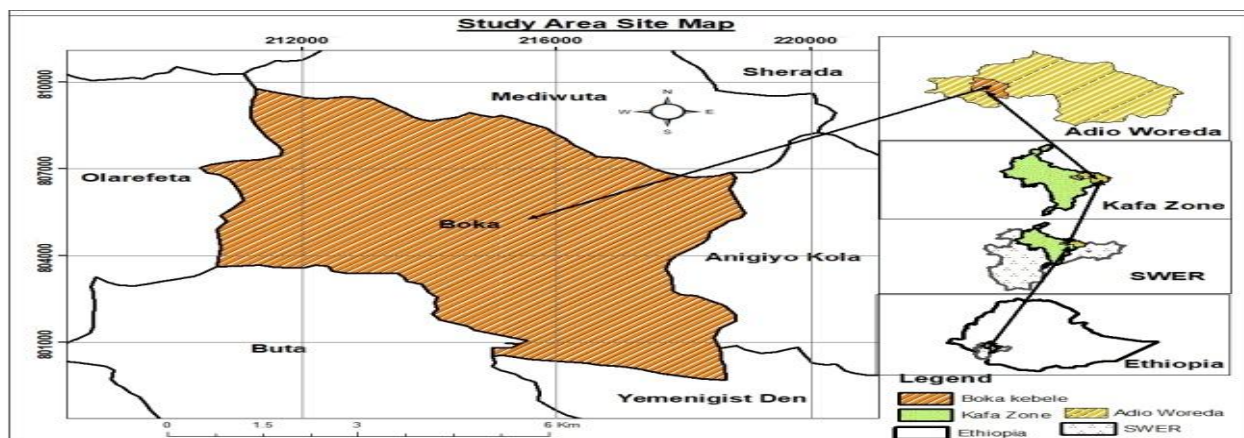


Figure 1. Map of the study area sub-district in Kaffa Zone, south-west Ethiopia.

Source: - Ocha GIS; WGS 1984 UTM Zone 37N Projection: Transverse Marcator Linear Unit Meter

The region exhibits a bimodal precipitation regime, comprising a minor rainy season (*belg*) from March to June and a principal rainy season (*meher*) extending from July to November. In 2023, the Wush-Wush Meteorological Station recorded an average annual precipitation of 1 334 mm. The climate is temperate, with mean minimum and maximum temperatures of 15 °C and 27 °C, respectively. Soils are predominantly reddish-black, and the agricultural system is characterized by mixed crop-livestock production. Principal crops cultivated include wheat, enset, faba bean, field pea, barley, and potato.

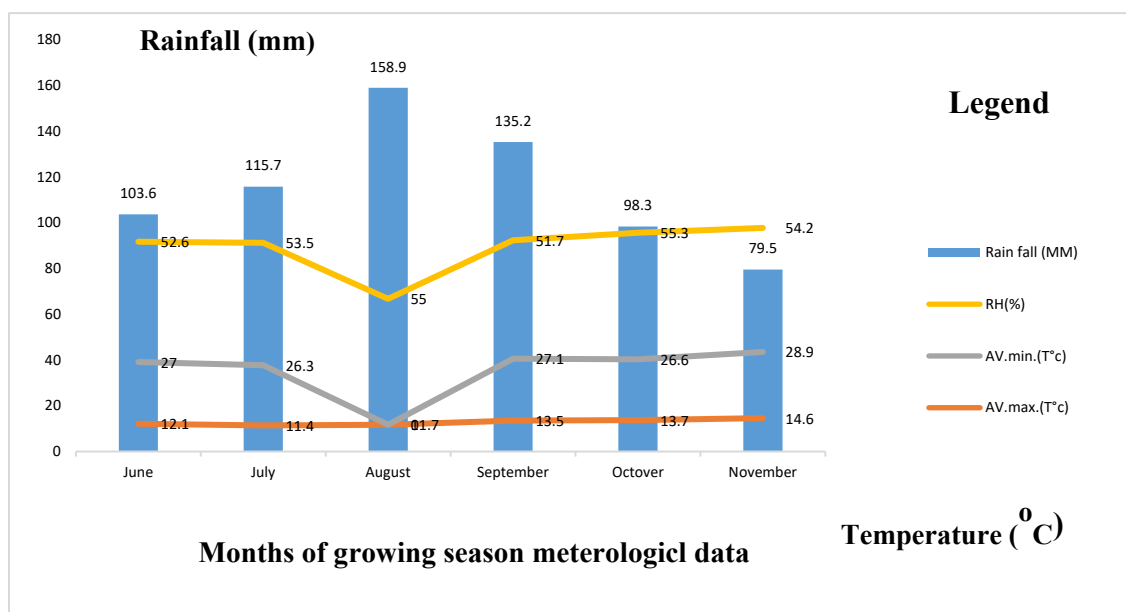


Figure 2. Weather condition of study area

Source: Wush-Wush Meteorological Station (2023)

2.2 Experimental Material

Three improved faba bean varieties such as Dosha (released 2009), Gebelcho (released 2006), and Tumsa (released 2010) were sourced from the Holeta Agricultural Research Center. These cultivars were selected for their superior agronomic traits, wide adaptability to diverse growing conditions, and high yield potential (2.5–6.9 t ha⁻¹ at the research center and 2.0–3.9 t ha⁻¹ in farmers' fields, according to HARC reports from 2006, 2009, and 2010; see Table 1). A local faba bean variety, obtained from farmers in the study area, was also included in the trial.

Table 1. Description of Faba Bean Varieties in Ethiopia

Varieties	Seed source	Year of release	Days to physiological maturity	Yield (Kg ha ⁻¹) on	
				Research	Farmers field
Tumsa	Holeta ARC	2010	121-176	25-69	20-38
Dosha	Holeta ARC	2009	120-165	25-62	23-39
Gabelcho	Holeta ARC	2006	103-167	25-44	20-30

Note: ARC = Agricultural Research Center

2.3. Treatments and Experimental Design

The experiment comprised three treatment factors: three rates of NPSB fertilizer (25, 50, and 75 kg ha⁻¹) and three rates of biochar (2.5, 5.0, and 7.5 t ha⁻¹) applied to faba bean cultivars. A full dose of NPSB (100 kg ha⁻¹) and biochar (7.5 t ha⁻¹) served as reference treatments. Experimental design employed a randomized complete block design (RCBD) with three replicates, yielding twelve treatment combinations. The field consisted of three blocks covering a gross area of 19.5 m × 10 m (195 m²); the net area from which crop data were collected measured 25.92 m². Each plot had a gross size of 2 m × 1 m (2 m²) and a net data-collection area of 0.72 m². Plot layout: each experimental unit measured 2 m × 1 m. Within each plot, six rows of faba bean were sown, with inter-row spacing of 40 cm and intra-row spacing of 10 cm. Border rows and terminal portions of each plot were omitted to avoid edge effects. Treatments were allocated to plots at random within each block. Prior to sowing, the land was prepared by three plowings followed by harrowing. Lime (CaCO₃) and biochar were incorporated manually one month before planting and mixed uniformly into the soil. Faba bean seeds were directly sown to a depth of 4 cm in designated holes, and NPSB fertilizer was applied uniformly at planting. All recommended agronomic practices were applied consistently throughout the growing season for all plots. The treatment combinations are presented in Table 2.

Table 2. Treatment Integration of biochar and different NPSB rates with recommended Lime

Treatment/T/ number	Varieties /V/	Integration rates of Biochar t ha ⁻¹ + NPSB ha ⁻¹
T1	LV	7.5 t + 25 kg
T2	LV	5 t + 50 kg
T3	LV	2.5 t + 75 kg
T4	V1	7.5 t + 25 kg
T5	V1	5 t + 50 kg
T6	V1	2.5 t + 75 kg
T7	V2	7.5 t + 25 kg
T8	V2	5 t + 50 kg
T9	V2	2.5 t + 75 kg
T10	V3	7.5 t + 25 kg
T11	V3	5 t + 50 kg

Where, LV = Local variety, V1 = Dosha, V2 = Gabalcho, and V3 = Tumsa faba bean varieties

The field was meticulously prepared using oxen, undergoing three plowing operations followed by harrowing. Certified seed sources, including the varieties Dosha, Gabalcho, and Tumsa, together with locally adapted cultivars, served as planting material. Experimental treatments comprised lime application combined with three levels of NPSB fertilizer and biochar at rates of 25 kg ha⁻¹, 50 kg ha⁻¹, and 75 kg ha⁻¹, and 7.5 t ha⁻¹, 5 t ha⁻¹, and 2.5 t ha⁻¹, respectively, each integrated with the recommended lime dosage. The requisite quantity of NPSB was placed in a band immediately prior to sowing. All agronomic practices were executed uniformly across plots at seedling emergence and during the mid-vegetative growth stage.

2.4 Data Collection

Plant growth and yield-related traits were measured on four randomly selected specimens from the central rows of each plot. Yield measurements were obtained for all individuals occupying the central rows, whereas plants situated in the peripheral border rows and at the extremities of each row were excluded.

2.4.1 Phonological parameters

Days to flowering (Days): Days to flowering would be recorded as the number of days from the date of sown till 50% of the plants produced flowers, in each plot.

Days to physiological maturity (Days): Days to maturity was recorded as the number of days from the date of sown till 90% of the plants changed their green color to yellowish, in each plot.

2.4.2 Growth parameters

Plant height (cm): This parameter was measured in centimeters from the ground level to the top of the plant at flowering and at physiological maturity from 4 randomly selected plants from each plot.

Total number of tillers (Number plant⁻¹): Total tillers were counted from randomly taken rows from the net plot area at physiological maturity.

Number of productive tillers (Number plant⁻¹): The number of tillers bearing pods was counted at physiological maturity by counting all from randomly taken rows from the net plot area.

2.4.3 Yield and yield components

Number of nodules per plant (Number plant⁻¹): This was determined as the total number of nodules was recorded at physiological maturity from randomly selected plants per plot.

Number of pods per plant (Pod plant⁻¹): This was determined as the total number of pods in each randomly selected plant was recorded after pod formation and at physiological maturity from 4 randomly selected plants per plot.

Length of pods (cm): This was measured from each randomly selected plant from the net plot area at physiological maturity.

Aboveground dry biomass yield (kg ha⁻¹): The plants in the net plot area were harvested at ground level, sun-dried for about 10 days until constant weight was attained, and weighed by spring balance to obtain the total biomass yield and expressed in kg ha⁻¹

Hundred seed weight (g): It would be determined based on the weight of 100 seeds sampled from the grain yields of each treatment, using an electric seed counter, weighed with an electronic balance, and adjusted to 10 % moisture level.

Grain yield (kg ha⁻¹): The grain yield was taken by harvesting and threshing the grain from the net plot area and converted to kg ha⁻¹. The yield was adjusted to 10% moisture content.

Harvest index /HI/ (%): It was calculated as the ratio of grain yield per plot to the aboveground dry biomass yield per plot expressed as a percentage.

$$HI (\%) = \frac{\frac{Grain\ Yield}{ha}}{\frac{Above\ ground\ biomass}{ha}} * 100$$

2.5 Partial budget analysis

The economic analysis employed the partial budget methodology delineated by CIMMYT (1988). The price of faba bean was derived from the mean market value at the time of harvest. Grain and straw yields were reduced by 10 % for the purposes of economic evaluation, in accordance with CIMMYT (1988). Variable costs, encompassing fertilizers and planting expenses, were incorporated into the treatment cost assessment and subjected to total variable cost (TVC) dominance analysis. This approach excludes treatments that incur higher costs and generate lower net benefits relative to less expensive alternatives. Consequently, the most profitable treatment emerged as non-dominated, exhibiting the greatest net benefit (CIMMYT, 1988).

3. Results and Discussion

3.1 Soil Physical and Chemical Properties

The soil at the experimental site was characterized by a texture comprising 60 % sand, 32 % clay, and 8 % silt, corresponding to a sandy clay loam (Table 3). According to Miyan et al. (2011), faba bean attains optimal growth in well-drained sandy loam to sandy clay loam soils. The cation exchange capacity (CEC) of the soil was measured at 18.34 cmol kg⁻¹ (Table 3), which falls within the medium range defined by Ethio SIS (2016) (18.31 cmol kg⁻¹). Total nitrogen content was 1.1 g kg⁻¹ (Table 3), classifying the soil as low in nitrogen according to the Ethio SIS (2016) rating; consequently, nitrogen constitutes a limiting factor for crop development at the site. Soil analysis also indicated an organic carbon concentration of 25.9 g kg⁻¹ (Table 3), placing it in the medium category as per Hazelton and Murphy (2007). The measured pH of 5.37 (Table 3) denotes a highly acidic condition under the Ethio SIS (2016) classification, yet it remains within the acceptable range for crop production (Gurmessa, 2021). The optimal pH interval for general agriculture spans 4.1–7.4, whereas faba bean specifically tolerates pH values from 6.5 to 9 (Pam & Brian, 2016). Accordingly, liming was deemed necessary for the experimental area.

Table 3. Soil physical and chemical properties of the experimental site

Soil property	Amount	Rating	References
Particle size distribution (%)	60		
Sand (%)	8		
Silt (%)	32		
Clay (%)			
Textural class		Sandy Clay loam	Brady and Weil (2002)
pH (soil: water in 1:2.5) (W/V)	5.37	Highly acidic	EthioSIS (2013)
TN (%)	0.11	Low	Tekalign (1991)
Av. P(ppm)	8.29	Low	Bray and Kurtz (1945)
OC (%)	2.59	Medium	Hazelton and Murphy(2007)
CEC (coml. (+) kg-1 soil)	18.34	Medium	Tekalign (1991)
Av. S mg kg-1	2.09	Very low	Ethio SIS (2013)
Av. B mg kg-1	0.67	Medium	Sippola and Ervio (1977)

Coml. = cent mole, pH= hydrogen ion concentration, OC= organic carbon, TN= total nitrogen, Av. p (ppm) = available Phosphorus parts per million, CEC= cation exchange capacity, Av. S mg kg⁻¹ =available sulfur milligram per kilogram, Av. B mg kg⁻¹ = available boron milligram per kilogram.

Analyzing the Chemical Properties of Biochar: Organic fertilizers are widely recognized for their ability to enhance soil fertility by supplying abundant nutrients that do not become depleted over time. Laboratory analyses indicated that the biochar employed in this study possessed high-quality characteristics. Although the biochar exhibited an inherently alkaline nature, its behavior varied according to the soil type. In alkaline soils, the biochar acted to moderate pH by exhibiting acidic properties, thereby contributing to pH balance. Consequently, the biochar was utilized to augment crop yields and improve soil fertility, a finding consistent with the observations of Hu et al. (2021). The most influential factors determining the magnitude of biochar's effect on crop yield and soil organic carbon were the biochar carbon-to-nitrogen (C:N) ratio and soil pH, as also noted by Hazelton and Murphy (2016). C:N ratios below 10 signify rapid decomposition, whereas organic matter with higher C:N ratios (> 20) can immobilize nitrogen during decomposition, reducing its availability to crops.

3.2 Phonological parameters

3.2.1 Days to flowering (days)

The main effects of variety, integrated application, and their interaction exhibited statistically significant ($P \leq 0.05$) differences in the number of days to 50 % flowering of faba bean (Table 4). The interaction of the local variety with 5 t ha⁻¹ CHB + 50 kg ha⁻¹ NPSB resulted in earlier flowering (55.67 days), whereas the Tumsa variety under the same treatment flowered later

(65 days); on limed versus unlimed soils, the local variety flowered at 47.67 days and the Tumsa variety at 55 days, respectively (Table 4). The premature flowering observed in the Local variety may be attributable to its inherent genetic characteristics. This observation concurs with Omer and Ufuk (2016), who documented genotype-specific differences in flowering time. Conversely, most variety-by-treatment interactions did not yield significant intra-treatment differences in flowering duration (Table 4). Such findings may reflect the suitability of the selected varieties and the optimal management combination that enhances tolerance to soil acidity and mitigates aluminium toxicity in the faba bean rhizosphere (Belachew, 2018). These results contrast with those of Asrat et al. (2020), who reported that the application of 1.5 t ha⁻¹ lime accelerated faba bean flowering. Nonetheless, early flowering may facilitate earlier physiological maturity, thereby conferring greater resilience to climatic stressors.

3.2.2 Days to physiological maturity (days)

The analysis showed a significant difference ($p \leq 0.05$) among faba bean varieties in the number of days to reach 90% physiological maturity. This result indicates that the maturity period is largely influenced by genetic factors. Physiological maturity is when about 90% of the pods turn yellow, and the seeds reach their maximum dry weight. This trait is important in agriculture because it affects the crop cycle, adaptation to specific environments, and suitability for various cropping systems. The Gebelcho variety took the longest time to reach 90% physiological maturity. It required 113.00 days in limed soil and 96.00 days in unlimed soil. In contrast, the local variety matured earlier, needing 101.67 days in limed soil and 86.67 days in unlimed soil (Table 3). This clearly shows that Gebelcho is a late-maturing variety, while the local variety matures earlier. The shorter maturity period in unlimed soil for both varieties may relate to stress caused by soil acidity. Acidic soils often limit nutrient availability and root growth. This limitation can speed up crop senescence and shorten the growth cycle. The overall pattern of results suggests that maturity differences mainly arise from the characteristics of the varieties, not the treatment effects. In other words, there was little variation within the treatments, but clear differences between the varieties. This confirms that the number of days to physiological maturity is mostly a genetically controlled trait. However, environmental factors like soil fertility and pH may have a slight impact on its duration. Late-maturing varieties, such as Gebelcho, usually have a longer vegetative and reproductive growth period. This allows more time for biomass accumulation, photosynthesis, and seed allocation. This often leads to higher grain yield potential under favorable conditions. On the other hand, early-maturing varieties like the local cultivar may be better in areas with short growing seasons, terminal drought, or moisture stress, as they avoid late-season environmental challenges. These findings support Al-Barri's (2012) report, which noted significant variation among accessions in the number of days to fruit setting, showing that phenological traits can vary greatly across genotypes. This variability in maturity duration is crucial for breeding and selection programs that aim to develop varieties suited to different agro-ecological conditions. Overall, the results emphasize that when selecting varieties, it is important to consider the maturity period along with yield potential. While late-maturing varieties like Gebelcho may deliver higher productivity in improved soil conditions, early-maturing local varieties may offer stability and adaptability in stressed environments.

Table 4. Interaction effects of faba bean varieties with NPSB and CHB fertilizer on DF and MD, under Limed and unlimed soil.

Varieties	Treatment combination	Lime-treated experiment site		Lime untreated experiment site	
		DF (day)	DM (day)	DF (day)	DM (day)
Local	7.5 t ha ⁻¹ CHB +25 kgha ⁻¹ NPSB ha ⁻¹	55.67 ^d	101.00 ^c	47.67 ^d	86.33 ^c
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	55.67 ^d	101.67 ^c	47.67 ^d	86.66 ^c
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	55.67 ^d	101.33 ^c	47.67 ^d	86.00 ^c
Gebelcho	7.5 t ha ⁻¹ CHB +25 kgha ⁻¹ NPSB ha ⁻¹	61.33 ^c	112.67 ^a	52.33 ^c	95.66 ^{ab}
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	61.33 ^c	112.00 ^{ab}	52.33 ^c	95.00 ^{ab}
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	61.33 ^c	113.00 ^a	52.33 ^c	96.00 ^a
Dosha	7.5 t ha ⁻¹ CHB +25 kgha ⁻¹ NPSB ha ⁻¹	64.67 ^{ab}	111.00 ^{ab}	54.67 ^{ab}	94.00 ^b
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	64.67 ^{ab}	111.33 ^{ab}	54.67 ^{ab}	94.66 ^{ab}
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	64.33 ^b	111.00 ^{ab}	54.33 ^b	94.00 ^b
Tumsa	7.5 t ha ⁻¹ CHB +25 kgha ⁻¹ NPSB ha ⁻¹	65.00 ^a	110.33 ^b	55.00 ^a	94.00 ^b
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	65.00 ^a	112.33 ^{ab}	55.00 ^a	95.33 ^{ab}
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	65.00 ^a	111.00 ^{ab}	55.00 ^a	94.33 ^{ab}
LSD (0.05)		0.58	2.17	0.58	1.99
CV (%)		5.56	11.18	7.66	1.27

Where, DF=Days to 50% flowering, DM= Days physiological maturity, *LSD* = *Least significance difference*, *CV*=*Coefficient of variance*, * = significance, ** = highly significance *** = Very highly significance

3.3 Growth parameters Faba Bean

3.3.1 Plant height (cm)

The application of both organic and inorganic amendments produced a statistically significant increase in plant height ($p \leq 0.05$). Specifically, the treatment combining 5 t ha⁻¹ of biochar with 50 kg ha⁻¹ of NPSB fertilizer enhanced the height of faba bean plants (Table 5). Further statistical analysis revealed highly significant differences in plant height ($p < 0.01$) between limed and unlimed soils as well as among the cultivars tested. The greatest height (114.33 cm) was observed in the Gebelcho cultivar under limed conditions receiving 5 t ha⁻¹ biochar plus 50 kg ha⁻¹ NPSB, whereas the shortest height (96.67 cm) occurred in the local cultivar under limed conditions receiving 5 t ha⁻¹ biochar plus 25 kg ha⁻¹ NPSB. Under unlimed conditions, the Gebelcho cultivar attained a height of 112.33 cm, while the local cultivar reached 96.6 cm (Table 5).

The superior plant height associated with high rates of biochar and NPSB blended fertilizer is likely attributable to increased nitrogen availability resulting from their combined application, which creates favorable conditions for vegetative growth and cellular division, thereby promoting greater plant stature. This interpretation aligns with Negasa et al. (2019), who documented significant effects of faba bean accession on plant height. Similarly, Situmeang et al. (2023) reported that compost treatments did not significantly affect plant height, whereas biochar

exerted a highly significant effect. Luiz (2017) also observed that incremental biochar concentrations enhanced faba bean growth, a response linked to improved nutrient uptake, as nutrient concentrations increased linearly with rising biochar doses.

3.3.2 Total number of tillers (Number plant⁻¹)

Data depicted in Table 5 shows that the integrated use of lime, biochar, and inorganic fertilisers causes a statistically significant ($p \leq 0.05$) increase in the number of tillers per plant. This shows the importance of both soil amendments and balanced nutrient supply, particularly in increasing faba bean vegetative and branching growth. The highest tiller number was observed in the Gebelcho variety where 8.66 tillers per plant was recorded in limed soil and 7.33 in unlimed soil. Conversely, the local variety had the least number of tillers, where 6.66 and 5.66 tillers per plant were recorded in limed and unlimed conditions, respectively. The genetic superiority of Gebelcho in tillering improved its nutrient use efficiency and response to favorable soil conditions. The decrease in the number of tillers in unlimed soils indicates the soil acidity and the associated nutrients which were unfavorable to the roots and vegetative growth.

The highest number of tillers was recorded in plots that were amended with 5 t CHB ha combined with 50 kg NPSB fertilizer. This integrated nutrient management approach possibly made the soil environment more conducive for plant growth. Coffee husk biochar (CHB) modifies soil structure, improves water holding capacity, increases cation exchange capacity, and elevates soil pH thus lessening aluminum toxicity in acid soils. On the other hand, NPSB fertilizer supplies the major nutrients nitrogen (N), phosphorus (P), sulfur (S), and boron (B) that are necessary for cell division, root formation, and vegetative growth. Specifically, nitrogen is highly involved in stimulating leaf area growth and branching which directly affects the number of tillers formed. Hence, the joint use of biochar and chemical fertilizer improved the supply and uptake of nutrients that led to increased vegetative growth and the production of tillers. The above results agree with those of Mahmud et al., (2016) who found that the combination of vermicompost and inorganic fertilizers (NPKS) led to a significant increment in the appearance of new tillers as well as improvement in tiller population dynamics in rice. Likewise, Frehiwot (2014) disclosed that nitrogen and phosphorus fertilizers were instrumental in increasing the total and effective number of tillers per plant.

Besides that, Abera et al. (2021) revealed that using blended NPS fertilizer significantly influenced both total and productive tiller numbers. It is evident from the findings that using lime, biochar, and balanced inorganic fertilizers together can improve soil fertility, increase nutrient availability, and stimulate strong vegetative growth that eventually leads to higher tiller production. As tiller number is a key yield factor that leads to pod formation and final grain yield, it is therefore very important to integrate soil fertility management practices when producing improved faba bean varieties, especially on acid, affected soils.

3.3.3 Number of productive tillers (Number plant⁻¹)

The analysis of variance indicated that the main effect of integrated use of organic and inorganic fertilizer with lime had a significant ($p \leq 0.05$) effect on the number of effective tillers (Table 5). The highest number of productive tillers was recorded from the Gebelcho variety (5, 4.33), while the lowest number of productive tillers was recorded from the Local variety (3.6, 3) on limed and unlimed soil, respectively. The maximum number of productive tillers per plant was produced by plants treated with 50 NPSB kg + 5 t CHB. Crop yield depends upon many yield-contributing

components, and among them, the number of fertile tillers is very important because the higher the number of fertile tillers, resulted to the grain yield of the crop. This result was concurrent with the work of Frehiwot (2014), who reported that N and P fertilizers had a potential role in the number of total and effective tiller production per plant. Similarly, Abera *et al.* (2021) reported that blended NPS fertilizer application had a highly significant effect on both the numbers of total and productive tillers.

Table 5. Interaction effects of faba bean varieties with NPSB and CHB fertilizer on TNT, NPT, and PH under Limed and unlimed soil.

Varieties	Treatment integration	Limed soil			Unlimed soil		
		TNT Plant ⁻¹	NPT Plant ⁻¹	PH (cm)	NTT Plant ⁻¹	NPT Plant ⁻¹	PH (cm)
Local	7.5 t ha ⁻¹ CHB + 25 kgha ⁻¹ NPSB ha ⁻¹	6.66 ^a	3.00 ^c	96.67 ^c	5.66 ^a	3.00 ^c	93.67 ^c
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	7.00 ^a	3.66 ^{bc}	98.00 ^c	6.00 ^a	3.33 ^{bc}	96.33 ^a
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	7.00 ^a	3.66 ^{bc}	97.50 ^c	6.00 ^a	3.00 ^c	94.00 ^{ab}
Gebelcho	7.5 t ha ⁻¹ CHB + 25 kgha ⁻¹ NPSB ha ⁻¹	8.00 ^a	4.33 ^{abc}	114.00 ^a	7.00 ^a	3.66 ^{abc}	111.67 ^c
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	8.66 ^a	5.00 ^a	114.33 ^a	7.33 ^a	4.33 ^a	112.33 ^a
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	8.33 ^a	5.00 ^a	113.33 ^{ab}	7.00 ^a	4.00 ^{ab}	111.67 ^a
Dosha	7.5 t ha ⁻¹ CHB + 25 kgha ⁻¹ NPSB ha ⁻¹	7.33 ^a	3.66 ^{bc}	113.17 ^{ab}	6.33 ^a	3.00 ^c	110.33 ^c
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	8.00 ^a	4.33 ^{bc}	113.50 ^{ab}	7.00 ^a	3.33 ^{bc}	110.67 ^{ab}
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	8.00 ^a	4.00 ^{abc}	111.67 ^b	7.00 ^a	3.33 ^{bc}	111.33 ^a
Tumsa	7.5 t ha ⁻¹ CHB + 25 kgha ⁻¹ NPSB ha ⁻¹	8.00 ^a	4.00 ^{abc}	114.00 ^a	7.00 ^a	3.33 ^{bc}	111.00 ^a
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	8.33 ^a	4.00 ^{abc}	114.00 ^a	7.33 ^a	3.00 ^c	111.00 ^a
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	8.00 ^a	3.66 ^{bc}	113.33 ^{ab}	7.00 ^a	3.00 ^c	110.33 ^{ab}
LSD (0.05)		2.70	1.37	1.94	2.48	0.85	2.019
Significance		**	**	**	*	*	*
CV (%)		11.56	15.27	1.07	16.81	15.03	1.12

Where, T NT= Total number tillers, NPT= Number of productive tillers, PH= Plant height, Least significance difference, CV=Coefficient of variance, * = significance, ** = highly significance *** = Very Highly significance

3.4 Yield and yield components

3.4.1 Number of nodules per plant (Nodules plant⁻¹)

Analysis variance revealed that the number of nodules per plant (NNPP) for faba bean cultivars was significantly ($p < 0.05$) different between lime and no lime treatments as well as due to combined effects of NPSB and Bochar rates (Table 6). The highest NNPP (167.77) was found for the Gebelcho cultivar on limed soil, whereas the local cultivar had the lowest NNPP (67.67). On unlimed soil, Gebelcho again had the highest NNPP (142.67) and Local the lowest (57). The interaction effect showed the highest NNPP in the treatments that received 50 kg NPSB ha⁻¹ + 5 t ha⁻¹ CHB, whereas the smallest NNPP was in the treatments that received the same combination,

indicating that there are significant differences between varieties. Those differences could be explained by the fact that phosphorus triggers the R, legume symbiosis and thus nodulation increases production of nitrogen in legumes (Negash et al., 2023). The authors in Sulfab et al. (2011) & Liu et al. (2022) also found that the use of only organic manure or a combination of Rhizobium inoculation and 20 kg N ha⁻¹ application significantly enlarged nodulation and formation of pods at the early stages in groundnuts as compared to the unamended control plots they both show. On the other hand, the use of very high rates of nitrogen fertilizer levels has been demonstrated to result in a notable decrease in both the nodule number and nodule dry weight per plant due to the negative impact of the inhibitor (Pons et al., 2007). Seed inoculation with rhizobium and liming was the most effective treatment to increase shoot P concentration and dry matter yield, with either full or half P fertilizer application leading to significantly higher shoot P content and dry matter yield than the non, P control. The results of the present study are in line with other reports (e.g., Ganeshamurthy et al., 2000) that the number, mass, and thus the nitrogen, fixing capacity of nodules on various legumes increase with the application of phosphorus (P) and farmyard manure (FYM). The finding is quite surprising that non, inoculated rhizobium plants that received FYM, lime, and P treatments produced more nodules than the inoculated ones under the same treatments. The observed effect may be explained by comparing the results of sole rhizobium inoculation and sole lime application treatments, which suggest that the soil hosts a population of indigenous rhizobia that can be stimulated and effectively used for nodule formation when soil pH is corrected, carbon availability is ensured, and P is supplemented. Liming reduces the concentration of Al³⁺ and H⁺ ions partly because it produces OH ions through the reaction with water; these then combine with Al³⁺ and H⁺ ions in acidic soils to form Al(OH) and HO, respectively. Since the lime raises the pH through the precipitation of Al³⁺ and H⁺ ions, microbial activity and nutrient availability are, therefore, enhanced (Hordofa et al., 2018). Plants need an ample supply of readily available mineral P to maintain the high energy turnover that occurs during nodule formation. In addition, P leads to greater root system development and the formation of root nodules that are singly or combined with lime, mineral P, FYM, compost, and rhizobium on acid soils. Thus, the lime based treatments led to a significant increase in growth and yield parameters.

The treatment combinations mainly revealed that lime has an ameliorative effect on soil acidity, biochar provides nutrients and energy, and phosphorus influences nodule formation as well as the total growth of faba bean. All in all, the application of 5 t ha⁻¹ of biochar together with 50 kg ha⁻¹ of N P S fertilizer may be cautiously put forward as a measure to alleviate soil acidity and increase faba bean yield in the research area. Nevertheless, the experiment should be repeated for a number of years and different acid soil adapted rhizobial strains should be included. Adding farmyard manure supplies organic materials to the microorganisms which, in turn, results in an increase of their population and hence promotes mineralization. Likewise, Joshi et al. (2019) reported that the application of manure increased the indigenous rhizobial population by providing a carbon source and creating an environment conducive to bacterial proliferation.

3.4.4 Number of pods per plant (pods plant⁻¹)

Statistical analysis indicated that faba bean cultivars were significantly influenced ($p < 0.05$) by the number of pods per plant under both limed and unlimed soil conditions. The greatest pod

count per plant (13.66 and 8.33) was observed in treatments receiving 5 t CHB + 50 kg NPSB, whereas the lowest count (7) occurred in treatments receiving 5 t CHB + 25 kg NPSB. Maximum pod numbers were recorded in limed soil for the Gebelcho cultivar (13.66, 11.66), followed by Dosha (12.77, 11.33), Tumsa (11.33, 9.66), and the local variety (8, 7) on limed and unlimed soils, respectively. Papakaloudis & Dordas (2023) also reported varietal differences in pod number per plant (Table 5). Agegnehu & Yirga (2009) demonstrated that farmyard manure and phosphorus fertilizer exerted highly significant effects on plant height, pod number per plant, total biomass, and seed yield of faba bean cultivated in acidic soils. Similarly, the combined application of chemical fertilizer, biofertilizer, and organic amendments significantly increased pod and seed yields per plant, yielding the highest values reported by Mekki (2016). Basu et al. (2007) and Liu et al. (2022) found that integrated use of organic wastes and chemical fertilizers together with lime markedly enhanced peanut yield and quality. Application of farmyard manure outperformed NPK fertilization, and additional liming produced the greatest increases in plant height, pod length, and pod number per plant of pea grown in acidic soils relative to the control (Negi et al., 2004).

3.4.3 Length of pods (cm)

The analysis of variance showed that the main effects of varieties as well as organic and inorganic fertilizer applications had a significant ($p \leq 0.05$) effect on pod length of faba bean (Table 6). It is clear that both the genetic traits and the soil fertility management practices are important factors in the determination of pod growth.

Among the three, Gebelcho was the variety with the longest pods, 4.66 cm under the limed soil and 3.66 cm under the unlimed soil. Whereas the local variety had the shortest ones, 3.58 cm and 3.00 cm, respectively, under the limed and unlimed conditions. Decrease in pod length under the unlimed soil conditions can be attributed to soil acidity which affected nutrient availability and plant growth leading to less reproductive development. Liming would have altered soil pH to a level more favorable to nutrient availability especially phosphorus, calcium, and magnesium and thus have promoted better root growth and higher yield in terms of pod formation.

Furthermore, the longest pods (4.66 and 3.66 cm) were obtained by the application of 5 t CHB ha⁻¹ combined with 50 kg ha⁻¹ NPSB on the Gebelcho variety (Table 7). This finding is a clear indication of the synergistic effect between organic and inorganic fertilizers. Coffee husk biochar (CHB) probably enhanced the soil structure, increased the soil's capacity to hold cations, improved moisture retention, and decreased soil acidity. When used together with the NPSB fertilizer that provides nitrogen, phosphorus, sulfur, and boron, the availability of nutrients and their uptake were at their peak. Such changes would allow for better photosynthesis, translocation of the resulting products as well as conferring strong development to reproductive organs, thereby giving rise to longer pods.

Variation in pod length between varieties and across different treatments can mostly be explained by genetic differences in growth habit, nutrient use efficiency, and reproductive potential. Pod size is considered an important yield component as longer pods usually have more seeds, leading to higher grain yield. However, the determination of this trait depends not only on genotype but also on favorable environmental and soil conditions. The current data agree with those of Agegel et al., (2021) who found that varietal differences had a very significant effect on soybean pod length. Furthermore, they revealed significant variation in pod length due to

different levels of blended NPSB fertilizer and the interaction between varieties and fertilizer application. This is in line with the idea that reproductive traits such as pod length are determined by the genetic potential as well as the nutrient management practices. In general, the data indicate that improved varieties such as Gebelcho used in conjunction with suitable organic and inorganic fertilizer applications can considerably increase pod development. This integrated nutrient management strategy is especially vital for acid, affected soils where alleviating the soil limitations and providing balanced nutrients can bring out the maximum varietal yield potential.

3.4.5 Number of seeds per pod (seed pod⁻¹)

The number of seeds per pod was significantly ($p \leq 0.05$) affected by the combined application of organic and inorganic amendments. The greatest seed-per-pod value was observed in the Gebelcho cultivar (4.77 ± 0.04), whereas the lowest value occurred in the local cultivar (3.33 ± 0.03) on limed and unlimed soils, respectively. Higher seed-per-pod counts were recorded on limed soils when 5 t ha^{-1} of CHB and 50 kg ha^{-1} of NPSB were applied to the Gebelcho variety (Table 6). Papakaloudis and Dordas (2023) reported that farmyard manure (FYM) and phosphorus fertilizer exerted a highly significant influence on plant height, pods per plant, total biomass, and seed yield of faba bean cultivated in acidic soils. Similarly, Mekki (2016) demonstrated that the simultaneous application of chemical, bio-fertilizer, and organic inputs markedly increased pod and seed yields per plant of faba bean. Basu et al. (2007) also found that integrating organic wastes with chemical fertilizers and lime substantially enhanced peanut yield and quality. FYM application outperformed NPK fertilization, and additional liming produced the greatest improvements in plant height, pod length, and pods per plant of peas grown on acidic soils compared with the control (Negi et al., 2004; Liu et al., 2022). The decomposition of FYM and the consequent release of nutrients, together with the pH increase induced by lime and phosphorus nutrition, contributed to the augmentation of grain, straw, and biological yields of faba bean. Hellal et al. (2014) attributed these yield enhancements to the provision of micro- and macronutrients from FYM, which likely stimulated photosynthetic activity and leaf protein synthesis, thereby positively influencing faba bean yield components.

497 **Table 6.** Interaction effects of faba bean varieties with NPSB and CHB fertilizer on NNPP, NPPP and PL on Limed and Unlime soil.

Varieties	Treatment integration	Limed				Unlimed			
		NNPP plant ⁻¹	NPPP plant ⁻¹	PL (cm)	NSPP pod ⁻¹	NNPP plant ⁻¹	NPPP plant ⁻¹	PL (cm)	NSPP plant ⁻¹
Local	7.5 t ha ⁻¹ CHB +25 kgha ⁻¹ NPSB ha ⁻¹	67.67 ^d	8.00 ^e	3.16 ^d	3.66 ^c	57.33 ^d	7.00 ^e	3.00 ^b	3.00 ^{cd}
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	67.10 ^d	8.33 ^e	3.58 ^{cd}	3.41 ^c	57.00 ^d	7.33 ^e	3.00 ^b	3.00 ^{cd}
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	67.00 ^d	8.66 ^e	3.58 ^{cd}	3.33 ^c	57.00 ^d	7.66 ^e	3.00 ^b	3.00 ^{cd}
Gebelcho	7.5 t ha ⁻¹ CHB +25 kgha ⁻¹ NPSB ha ⁻¹	167.00 ^a	12.00 ^{abcd}	4.33 ^{bc}	4.25 ^b	142.00 ^a	10.00 ^{bcd}	3.33 ^b	4.00 ^a
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	167.77 ^a	13.66 ^a	4.66 ^{ab}	4.77 ^a	142.67 ^a	11.66 ^a	3.66 ^a	4.00 ^a
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	166.50 ^a	12.66 ^{abcd}	4.66 ^{ab}	4.08 ^b	141.33 ^a	10.66 ^{abcd}	3.66 ^a	3.00 ^{cd}
Dosha	7.5 t ha ⁻¹ CHB +25 kgha ⁻¹ NPSB ha ⁻¹	146.00 ^b	12.00 ^{abcd}	4.33 ^{bc}	4.3 ^b	124.67 ^b	10.00 ^{bcd}	3.33 ^b	3.33 ^b
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	146.33 ^b	13.00 ^{abc}	4.66 ^{ab}	4.50 ^a	124.67 ^b	11.00 ^{abc}	3.66 ^a	4.00 ^a
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	146.10 ^b	13.33 ^{ab}	4.66 ^{ab}	4.66 ^a	124.00 ^b	11.33 ^{ab}	3.66 ^a	3.22 ^b
Tumsa	7.5 t ha ⁻¹ CHB +25 kgha ⁻¹ NPSB ha ⁻¹	128.67 ^c	11.00 ^d	4.00 ^{bc}	3.41 ^c	109.33 ^c	9.33 ^d	3.00 ^b	3.33 ^c
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	129.17 ^c	11.66 ^{bcd}	4.41 ^b	3.25 ^c	109.67 ^c	9.66 ^{cd}	3.66 ^a	3.00 ^{cd}
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	129.33 ^c	11.33 ^{cd}	4.33 ^{bc}	3.00 ^c	110.33 ^c	9.66 ^{cd}	3.66 ^a	3.00 ^{cd}
LSD (0.05)		11.20	1.70	0.78	0.73	9.46	1.58	0.82	0.48
Significance		**	**	**	**	*	*	*	*
CV (%)		5.19	8.90	10.89	11.34	5.16	9.74	14.11	8.39

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499 Where, NNPP =number of nodules plant⁻¹, NPPP = number of pod plant⁻¹, PL = Pod length (cm), NSPP: Number of seed Pod⁻¹, LSD = Least
500 significance difference, CV=Coefficient of variance, * = significance, ** = highly significance, *** = Very Highly significance

3.4.6. Above-ground dry biomass (kg ha⁻¹)

The data analysis showed that there were statistically significant differences ($p \leq 0.05$) in dry matter biomass among the different faba bean varieties. This means that the total biomass production is mainly attributable to the genetic makeup of the varieties and to a lesser extent, the influence of soil management practices. Dry biomass is an indicator of the total vegetative growth of a plant and its photosynthetic capacity, and it is a major determinant of the final grain yield. Gebelcho gave the highest average dry biomass, with 11, 874 kg ha⁻¹ under limed conditions and 10, 093 kg ha⁻¹ under unlimed soil. On the other hand, the local variety had the lowest biomass with 4215 kg ha⁻¹ on limed soil and 3583 kg ha⁻¹ on unlimed soil (Table 7). Gebelcho's better performance could be due to that it has genetically superior vegetative growth capacity, better utilization of nutrients and higher photosynthetic activity. That its biomass was higher in the limed treatment means that the soil acidity correction had a positive impact on root growth and nutrient absorption which in turn resulted in better plant growth.

The much lower harvest index of the local variety on the unlimed soil indicates that the limitation of total biomass was probably accompanied by a decrease in the efficiency of assimilate partitioning to grain. Acidic soil problems often limit root elongation and nodulation as a result of aluminum toxicity and phosphorus fixation. Consequently, the extent of biological nitrogen fixation and nutrient uptake decreases, growth is retarded and the accumulation of dry matter is reduced. The difference in biomass production due to various treatments of biochar (BC) and PO can be accounted for by the soil, ameliorating effects of biochar. Biochar enhances soil physical and chemical properties through elevating the pH, increasing the cation exchange capacity, improving soil structure, and stimulating microbial activities. Biochar, by increasing the soil pH, limits phosphorus fixation and consequently, the P₂O₅ applied becomes more readily available. Phosphorus plays an important role in the development of roots, energy transfer (ATP formation), and nodule establishment in legumes. With better root and nodule formation, nitrogen fixation, nutrient uptake will be more efficient, and these changes will lead to a promotion of the growth of aboveground plant parts, which results in increased production of dry biomass.

The findings of the study are in line with the results of Elka and Laekemariam (2020) who found that the haricot bean biomass yield was significantly increased by the interaction of NPS fertilizer and organic amendments. Similarly, Luiz et al. (2017) pointed out that biochar application led to increased biomass production and they explained that biochar amendment to the soil results in favorable conditions for the growth and productivity of legumes. Overall, the findings indicate that dry matter accumulation in faba bean can be greatly increased through the combined effects of improved varieties, liming, biochar application, and phosphorus fertilization. Improved varieties like Gebelcho are more efficient in utilizing the enhanced soil conditions which results in higher biomass production and better yield potential especially in soils that are naturally acid.

3.4.7 Hundred seed weight (gram)

Analysis of variance results revealed that hundred, grain weight (HGW) of faba bean was significantly ($p \leq 0.05$) affected by varietal differences both under limed and unlimed soil conditions. This is an indication that seed weight is mainly dependent on the genetic potential of the variety; however, soil management practices can also influence the extent of its expression.

The highest hundred, grain weight was obtained from the Gebelcho variety, which gave 87.67 g under limed soil and 77.00 g under unlimed soil. On the other hand, the local variety was the one that produced the lowest hundred, grain weight at 56.00 g and 52.66 g under limed and unlimed conditions, respectively (Table 7). The decrease in seed weight under unlimed soil conditions may be due to soil acidity which adversely affected nutrient uptake and assimilate translocation during seed filling, thus, limiting grain development. Liming could have increased soil pH and nutrient availability, especially phosphorus and calcium which are necessary for seed formation and grain filling. Considering the seed weight values, the varieties might be grouped based on seed size where Gebelcho and Dosha would be considered large, seeded types, Tumsa a medium, seeded type, and the local cultivar a small, seeded type. Seed size is an important agronomic and market trait in faba bean production. Large, seeded varieties are commonly favored by both farmers and consumers as they can fetch higher prices in the market, have a better look, and are more suitable for specific food preparations. Moreover, bigger seeds on average lead to higher grain yield as grain weight is one of the main contributors to total yield.

The lighter seed weight observed with the local variety explains in part why it produced less grain yield. A small seed size might be an indication of limited assimilate accumulation in the grains that are growing, which can mean slightly less photosynthesis, lower sink strength, or decreased nutrient use efficiency. Therefore, even if the number of pods or seeds per plant is equal, the final yield might still be low due to smaller grain weight. The current results are in agreement with the findings of Tamane et al., (2015) who reported that the Gebelcho, Dosha, and Tumsa varieties had higher thousand, grain weights whereas the local variety had the smallest grain weight. This consistency strengthens the notion that improved varieties have a higher genetic potential for seed size and yield components than the traditional local varieties. In general, the findings emphasize that varietal selection is crucial for determining seed size, which in turn has an impact on grain yield. The combined use of improved large-seeded varieties such as Gebelcho and appropriate soil management practices like liming can substantially enhance both grain weight and overall productivity in faba bean production systems.

3.4.8 Grain yield per hectare (kg ha⁻¹)

The statistical analysis demonstrated that both variety and soil treatment (limed versus unlimed) had a significant ($p \leq 0.05$) effect on faba bean grain yield, indicating that yield performance was strongly influenced by genetic potential as well as soil amendment practices. This confirms the importance of considering both varietal selection and soil fertility management to achieve optimum productivity.

The highest grain yield (4,184 kg ha⁻¹) was obtained from the Gebelcho variety grown on limed soil, while the local variety produced a substantially lower yield (1,218 kg ha⁻¹) under the same limed condition. Similarly, under unlimed soil conditions, the Gebelcho variety yielded 3,483 kg ha⁻¹, whereas the local variety produced only 946 kg ha⁻¹ (Table 6). The consistently superior performance of the Gebelcho variety across both soil conditions reflects its improved genetic potential, better nutrient use efficiency, and enhanced tolerance to soil acidity compared with the local cultivar. The large yield gap between improved and local varieties aligns with findings from International Center for Agricultural Research in the Dry Areas (ICARDA, 2008), which reported that replacing traditional varieties with improved cultivars resulted in yield gains of 18 % in Egypt, 8 % in Sudan, and 42 % in Ethiopia. These differences highlight the critical role of improved germplasm in boosting faba bean productivity, particularly in regions where soil fertility constraints limit crop performance.

Lime application also exerted a significant positive effect on grain yield. The substantial increase in grain yield and total dry biomass observed under limed conditions compared with unlimed soil can be attributed to the correction of soil acidity. In acidic soils, high concentrations of exchangeable aluminum and hydrogen ions limit root growth, restrict nutrient uptake, and reduce biological nitrogen fixation. Liming raises soil pH, neutralizes toxic aluminum, improves root proliferation, and enhances the availability of essential nutrients such as phosphorus, calcium, and magnesium. Improved phosphorus availability is particularly important for faba bean because it plays a key role in root development, nodulation, energy transfer, and grain formation. The present results are consistent with the findings of Zerihun and Abera (2014) who reported a linear increase in faba bean grain yield with increasing lime rates. They also noted that liming significantly enhanced nutrient availability, especially phosphorus, by raising soil pH to levels that maximize phosphorus solubility and uptake. This improved nutrient status likely contributed to greater biomass production and more efficient partitioning of assimilates to grain. Additionally, the relationship between liming and improved variety implies that high-yielding genotypes are better able to take advantage of improved soil conditions. When compared to its performance in unlimed soil, the Gebelcho variety exhibited a significant yield advantage when grown in limed soil, suggesting that genetic potential is only fully realized when soil constraints are reduced. The local variety, on the other hand, produced comparatively little in both circumstances, indicating a limited ability to respond to soil improvement initiatives. Overall, the results show that grain yield can be significantly increased by combining improved faba bean varieties with suitable soil acidity management techniques, especially liming. This integrated strategy is particularly important in highland regions that are prone to acidity, as soil acidity continues to be a significant barrier to the production of legumes.

3.4.9 Harvest index (%)

Harvest index (HI) which is a measure of the proportion of total aboveground biomass that is converted into grain, was significantly ($p < 0.05$) affected by faba bean varieties under both limed and un, limed soil conditions. This means that the genetic differences among the varieties had a major impact on the ability of the plants to efficiently use the assimilates to produce the grain and yield the final grain. Under limed soil conditions, the highest harvest index was obtained from the Gebelcho variety (35.287%), but the local variety showed the lowest value (29.17%). Similarly, under un, limed soil conditions, the Gebelcho variety still had a relatively higher harvest index (35.287% and 29.66%), whereas the local variety had lower values (29.66% and 22.33%) (Table 7). The constantly better performance of the Gebelcho variety in different soil conditions indicates that it is better at allocating the assimilates to the economic yield (grain) rather than the vegetative biomass. The large variation in harvest index of the varieties to a great extent is due to the genetic make, up of the varieties which affects the various physiological processes such as the efficiency of the photosynthesis process, accumulation of dry matter, the capacity of nutrient uptake, and the translocation of the formed assimilates to the reproductive organs. It is probable that liming brought about an increase in the soil pH, a decrease in aluminum toxicity in the soil, and better availability of nutrients hence phosphorus and calcium in particular which in turn resulted in better root growth and nutrient uptake. All these factors might have helped the process of distributing produced materials even more in the case of the varieties that are responsive to the use of fertilizer such as Gebelcho. To the contrary, the local variety probably has a lower genetic potential for the efficient partitioning of biomass particularly under acidic soil conditions.

The present results agree with the findings of Gebremeskel et al., (2011) who recorded considerable differences in harvest index among various faba bean varieties pointing out that genotype is an important factor in determining the yield efficiency. Along the same line, Abdulla et al. (2015) have found great variation in harvest index among the different faba bean genotypes. On the other hand, these results are different from those of Agung and McDonald, (1998) who found only a slight difference in harvest index among genotypes and emphasized the role of environmental conditions and genotype environment interactions in determining the extent of varietal differences. In our study, the grain, yielding varieties showed higher harvest index values and the low, yielding varieties had lower harvest index. Thus, it is implied that improving grain yield in faba bean may be mostly realized by raising the efficiency of dry matter partitioning to seeds rather than just increasing total biomass production. Gebremeskel et al., (2011) have also made such observations leading to the conclusion that harvest index is the main factor of yield performance. Collectively, the findings reveal that selection of varieties, especially the adoption of high harvest index genotypes like Gebelcho, along with suitable soil management practices such as liming, can significantly escalate grain yield performance in acidic soil conditions.

677 **Table 7.** Interaction effects of Faba bean varieties with NPSB and CHB fertilizer on AGDBM (kg), HSW (g), GYPH (kg), and HI (%)
678 faba bean varieties on Limed and Unlimed soil.

Varieties	Treatment integration	Limed				Unlimed			
		AGDBM	HSW	GYPH	HI	AGDBM	HSW	GYPH	HI
Local	7.5 t ha ⁻¹ CHB +25 kgha ⁻¹ NPSB ha ⁻¹	4202 ^c	55.33 ^c	1218.3 ^f	29.06 ^c	3572 ^c	51.66 ^f	948.7 ^d	22.33 ^b
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	4215 ^c	56.00 ^c	1226.7 ^f	29.17 ^c	3583 ^c	52.66 ^f	946.0 ^d	22.33 ^b
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹	4207 ^c	54.83 ^c	1221.7 ^f	29.10 ^c	3576 ^c	52.33 ^f	946.0 ^d	22.33 ^b
Gebelcho	7.5 t ha ⁻¹ CHB +25 kgha ⁻¹ NPSB ha ⁻¹	11851 ^a	86.41 ^a	4097.3 ^{ab}	34.59 ^{ab}	10073 ^a	74.66 ^{bc}	3479.0 ^a	29.66 ^a
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	11874 ^a	87.66 ^a	4184.0 ^a	35.28 ^a	10093 ^a	77.00 ^a	3483.7 ^a	29.66 ^a
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	11855 ^a	86.25 ^a	4093.3 ^{abc}	34.54 ^{ab}	10077 ^a	75.00 ^b	3479.3 ^a	28.00 ^a
Dosha	7.5 t ha ⁻¹ CHB +25 kgha ⁻¹ NPSB ha ⁻¹	11489 ^a	80.00 ^b	3956.3 ^d	34.64 ^{ab}	9766 ^a	70.66 ^c	3398.0 ^b	29.33 ^a
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	11495 ^a	81.00 ^b	3972.0 ^{bcd}	34.76 ^{ab}	9770 ^a	73.66 ^{bcd}	3396.7 ^b	29.33 ^a
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	11497 ^a	79.75 ^b	3961.3 ^{cd}	34.66 ^{ab}	9773 ^a	73.00 ^{cd}	3396.7 ^b	29.33 ^a
Tumsa	7.5 t ha ⁻¹ CHB +25 kgha ⁻¹ NPSB ha ⁻¹	10596 ^b	81.16 ^b	3492.0 ^e	33.01 ^b	9006 ^b	72.66 ^d	2968.3 ^c	28.00 ^a
	5 t ha ⁻¹ CHB + 50 kg ha ⁻¹ NPSB	10618 ^b	81.33 ^b	3492.0 ^e	34.76 ^{ab}	9025 ^b	74.00 ^{bcd}	2968.3 ^c	29.33 ^a
	2.5 t ha ⁻¹ CHB + 75 kgha ⁻¹ NPSB	10587 ^b	79.79 ^b	3491.0 ^e	33.02 ^b	8999 ^b	72.66 ^d	2967.3 ^c	29.66 ^a
LSD (0.05)		15.45	3.22	13.60	1.87	17.23	1.72	17.36	1.87
Significance		***	**	***	**	**	*	**	**
CV (%)		3.43	2.51	2.48	3.36	3.43	1.49	1.62	3.36

679

680 Where, AGDBM = above ground dry biomass (kg), HSW=Hundred seed weight (kg), GYPH=Grain yield ha⁻¹ (kg), LSD = Least
681 significance difference, CV=Coefficient of variance, * = significance, ** = highly significance *** = Very Highly significance

682

3.4.10 Partial Budget Analysis

683 Analysis of the partial budget, as listed in Tables 8 and 9, indicated that treatments (T1, T2, T3,
684 T10, and T11) were dominant, and treatments (T12, T6, T9, T5, T8, T4, and T7) were non-
685 dominated and thus selected for the analysis of the marginal rate of return (MRR). As shown in
686 Table 12, higher net benefits of 293,532 Ethiopian Birr (ETB ha⁻¹) or (\$ 4892.2) were recorded
687 from (T8) with application of 5 t CHB ha⁻¹ + 50 kg NPSB ha⁻¹ on lime-treated soil in the meher
688 season. The higher MRR was recorded from T8 (15900%), Table 8 and 9. Application 5 t CHB
689 ha⁻¹ + 50 kg NPSB ha⁻¹ (T5) was found to have the highest marginal net benefit compared to
690 other treatments tested in this study. This integration or treatment was relatively the best
691 integration by means of economic return. Hence, the usage of 5 t CHB ha⁻¹ + 50 kg NPSB was
692 found to be the best treatment to enhance the productivity for faba bean in the study area, Table 8
693 and 9. Then the variable and labor costs based on the current market were listed as NPSB 46 =
694 birr kg⁻¹, Biochar = 1 birr kg⁻¹, faba bean = 80 birr kg⁻¹, fertilizer application cost per person =
695 100 birr, and threshing cost per person = 0.5 birr kg⁻¹ Birr according to Adiyo Woreda Trade and
696 market development office (2023).

697 Table 8. Results of partial budget analysis to estimate the net benefit of fertilizer management of
698 Faba bean production in the meher season on limed soil.

Trt. No	Costs				TVC	AVGYH	AJ.GYH	GB	NB	MRR
	NPSB cost	CHB. Cost	Fert. App. Cost	Tresh. Cost						
T3	3450	1666.66	200	549.765	5866.43	1221.7	1099.53	76967.1	71100.7	-
T2	2300	3333.33	200	552.015	6385.35	1226.7	1104.03	77282.1	70896.8	D
T1	1150	5000	150	548.235	6848.24	1218.3	1096.47	76752.9	69904.7	D
T12	3450	1666.66	200	1570.95	6887.61	3491	3141.9	251352	244464	ND
T6	3450	1666.66	200	1782.45	7099.11	3961	3564.9	285192	278093	ND
T9	3450	1666.66	200	1841.85	7158.51	4093	3683.7	294696	287537	ND
T11	2300	3333.33	200	1571.4	7404.73	3492	3142.8	251424	244019	D
T5	2300	3333.33	200	1787.4	7620.73	3972	3574.8	285984	278363	ND
T8	2300	3333.33	200	1882.8	7716.13	4184	3765.6	301248	293532	ND
T10	1150	5000	150	1571.4	7871.4	3492	3142.8	251424	243553	D
T4	1150	5000	150	1780.2	8080.2	3956	3560.4	284832	276752	ND
T7	1150	5000	150	1843.65	8143.65	4097	3687.3	294984	286840	ND

699 Where, Trt = Treatments, NPSB cost= NPSB fertilizer cost, CHB cost = Coffee husk biochar cost, Fert.
700 App. Cost = Fertilizer application cost, Tresh. Cost = Threshing cost, AY = Average yield, Adj.y =
701 Adjusted yield, GFB = Gross field benefit, TVC = Total variable cost, NB = Net benefit, MRR =
702 Marginal return rate, D = Dominance, ND = Non- dominance

703 The treatment recorded the highest marginal rate of return, the integrated application of 2.5 t
704 CHB ha⁻¹ and 75 kg NPSB ha⁻¹(15900 %). The treatment received 7.5 t ha⁻¹ CHB + 25 kg ha⁻¹
705 NPSB (4609.1%), 5 t ha⁻¹ CHB + 50 kg ha⁻¹ NPSB (1984.8%) recorded from lime-managed soil.

706 Table 9. Marginal rate analysis of return from blended NPSB fertilizer rate and biochar on acidic
707 soil.

Trt. No	TVC	NB	MC	MNB	MRR (%)
T12	6887.61	244464	-	-	-
T6	7099.11	278093	211.5	33628.5	15900
T9	7158.51	287537	59.4	9444.6	15900
T5	7620.73	278363	462.223	9174.2	1984.8
T8	7716.13	293532	95.4	15168.6	15900
T4	8080.2	276752	364.067	16780	4609.1
T7	8143.65	286840	63.45	10088.6	15900

708 Where, Trt. = Treatment, TVC= Total variable cost, NB = Net benefit, MC= Marginal cost, MNB=
709 Marginal net benefit, MRR= Marginal rate of return.

710 Analysis of the partial budget as listed in Tables 10 and 11 indicated that treatments (T1, T2, T4,
711 T9, T10, and T11) was dominants and treatments (T7, T8, T5, T3, T6, and T12) were non-
712 dominated and thus selected for the analysis of marginal rate of return (MRR). As shown in
713 Table 11, higher net benefits of 243,627 Ethiopian Birr (ETB ha⁻¹) or (\$4,060.46) were recorded
714 from T5 with application of 5 t CHB ha⁻¹ + 50 kg NPSB ha⁻¹. The higher MRR was recorded
715 from T8 (156161%), followed by T7 (39106.6%), Table 10. Application 5 t CHB ha⁻¹ + 25 kg
716 NPSB ha⁻¹ (T8 and T7) was found to have the highest MRR compared to other treatments tested
717 in this study. This integration or treatment was relatively the best in terms of economic return.

718 Table 10. Partial budget analysis as influenced by blended NPSB fertilizer rate and biochar on
719 acidic soil in faba bean at Boka.

Trt. No	AVGYH	AJ.GYH	GB	TVC	NB	Dominance
T1	948.s6	851.4	59598	5742.36	53855.6	-
T4	946	851.4	59598	6259.03	53339	D
T7	2967.3	2670.57	213646	6651.95	206994	ND
T10	948.7	853.83	68306.4	6726.92	61579.5	D
T5	948.7	853.83	59768.1	6726.92	53041.2	D
T8	3396.7	3057.03	244562	6845.18	237717	ND
T5	3479.3	3131.37	250510	6882.35	243627	ND
T11	2968.3	2671.47	213718	7169.07	206549	D
T3	3396.7	3057.03	244562	7361.85	237201	ND
T6	3483	3134.7	250776	7400.68	243375	ND
T9	2968.3	2671.47	213718	7635.74	206082	D
T12	3398	3058.2	244656	7829.1	236827	ND

720 Where, Trt = Treatments, NPSB cost= NPSB fertilizer cost, CHB cost = Coffee husk biochar cost, Fert.
721 App. Cost = Fertilizer application cost, Tresh. Cost = Threshing cost, AY = Average yield, Adj.y =
722 Adjusted yield, GFB = Gross field benefit, TVC = Total variable cost, NB = Net benefit, MRR =
723 Marginal return rate, D = Dominance, ND = Non- dominance

Table 11. Marginal rate analysis of return from blended NPSB fertilizer rate and biochar on acidic soil.

Trt. No	TVC	NB	MC	MNB	MRR%
T12	6651.95	206994	-	-	-
T9	6845.18	237717	193.23	30723.6	15900
T6	6882.35	243627	37.17	5910.03	15900
T8	7361.85	237201	479.503	6426.7	15900
T5	7400.68	243375	38.835	6174.77	15900
T7	7829.1	236827	428.417	6548.4	156161

Where, Trt. = Treatment, TVC= Total variable cost, NB = Net benefit, MC= Marginal cost, MNB= Marginal net benefit, MRR= Marginal rate of return

Author Contributions

Nigatu Beyene: Conceptualization, Investigation, Software, Writing—original draft, Methodology, Validation, Visualization, Formal analysis, and Data curation. **Isreal Zewide** and **Girma Abebe:** Conceptualization, Methodology, Validation, Writing—review and editing, Investigation, Formal analysis, and Data curation. **Tamirat Wato:** Conceptualization, Investigation, Visualization, Validation, Data curation, Writing—review and editing. Finally all authors were approved the final version of the paper.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Research funding

This study did not receive any funding.

Acknowledgement

None

Conflict of Interest

The authors declared that there is no conflict of interest.

4. Conclusion

The study demonstrated that faba bean grain yield and yield-related traits were influenced by varietal differences and integrated soil fertility management practices under the acidic soil conditions of Boka Kebele, Adiyo District. Among the tested varieties, Gebelcho produced the highest grain yield (4,184 kg ha⁻¹), followed by Dosha (3,972 kg ha⁻¹) and Tumsa (3,492 kg ha⁻¹), whereas the local variety recorded the lowest yield (1,226.7 kg ha⁻¹). This indicates that the

improved varieties, particularly Gebelcho, have considerable potential for increasing faba bean productivity under the conditions of the study. The combined use of coffee husk biochar, NPSB fertilizer, and lime also resulted in improved crop performance compared with less integrated fertility-management practices. In particular, the application of 5 t ha⁻¹ coffee husk biochar with 50 kg ha⁻¹ NPSB fertilizer on lime-treated soil was among the best-performing treatment combinations for grain yield and yield components. The improved performance may reflect the complementary contribution of nutrient supply from NPSB, acidity correction through lime, and the potential contribution of biochar to nutrient retention and other soil properties. However, these mechanisms were not directly quantified in the present study and therefore require further investigation. Overall, the findings suggest that integrating an adapted improved variety with appropriate soil fertility management can be a promising strategy for improving faba bean production in acidic soils. Under the specific conditions of Boka Kebele, the Gebelcho variety combined with 5 t ha⁻¹ coffee husk biochar, 50 kg ha⁻¹ NPSB fertilizer, and lime can be considered a promising management option. Nevertheless, the recommendation should be interpreted within the conditions and scope of the experiment because the study was conducted at a limited location and over a limited period. Further multi-location and multi-season research is required to validate the consistency of these results and to determine the long-term effects, economic feasibility, and effects on soil fertility before wider recommendation.

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