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Research Article

Phosphorus Use Efficiency and Yield Performance of Haricot Bean (Phaseolus vulgaris L.) in South Omo Zone, Southern regional state, Ethiopia

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Abstract

Haricot bean (Phaseolus vulgaris L.) is an important pulse crop in Ethiopia, serving as a major source of food, income, and soil fertility improvement. Despite its importance, haricot bean productivity in many parts of the country remains low, mainly due to phosphorus (P) deficiency in soils and the use of low-yielding varieties. This study was conducted to evaluate the phosphorus yield efficiency of fifteen haricot bean varieties under contrasting phosphorus conditions in two districts (Ben Tsemay and Bako Dawula) of South Omo Zone, Southern Ethiopia. The experiment was laid out in a randomized complete block design with three replications at each location. Each variety was grown under two phosphorus treatments: with the recommended rate of phosphorus fertilizer and without phosphorus application. Data were collected on phenological traits (days to 50% flowering and 90% maturity), growth parameters (plant height and number of branches), and yield and yield components, including number of pods per plant, number of seeds per pod, thousand seed weight, biological yield, grain yield, and harvest index. Analysis of variance was conducted for individual locations and combined across locations. The results revealed significant differences among the haricot bean varieties in terms of phosphorus yield efficiency, grain yield, and other yield-related traits under both phosphorus conditions. Under the recommended phosphorus application, varieties Sere 119, Nasir, and Sere 125 produced the highest grain yields. In contrast, under no phosphorus application, Sere 125, Sere 119, Dinknesh, and Nasir performed better than the other varieties. Moreover, DRK, SAB 736, and Sere 125 exhibited superior phosphorus yield efficiency. These varieties show strong potential for improving haricot bean productivity in phosphorus-deficient soils and in low-input farming systems where phosphorus fertilizer use is limited.

Keywords: Haricot bean, Phosphorus, Yield efficiency.

Introduction

Haricot bean *(Phaseolus vulgaris L.)* is one of the most important pulse crops grown in Ethiopia, widely distributed across different agroecological zones depending on climatic conditions and socio-economic factors. The crop plays a vital role in food security and household income, serving as both a staple food and a major cash crop for smallholder farmers. In addition to domestic consumption, haricot bean is exported and contributes to foreign exchange earnings for the country [1,2]. In Ethiopia, both red and white seeded haricot bean types are among the most widely cultivated pulse crops. According to the Central Statistical Agency [3], Ethiopia's total annual production of haricot bean is estimated at 357,942.4 tons, with a national average yield of 1.69 t ha^{-1}. In the Southern Nations, Nationalities and Peoples' Regional State (SNNPRS), production reaches approximately 146,867.2 tons from 94,005.38 ha, resulting in an average productivity of 1.56 t ha^{-1}. However, haricot bean productivity in South Omo Zone is considerably lower, with a total production of only 5,125.2 tons harvested from 4,584.52 ha and an average yield of 1.2 t ha^{-1} [3]. In southern Ethiopia, haricot bean is widely cultivated and consumed as part of traditional diets, serving as an affordable source of protein that complements cereal-based staple foods such as maize (Zea mays L.) and Enset (Enset ventricosum), commonly known as false banana [2]. Beyond its use as grain, haricot bean residues play a vital role in smallholder farming systems, being utilized as livestock feed, fuel, mulching material, bedding, and construction inputs for rural housing, particularly among resource-poor farmers.

Despite its importance, haricot bean productivity in Ethiopia is constrained by several biotic and abiotic factors. Biotic constraints include diseases, insect pests, weeds, and the low yield potential of local landraces, while major abiotic constraints include low soil fertility, soil acidity, drought, waterlogging, and frost. Among soil fertility constraints, phosphorus (P) deficiency is one of the most critical factors limiting crop production [4]. Phosphorus is the second most important plant nutrient after nitrogen and is required in relatively large amounts for optimal plant growth and development [5]. Studies on Ethiopian soils have consistently shown that available phosphorus levels are generally low and insufficient to support optimum crop growth [6]. Although phosphorus fertilization can significantly increase crop yield, the high cost of inorganic fertilizers makes them unaffordable for many smallholder farmers [7-8].

Research findings under Ethiopian conditions and elsewhere in Africa have demonstrated substantial yield increases in haricot bean and other crops in response to phosphorus application [9-10]. However, long-term and continuous use of inorganic fertilizers may negatively affect soil quality. An alternative and sustainable approach is the use of crop varieties with higher phosphorus use efficiency, particularly in soils with low available phosphorus. Significant genetic variation in phosphorus use efficiency among crop varieties has been reported [11-15]. [16] emphasized the importance of selecting crop cultivars adapted to low or medium soil fertility conditions to address soil fertility challenges in Ethiopia.

Although breeding programs for haricot bean in Ethiopia have largely focused on improving grain yield and seed quality through varietal development and fertilizer application, limited attention has been given to improving phosphorus yield efficiency. This gap highlights the need for systematic evaluation of released haricot bean varieties under contrasting phosphorus conditions. Therefore, this study was conducted to evaluate the phosphorus use efficiency and yield performance of haricot bean (Phaseolus vulgaris L.) in the South Omo Zone, Southern Ethiopia.

Materials and Methods

Description of the Study Area

The experiment was conducted at two locations, Bena Tsemay and Bako Dawula districts, in the South Omo Administrative Zone of the Southern Regional State, Ethiopia. Since the districts are recently established and reliable agroecological data are limited, site-specific information was generated during the study. Soil samples were collected from each experimental field and analyzed for selected physicochemical properties, including texture, pH, and organic matter. Altitude of each experimental site was determined using a Global Positioning System (GPS).

Treatments and Experimental Design

Fifteen nationally released haricot bean (Phaseolus vulgaris L.) varieties obtained from Melkassa and Debre Zeit Agricultural Research Centers were evaluated (Table 1). The experiment was laid out in a randomized complete block design with three replications. Two phosphorus treatments were applied: recommended phosphorus rate and no phosphorus application. Each block was divided into two adjacent sub-blocks representing the phosphorus treatments, separated by 1 m. Each plot had a size of 3.2 m² (1.6 m × 2 m) and consisted of four rows with inter-row and intra-row spacing of 40 cm and 10 cm, respectively. Twenty-five seeds were planted per row. Phosphorus was applied as triple superphosphate (TSP, 46% P_2O_5) at the recommended rate as a basal application. Nitrogen was uniformly applied to all plots in the form of urea at a rate of 25 kg ha^{-1}. All other agronomic practices were carried out according to the national recommendations for haricot bean production

No	Name of varieties	Year of release	Altitude	Seed color	Productivity	
					On research's	On farmer's
1	Ser 125	2017	1000-1850	Medium red	21	19-21
2	Ser 119	2014	1300-1800	Large red	22-26	19-24
3	Deme	2008	1300-1800	Large red	19-22	18-20
4	DRK	2007	1300-1950	Large dark	19-22	16
5	Awash 2	2007	1300-1950	Large red	19-27	16
6	KAT B9	2017	1100-1950	Large red	17-27	17-23
7	Awashmitin	2017	1100-2150	Large yellow	21	19-21

8	SAB 736	2017	1100-1950	Large red	19-24	21
9	Birazil	2013	1300-1650	Medium red	22-30	19-23
10	Dinkinesh	2013	1300-1650	Medium yellow	19-33	17-25
11	SAB 632	2012	1400-2200	Large red	25	20
12	KAT B1	2011	1400-2200	Large red	30	22
13	Melkadme	2006	1300-1800	Medium red	28	18
14	Local	2006	1400-1850	Small red	25-30	20-23
15	Nasir	2014	1450-2000	Small red	33	25

Table 1. Released haricot bean varieties used in phosphorus yield efficiency trial

Source of the varieties: MARC

Physico-chemical Properties of the Soil

The physico-chemical properties of the soils at the experimental sites were determined before sowing of the haricot bean crop and are presented in Table 2. Soil pH at both locations ranged from slightly acidic to near neutral. The soils contained moderate levels of organic matter and organic carbon, while total nitrogen content varied between the sites. Cation exchange capacity (CEC) values indicated low to moderate nutrient-holding capacity. Available phosphorus levels were generally low, confirming phosphorus deficiency at the study sites and justifying the evaluation of haricot bean varieties under contrasting phosphorus conditions.

Location	pH	OM (%)	OC (%)	TN (%)	CEC (cmol kg^{-1})	Available P (mg kg^{-1})
Goldiya	6.88	4.57	2.65	0.07	13.8	12.35
Kure	6.57	4.61	2.69	0.11	9.6	13.83

Where pH = soil-to-water suspension ratio (1:2.5), OM = organic matter, OC = organic carbon, TN = total nitrogen, CEC = cation exchange capacity, and P = available phosphorus

Table 2. Major physico-chemical characteristics of the soils of the study area before sowing

Data Collected

Data were collected on phenological, growth, and yield-related parameters.

Phenological Observations Included

Days to 50% flowering:-recorded as the number of days from planting to when 50% of plants in a plot had at least one open flower.

Days to 90% maturity:- measured as the number of days from planting to when 90% of plants in a plot showed physiological maturity, indicated by a change in pod and leaf color.

Plant height :- was measured in centimeters from the soil surface to the tip of the main stem at maturity.

The number of branches per plant:- was determined by counting branches on ten randomly selected plants per plot.

Yield and yield component data included

The number of pods per plant :recorded as the average number of mature pods counted from ten randomly selected plants at harvest.

The number of seeds per pod :-determined from five randomly selected pods per plant.

Hundred seed weight:- was measured in grams by weighing 100 seeds after harvest.

Grain yield :- was estimated by harvesting the two central rows of each plot and converting the yield to a plot basis.

Biological yield :- was determined by oven-drying the aboveground biomass of five sampled plants and expressing the average weight per plant.

Harvest index:-was calculated as the ratio of grain yield to biological yield, multiplied by 100.

Phosphorus yield efficiency (PYE): The efficiency of phosphorus yield was calculated according to the equation formulated by Khair et al., 2002

$$PYE = \frac{\text{Grain yield of treated plants (g)}}{\text{Phosphorus applied to treated plants (g)}}$$

Statistical Analysis

Data were first subjected to analysis of variance (ANOVA) for each location and phosphorus level separately. Homogeneity of error variances between locations was tested using the F-ratio (larger mean square error divided by smaller mean square error) before conducting combined analysis. Pooled analysis of variance across locations and phosphorus levels was performed using [17]. Treatment means were compared using Duncan's Multiple Range Test (DMRT) at the appropriate significance level, following the procedure described by [18] Gomez and Gomez (1984).

Result

Analysis of Variance

The analysis of variance revealed significant differences among haricot bean genotypes for most agronomic and yield-related traits under both phosphorus-applied and phosphorus-deficient conditions across locations (Tables 3 and 4). This indicates the presence of substantial genetic variability among the tested genotypes. Under phosphorus application, genotypes exhibited significant variation for all traits except days to 90% maturity, number of seeds per pod, and harvest index across locations (Table 4). Conversely, under no phosphorus application, genotypic differences were significant for most traits, except days to 50% flowering and days to 90% maturity at both locations (Table 3).

The combined analysis across locations showed that genotype effects were significant for nearly all traits, except 100-seed weight and harvest index under phosphorus application (Table 4), and days to 50% flowering, days to 90% maturity, and 100-seed weight under phosphorus-deficient conditions (Table 3).The genotype × location (G × L) interaction was highly significant for most traits under both phosphorus regimes, except days to 50% flowering, days to 90% maturity, and harvest index (Tables 3 and 4). At Goldiya, phosphorus application significantly affected days to 50% flowering, plant height, number of pods per plant, biological yield, and grain yield across genotypes (Table 4). The genotype × phosphorus (G × P) interaction was significant for days to 90% maturity, plant height, number of seeds per pod, grain yield, and harvest index (Table 4). At Kure, phosphorus application had a highly significant effect on most traits, except days to 90% maturity and plant height (Table 4). The genotype × phosphorus interaction was significant for all traits except days to 50% flowering, days to 90% maturity, and plant height. Genotypes also showed highly significant differences for most traits at this location (Table 4). The three-way interaction (genotype × location × phosphorus) was significant for most traits, except days to 50% flowering, days to 90% maturity, plant height, and number of pods per plant when evaluated across environments. In addition, the main effects of location, phosphorus, and genotype were highly significant for most traits (Table 5)

Goldiya					Kure			Combined			
trait	G	Error		G	Error		L	G	G X L	Error	
	df=14	df=28	CV	df=14	df=28	CV	df=1	df=14	df=14	df=58	CV
DF	13*	3.2	4.2	13.3n	11.8	8.3	15.2	17.3n	9.94n	7.22	6.4
DM	8.5n	7.3	3.7	11.8n	6.8	3.6	40	13.7n	6.7n	8.7	4.1
PLH	154**	28	13.9	386	29	12	1.2*	453**	87*	28	12.7
NB	23**	0.5	7.3	0.5n	0.4	14	645*	13.4**	10.7*	0.4	9.4
PPP	34**	2	10.3	0.27**	0.9	7.4	41.3*	39**	23**	1.5	9.1
PPP	2.9*	0.6	13.2	2.6**	0.4	12.7	22.5	3.55**	2.1**	0.54	13
HW	**		4.4	**		8.4					6.6
GY	0.01**		5.3	16.3**		15.3		0.55**	0.02**	0.01	11.4
BY	0.3**	0.01	5.4	0.24**	0.1	12.8	0.38	0.45**	0.09**	0.02	10.5
HI	190**	5.2	7.5	169**	16.3	14.3	359	219**	139**	12.2	11.56

DF = Days to 50% flowering, DM = Days to 90% maturity, GFP= Grain filling period, CHS= chocolate spot, PLH = Plant Height, PPP = Number of pod per plant, SPP = Number of seed per pod, TSW = Thousand seed weight, BY= Biological yield, GY=Grain yield, HI = Harvest index, CV = Coefficient of variation, ** = highly significant (P < 0.01), *= significant (P 0.05

Table 3. Mean square of genotypes for grain yield and other agronomic traits evaluated under no P application at Goldiya , kure and combined over location.

Goldiya				Kure		Combined				
Trait	Genotype	error	CV	Error	CV	L	G	G X L	Error	CV
	df=14	df=28		df=28		d=1	df=14	df=14	df=58	
DF	8.2**	1.4	2.8	1.4		21.5	20**	10	6.8	6.2
DM	10n	4.2	2.8	4.2	2.8	32	25**	10.9**	3.12	2.5
PLH	130n	63	17	63	17	2.9	306**	81.5ns	41.5	13.7

NB	14*	3.8	18.5	3.8	18	677	8.5**	7.83**	2.11	18.6
PPP	25**	4.7	12.6	4.6	12	291	48**	21.2**	3.36	11.9
PPP	2.3n	0.9	17.4	0.9	17	3.6	3.3**	2.4ns	0.76	15.8
HW	**		5.1		5	0.01	0.002	0.001	0.001	7.1
GY	0.03**		7.7		7.7	0.08	0.05**	0.02**	0.001	9.4
BY	0.28**	0.1	11.3		11	0.66	0.04**	0.18**	0.02	9.6
HI	38n	11	12.4	11	12	17.5	0.22n	64.1ns	11.6	12.8

** = highly significant (P < 0.01), *= significant (P 0.050) ns= non-significant

Table 4. Mean squares of genotypes for grain yield and agronomic characters evaluated under application of recommended rate of P at Goldiya, kure and combined over location

trait	Location	phosphors	Genotype	G X L	G X P	L X P	L X P X G	Error	CV
	df=1	df=1	df=14	df=14	df=14	df=14	df=14	df=58	
DF	36.4	0.05	33.9**	12.8	3.8	0.27	7.1	7.1	6
DM	72**	5.6ns	36.4**	12	2.3	0.2	4.8	5.6	3
PLH	646**	1085**	71.6**	121**	4.4n	5.3ns	46ns	34	13
NB	1333**	10ns	15.6*	12**	6.7**	0.3ns	65**	0.8	12
PPP	276**	123**	70**	32**	16**	56**	11**	2.4	10
PPP	22**	1.2ns	4.6**	1.9*	2.2**	4ns	1.8ns	0.6	14
HW	*	ns	**	**	**	ns	*		7
GY	0.1ns	4.3**	0.7**	0.2**	0.1**	1.1**	0.1**	0.1	10
BY	0.05**	0.1**	0.1**	0.2**	0.2**	0.3**	0.1**	0.01	10
HI	268*	574**	158**	73**	12**	109ns	129**	12	12

** = highly significant (P < 0.01), *= significant (P 0.050) ns= non-significant

Table 5. Combined analyses of variances for grain yield and other traits under P and no P condition for the 15 genotypes at Goldiya and kure.

Combined Mean Performance under No Phosphorus Application

The combined mean performance of haricot bean varieties evaluated across Goldiya and Kure locations under no phosphorus application revealed significant variation among genotypes for grain yield and yield-related traits (Table 6). This variation indicates differential ability of the varieties to perform under phosphorus-deficient conditions.

Under no phosphorus application, Sere 119, Nasir, and Sere 125 were identified as the superior varieties in terms of grain yield, producing 1.75, 1.65, and 1.60 t ha^{-1}, respectively (Table 6). The better performance of these varieties under low phosphorus conditions suggests their higher efficiency in phosphorus uptake and utilization, making them suitable for cultivation in phosphorus-deficient soils. In contrast, Birazil, KAT B9, and Melkadme recorded relatively lower grain yield values, indicating their poor adaptation to low soil phosphorus availability.

Varieties also exhibited significant differences in phenological traits. Days to 50% flowering ranged from 38.5 days (DRK) to 43.6 days (Deme and Awash Mitin), while days to 90% maturity varied between 70.0 days (Birazil) and 74.8 days (Awash Mitin) (Table 6). These differences suggest variability in growth duration among genotypes, which can influence adaptation to stress-prone environments.

Plant height showed wide variation, with Deme (56.2 cm), Awash Mitin (51.5 cm), and Dinkinesh (51.1 cm) recording taller plants, while KAT B9 (28.4 cm) and SAB 736 (31.3 cm) were relatively shorter (Table 6). Taller plant stature may have contributed to increased biomass production; however, higher biomass did not always correspond to higher grain yield, indicating differences in assimilate partitioning.

Yield components such as number of pods per plant (PPP) and number of seeds per pod (SPP) also varied significantly among varieties. Awash Mitin, Sere 119, and Sere 125 recorded higher pod numbers, which contributed to their relatively better grain yield performance (Table 6). Grain yield differences among varieties were closely associated with these yield components rather than with hundred seed weight, which showed limited contribution under phosphorus stress.

Biological yield and harvest index also differed significantly. Sere 119 recorded the highest biological yield (0.62 kg) with a relatively high harvest index (35.3%), reflecting its efficient conversion of biomass into grain under phosphorus-deficient conditions (Table 6). Similarly, Melkadme showed the highest harvest index (41.8%), though this did not translate into the highest grain yield due to lower total biomass production. Overall, the results demonstrated that varieties such as Sere 119, Sere 125, and Nasir consistently performed better under no phosphorus application across locations (Table 6). These varieties can therefore be considered suitable candidates for cultivation in low-phosphorus soils and can serve as valuable genetic resources for breeding programs aimed at improving phosphorus use efficiency in haricot bean

Entry	DF	DM	PLH	NB	PPP	SPP	HSW	GY	BY	HI
Ser 125	41bac*	72bac	44.03cd	8.8bc	15.5c	6.3bac	0.02h	1.6bac	0.49b	30.3ed
Ser 119	42.8ba	73.6bac	47.5bc	9.2b	17.2b	6bc	0.03dc	1.75a	0.62a	35.3cb
Deme	43.6a	74.5ba	56.2a	8.2cd	13.3ed	5.8bdc	0.034ba	1.58c	0.42cd	27gh
DRK	38.5d	70.2ed	38.7fg	7gh	11.2gh	5.5dc	0.033bc	1.2gf	0.3f	27.8ef
Awash 2	43.3ba	73bac	51.1ba	8.3cd	14.8cd	6.5ba	0.02fg	1.4d	0.28gh	19.9j
KAT B9	40.8dc	71edc	28.4i	7.6dc	12.3fg	4f	0.03de	1.0h	0.31f	36.2b
Awashmitin	43.6ba	74.8a	51.5ba	10.2a	19.2a	7a	0.01i	1.38de	0.30gf	22.3j
SAB 736	41.2bc	71.2edc	31.3hi	5.8i	10.3h	5.2d	0.03de	1.2gf	0.35ef	29.4ed
Birazil	38.6dc	70e	35.5fg	6h	14.2cd	6.3bac	0.02g	0.8hi	0.24h	35cb
Dinkinesh	43.3ba	73.2bac	51.1ba	7.2fg	14.3de	6bdc	0.01i	1.3ed	0.4ed	31.3ed
SAB 632	41.6bac	71.5edc	32.6hg	7.5de	13.6ef	5.8bdc	0.035a	1.2ef	0.43cd	34.6cb
KAT B1	41.5bc	70.5ed	31.6hi	6.2h	10.2h	5.2ed	0.02f	0.9h	0.31f	33.4cb
Melkadme	40.5dc	72.3edc	40.1fe	7.8de	15c	5.6bdc	0.031dc	1.1gh	0.46cb	41.8a
Local	43.1ba	71.6edc	42.8cd	4.3j	10.5h	4.5ef	0.026f	1.4dc	0.33f	23.2hi
Nasir	43ba	73.1bdc	45.9bc	6.3h	13.8dc	5.6bdc	0.019i	1.65ba	0.4d	24.9gh
Mean	41.78	72	41	7.3	13	5.7	6.6	0.38	1.32	30
CV	6.5	3.7	12.7	9.4	9	13	0.027	11	10	11
LSD	3.2	3.2	6.2	0.8	1.4	0.8		0.2	0.05	4.03

*Values followed by the same letters within a column are not significantly different at $p \leq 0.05$ according to Duncan's Multiple Range Test (DMRT).

Table 6. Combined mean performance for yield and yield components of haricot bean under no P application across Goldiya and kure locations

Combined over location mean performance of haricot bean varieties under recommended rate of P application

The combined mean performance of haricot bean Genotypes across locations under the application of the recommended rate of phosphorus is presented in Table 7. The results of the combined analysis indicated that Sere 125 and Sere 119 were the superior varieties in terms of grain yield, each producing 0.59 kg under the recommended phosphorus application. In addition, Dikinesh and Sere 119 recorded the highest biological yield and number of seeds per pod, respectively, suggesting that these varieties efficiently converted applied phosphorus into biomass production and reproductive development. The superior performance of these genotypes under phosphorus application highlights their potential for cultivation in areas where phosphorus fertilizer is available and supports their suitability for improving haricot bean productivity under enhanced soil fertility conditions (Table 7).

Entry	DF	DM	PLH	NB	PPP	SPP	HSW	GY	BY	HI
Ser 125	42.66b*	72.8bac	52ba	9ba	20.2a	5.6bac	0.02ef	0.59a	1.76dc	33.5a
Ser 119	42.8ba	73.3ba	49.9bc	7.3bdc	19.5a	5.8bac	0.02ef	0.59a	1.9ba	30.69ba
Deme	42.2ba	74.5a	50.8bac	6.8dce	13.1g	6bac	0.03ba	0.42ed	1.7ed	24.8cd
DRK	40.5bc	69f	44.1de	9ba	14.1fg	5.5ed	0.04a	0.45cbd	1.5fg	31.2a

Awash 2	44.6a	71.8dc	56.2a	8bac	18.3a	5.8bac	0.01f	0.35f	1.5fg	23.6ed
KAT B9	40.3bc	70.2ef	39.6ef	9ba	15.5cd	5.5dc	0.03ba	0.43cd	1.56ef	27.7bc
Awashmitin	42.5ba	74.5a	55ba	9ba	16.5cd	6.6a	0.01f	0.42ed	1.78dc	23.4e
SAB 736	40.5bc	70ef	38.8f	9.3a	15.3cd	6bac	0.02ef	0.27g	1.08h	25.8cd
Birazil	37.8c	68.8f	36.8f	6e	14efg	4.5ed	0.02ef	0.28g	1.23h	23.3e
Dinkinesh	44.8a	74.3a	56.5a	6.8cde	15efg	6bac	o.o3ba	0.48b	2.0a	24.05cd
SAB 632	42.5ba	70.3ef	37.4f	7.8bac	13.3fg	5dc	0.03ba	0.45cbd	1.66ef	27.4cd
KAT B1	40.6bc	68.3f	37.8f	5.8e	8.6h	3.6e	0.03ba	0.38ed	1.4g	27.8bc
Melkadme	40bc	72.3dc	46.9dc	8.6ba	17.3bc	6.2ba	0.03	0.36f	1.56fg	23.5ed
Local	42.6ba	73bac	51.2bac	6e	15efg	5dc	0.02	0.45bd	1.76dc	26.07cd
Nasir	42.6ba	73bac	48.6bdc	8.3bac	14.3efg	5.6bac	0.02	0.48b	1.92bac	25.4ecd
Mean	41.8	71	14.9	7.8	15	5.5	0.03	0.43	1.6	26
CV	6.5	3	46.8	22	17	17.6	14	17	14	17
LSD	3.1	2.5	8.07	2.1	3	1.12	0.05	0.08	0.27	5.4

* Values followed by the same letters within a column are not significantly different at p ≤ 0.05 according to Duncan's Multiple Range Test (DMRT).

Table 7. Combined mean performances of yield and yield components of haricot bean varieties under application of recommended rate of phosphorus across location.

Phosphorus Yield Efficiency

Following the methodology of Ozturk et al. (2005), varieties were classified as phosphorus yield (PYE) efficient if their PYE values were equal to or above the mean, and as inefficient if their PYE values fell below the mean. Based on this criterion, 46% of the varieties at Goldiya and 73% of the varieties at Kure were identified as PYE efficient. In the combined analysis across locations, 60% of the varieties were classified as PYE efficient (Table 8).

Correlation

Relationship between Agronomic Characters

The Genotypic correlation patterns among traits under both no phosphorus (no P) and phosphorus (P) fertilizer application are presented in Table 9. Some traits showed similar correlation patterns under both P levels, while others differed. For instance, grain yield exhibited a strong positive correlation with the number of pods per plant and biomass yield under P application, and it did not show any negative correlations with other traits. Under no P application, grain yield had a strong positive correlation with the number of pods per plant, and under P application, it showed a strong correlation with the number of days to grain filling. Conversely, grain yield was not correlated with the number of seeds per pod at either P level, with the number of days to grain filling under no P application, or with the number of pods per plant under P application. However, it was positively correlated with thousand-seed weight under both P levels (Table 9).

	Goldiya			Kure			Combined		
Variety	**GY WP**	**GY WOP**	**PYE**	**GYWP**	**GY WOP**	**PYE**	**GYWP**	**GYWOP**	**PYE**
Ser 125	0.63	0.48	4.79	0.65	0.49	1.66	0.59	1.6	3.22
Ser 119	0.5	0.52	0.73	0.68	0.71	-0.73	0.59	1.75	-0.73
Deme	0.54	0.48	1.77	0.31	0.35	-1.35	0.42	1.58	0.21
DRK	0.52	0.33	5.73	0.39	0.33	2.1	0.45	1.2	3.91
Awash 2	0.4	0.28	3.65	0.3	0.27	0.73	0.35	1.4	2.2
KAT B9	0.56	0.33	7.2	0.3	0.28	0.81	0.43	1.0	4
Awashmitin	0.43	0.33	2.94	0.4	0.27	3.96	0.42	1.38	3.44
SAB 736	0.23	0.47	-7.5	0.3	0.23	2.81	0.27	1.2	-2.34
Birazil	0.27	0.25	0.52	0.3	0.23	2.29	0.28	0.8	1.41
Dinkinesh	0.53	0.38	4.58	0.43	0.42	0.3	0.48	1.3	2.45

SAB 632	0.46	0.44	0.72	0.45	0.42	0.94	0.45	1.2	0.83
KAT B1	0.43	0.37	1.8	0.32	0.24	2.5	0.38	0.9	2.18
Melkadme	0.43	0.37	2.08	0.28	0.55	-2.44	0.36	1.1	-3.2
Local	0.51	0.31	6.25	0.39	0.36	0.94	0.45	1.4	3.59
Nasir	0.45	0.35	3.02	0.52	0.46	1.98	0.48	1.65	2.5
Mean	0.42	0.38	2.45	0.4	0.4	0.64	0.43	0.38	1.58
CV	7.7	5.33	15.2	11.2	15.4	18	17	11	14
LSD	0.1	0.04	2.32	0.07	0.1	2.31	0.08	0.2	2.32

WP=with P fertilizer application; WOP=without P fertilizer application; PYE =Phosphorus yield efficiency, CV= Coefficient of variation; LSD= Least significant differences

Table 8. Phosphorus yield efficiency of 15 released haricot bean varieties grown under P and no P fertilizer application at Goldiya and kure

	DF	DM	PLH	NB	PPP	SPP	HSW	GY	BY	HI
DF1	1	0.41**	0.38**	0.18	0.26	0.23	-0.22	0.31	0.41**	-0.02
DF0	1	0.11	0.18	0.45	0.18	0.13	-0.09	0.22	0.3	-0.05
DM1		1	0.47**	0.22	0.32	0.23	-0.22	0.31	0.41**	-0.02
DM0		1	0.26	0.29	0.25	0.24	-0.09	0.166	0.26	-0.07
PLH1			1	0.002	0.3	0.44**	-0.33	0.22	0.43**	-0.13
PLH0			1	-0.13	0.21	0.21	-0.3	0.18	0.55	-0.37
NP1				1	0.56**	0.3	-0.02	0.27	0.2	0.12
NB0				1	0.52**	0.55**	-0.07	0.1	0.01	0.08
PPP1					1	0.43**	-0.15	0.39**	0.34**	0.13
PPP0					1	0.52**	-0.25	0.29	0.25	0.02
SPP1						1	-0.14	0.13	0.38	-0.24
SPP0						1	-0.25	0.09	0.06	0.006
HSW1							1	0.01	-0.15	0.2
HSW0							1	0.15	-0.11	0.17
GY1								1	0.68**	0.62**
GY0								1	0.54**	0.36
BY1									1	-0.12
BY0									1	-0.07
HI1										1
HI0										1

Subscript "0" indicates that the trait is under no P application while "1" indicates the trait is under P fertilizer application.; * and ** indicate significant correlation among the traits at 5 and 1% significance levels while ns indicates none significant correlation

Table 9. Correlation coefficients (r) between agronomic traits in 15 faba bean genotypes in the absence and presence of P fertilizer in Ethiopia

Discussion

Analysis of variance

The significant genotypic differences observed for most agronomic and yield-related traits under both phosphorus regimes indicate substantial genetic variability among the tested haricot bean genotypes. Such variability is essential for the effective selection and improvement of phosphorus-efficient genotypes, as also reported by [14,19]. The lack of significant genotypic variation for phenological traits such as days to 50% flowering and days to 90% maturity under phosphorus-deficient conditions suggests that these traits are relatively stable and less influenced by phosphorus availability. Similar findings were reported by [20 -21] common bean is largely under genetic control and less responsive to soil nutrient variation. In contrast, yield and biomass-related traits showed greater responsiveness to phosphorus availability, as evidenced by significant genotype effects and interactions. This confirms that phosphorus plays a crucial role in enhancing biomass accumulation and yield formation, consistent with the findings of [22] , who emphasized the importance of phosphorus in root development and carbon partitioning. The highly significant genotype × location interactions for most traits under both phosphorus regimes indicate differential genotype performance across environments. This underscores the need for multi-location testing to identify genotypes with stable performance and wide adaptation, as suggested by[23 -24]. The significant genotype × phosphorus interactions observed at both Goldiya and Kure further demonstrate variability in phosphorus use efficiency among genotypes. This suggests that certain genotypes possess superior ability to utilize applied or native soil phosphorus, making them promising candidates for low-input production systems. Finally, the significant three-way interaction (genotype × location × phosphorus) for most traits indicates that genotype response to phosphorus application is strongly influenced by environmental conditions. This highlights the combined influence of genetic factors, nutrient management, and location-specific conditions on haricot bean performance

Effect of Phosphorus on Agronomic and Phenological Characters

Plant Height

Phosphorus application significantly influenced plant height of haricot bean varieties at both experimental locations (Goldiya and Kure), indicating the important role of phosphorus in vegetative growth . The maximum plant height values of 69.2 cm under no phosphorus application and 61.0 cm under phosphorus application were recorded at Kure, demonstrating considerable variation among genotypes and environments. Overall, phosphorus application enhanced plant height across locations, suggesting improved root development, nutrient uptake, and cell division. These findings are consistent with the reports of [25], who observed increased plant growth in legumes with phosphorus fertilization. Phosphorus is known to stimulate early root growth and energy transfer processes, which ultimately enhance vegetative development and plant stature [26-27]. The observed variation between locations may be attributed to differences in inherent soil fertility, moisture availability, and genotype–environment interaction.

Effect of Phosphorus on Yield and Yield Components of Haricot Bean Varieties

Number of Pods per Plant

The number of pods per plant, a key yield component, was significantly increased by phosphorus application at both locations . Maximum pod numbers were consistently recorded under phosphorus-applied conditions for most varieties, indicating improved reproductive performance. This increase in pod number may be attributed to enhanced photosynthetic efficiency and better assimilate partitioning resulting from adequate phosphorus availability.

These results agree with [28], who reported a significant increase in pod number of haricot bean with increasing phosphorus rates. Similar findings were also reported by [29] in soybean, where phosphorus application resulted in increased pod formation due to improved flowering and reduced flower and pod abortion. The strong response of pod number to phosphorus highlights its importance as a major determinant of grain yield under phosphorus-limited conditions.

Grain Yield

Grain yield responded positively to phosphorus application, although the magnitude of response varied among varieties and locations. At Kure, the maximum grain yield values of 0.71 kg under no phosphorus application and 0.68 kg under phosphorus application were recorded for Sere 125, indicating its superior adaptation to both low and adequate phosphorus conditions. At Goldiya, phosphorus application increased grain yield across all varieties, reflecting a clear yield response to phosphorus fertilizer.

These findings are in agreement with [30], who reported increased bean yield with increasing phosphorus rates, [31], who observed a significant and linear increase in haricot bean grain yield in response to phosphorus fertilization. The yield improvement associated with phosphorus application is largely due to its role in energy transfer, root proliferation, nodulation, and efficient utilization of photosynthates for grain formation [22].

Phosphorus Yield Efficiency

Phosphorus yield efficiency (PYE) varied markedly among haricot bean varieties and locations , reflecting differences in the ability of genotypes to acquire and utilize applied phosphorus. At Goldiya, the genotypes Local, Sere 125, and Dinkinesh exhibited the highest phosphorus yield efficiency, while SAB 736, Sere 119, and KAT B1 showed the lowest PYE values. In contrast, at Kure, the highest phosphorus yield efficiency was recorded for Awash Mitin, SAB 736, and Birazil, whereas Melkadme, Deme, and Deme exhibited the lowest PYE. When data were combined across locations, KAT B9, Awash Mitin, and DRK were identified as the most phosphorus-yield-efficient genotypes. Across all varieties, the mean PYE at Kure was lower than that of Goldiya, indicating a reduced response to applied phosphorus at Kure. This limited response may be attributed to relatively adequate soil phosphorus levels at Kure, as indicated by pre-sowing soil analysis. Similar observations have been reported by[32- 33], who noted that phosphorus-efficient genotypes often show reduced yield response to fertilizer application when grown on soils with sufficient available phosphorus. This suggests that phosphorus-efficient varieties are particularly valuable for low-input production systems and phosphorus-deficient soils, where fertilizer accessibility is limited

Conculsion

The present study demonstrated considerable genetic variability among haricot bean varieties in terms of phosphorus yield efficiency, grain yield, and associated agronomic traits under both phosphorus-applied and phosphorus-deficient environments. The superior performance of Sere 119, Sere 125, Nasir, and Dinknesh across contrasting phosphorus conditions highlights their adaptability and efficiency in utilizing limited soil phosphorus. Furthermore, the identification of DRK, SAB 736, and Sere 125 as phosphorus-efficient varieties confirms the potential of exploiting varietal differences to improve productivity on phosphorus-deficient soils. Overall, the results indicate that the use of phosphorus-efficient haricot bean varieties can serve as a sustainable and cost-effective approach to enhance crop productivity, particularly for smallholder farmers cultivating crops on low-fertility soils in Ethiopia.

Recommendation

Based on the findings of this study, the following recommendations are proposed:

1. Sere 119, Sere 125, Nasir, and Dinknesh should be promoted for cultivation in phosphorus-deficient areas due to their superior grain yield and phosphorus use efficiency.
2. Farmers with limited access to phosphorus fertilizers can adopt phosphorus-efficient varieties as a practical strategy to improve haricot bean productivity.
3. Plant breeding programs should prioritize phosphorus yield efficiency as a key selection criterion for developing varieties adapted to low-phosphorus soils.
4. Further research should be conducted to investigate the physiological and genetic mechanisms responsible for enhanced phosphorus uptake and utilization in haricot bean varieties.
5. Multi-location and multi-season studies are recommended to validate the stability and performance of identified phosphorus-efficient varieties under diverse agroecological conditions.

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References

1. Mitiku Haile (1990), “Biological nitrogen fixation by haricot bean in Ethiopia”, Research on Haricot Bean in Ethiopia: an Assessment of Status, Progress Priorities and Strategies, *Proceedings of a National Workshop held in Addis Ababa*, 1-3 October 1990, 114 p.
2. Tenaw Workayehu and Yeshi Chiche (1990), “Importance, production system and problems of haricot bean in the southern zone of Ethiopia”, Research on Haricot Bean in Ethiopia: an Assessment of Status, Progress, Priorities and Strategies, Proceedings of a *National Workshop held in Addis Ababa*, 1-3 October 1990, 114 p
3. Central Statistical Agency (CSA). (2017). Agricultural Sample Survey 2016/2017 (Volume I): Report on Area and Production of Major Crops. Addis Ababa, Ethiopia
4. Asfaw, Asrat, Conny JM Almekinders, Matthew W. Blair, and Paul C. Struik. "Participatory approach in common bean (Phaseolus vulgaris L.) breeding for drought tolerance for southern Ethiopia." *Plant breeding* 131, no. 1 (2012): 125-134.
5. FAO (Food and Agriculture Organization). (1984). Fertilizer and Plant Nutrition Guide. FAO Fertilizer and *Plant Nutrition* Bulletin No. 9. Rome, Italy.
6. Tamirat, B. (1992). Phosphorus status of Ethiopian soils. Soil Science Bulletin, 3, 45–52.
7. Beem, P. C., & Smith, M. E. (1997).Economic constraints to fertilizer use by smallholder farmers in *sub-Saharan Africa*. Fertilizer Research, 48(2), 121–128.
8. Quiñones, Marco A., Norman E. Borlaug, and Christopher R. Dowswell. "A fertilizer-based green revolution for Africa." *Replenishing soil fertility in Africa* 51 (1997): 81-95.
9. Amare, G., Tarekegn, B., & Mekonnen, H. (2005). Response of haricot bean (Phaseolus vulgaris L.) to phosphorus fertilization under Ethiopian conditions. *Ethiopian Journal of Agricultural Sciences*, 18(1), 45–56.

10. Fisseha, A., & Yayis, R. (2015). Effect of phosphorus fertilizer rates on yield and yield components of haricot bean (Phaseolus vulgaris L.) in southern Ethiopia. *African Journal of Agricultural Research*.
11. Rao, Idupulapati M., Dennis K. Friesen, and Mitsuru Osaki. "Plant adaptation to phosphorus-limited tropical soils." *Handbook of plant and crop stress* 2 (1999): 61-95.
12. Garcia, A., G. Hernandez, A. Nuviola, N. Mendez, G. Herrero, and J. J. Drevon. "Evaluating the response of selected common bean genotypes to the application of phosphate rock products in acid soils of Cuba." Proceedings Series (2006): 147.
13. Lopez, M., N. Alfonzo, M. Espana, and E. Cabrera-Bisbal. "Phosphorus uptake efficiency of sorghum and rice genotypes as affected by phosphate sources of varying solubility." Proceedings Series (2006): 161.
14. Fageria, Nand Kumar, Virupax C. Baligar, and Charles Allan Jones. Growth and mineral nutrition of field crops. CRC press, 2010.
15. Oladiran, Olaleye, Fagbola Olajire, Abaidoo C. Robert, and Ikeorah Nnenna. "Phosphorus response efficiency in cowpea genotypes." Journal of Agricultural Science 4, no. 1 (2012): 81.
16. Mesfin Abebe. (2007). Nature and Management of Acid Soils in Ethiopia. Addis Abeba, Ethiopia.
17. SAS Institute. (2004). SAS/STAT® 9.1 User's Guide. SAS Institute Inc., Cary, NC, USA.
18. Gomez, Kwanchai A., and Arturo A. Gomez. Statistical procedures for agricultural research. John wiley & sons, 1984.
19. Singh, Shree P. "Broadening the genetic base of common bean cultivars: a review." Crop science 41, no. 6 (2001): 1659-1675.
20. Acosta-Gallegos, Jeorge A., and Jeffrey W. White. "Phenological plasticity as an adaptation by common bean to rainfed environments." *Crop Science* 35, no. 1 (1995): 199-204.
21. Beebe, Stephen E., Idupulapati M. Rao, Matthew W. Blair, and Jorge A. Acosta-Gallegos. "Phenotyping common beans for adaptation to drought." *Frontiers in physiology* 4 (2013): 35.
22. Lynch, Jonathan P. "Root phenes for enhanced soil exploration and phosphorus acquisition: tools for future crops." *Plant physiology* 156, no. 3 (2011): 1041-1049.
23. Annicchiarico, Paolo. "Genotype x environment interactions: challenges and opportunities for plant breeding and cultivar recommendations." (2002).
24. Yan, Weikai, and Manjit S. Kang. GGE biplot analysis: A graphical tool for breeders, geneticists, and agronomists. CRC press, 2002.
25. Kisinyo, P. O., S. O. Gudu, C. O. Othieno, J. R. Okalebo, P. A. Opala, J. K. Maghanga, J. J. Agalo et al. "Effects of lime, phosphorus and rhizobia on Sesbania sesban performance in a Western Kenyan acid soil." (2012).
26. Hinsinger, Philippe. "Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review." Plant and soil 237, no. 2 (2001): 173-195.
27. Fageria, N. K., and V. C. Baligar. "Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production." Advances in agronomy 99 (2008): 345-399.
28. Girma Abebe. (2009).Effect of phosphorus fertilization on yield and yield components of haricot bean (Phaseolus vulgaris L.) in southern Ethiopia. *African Journal of Agricultural Research*, 4(6), 512–518.
29. Malik, M. A., Saleem, M. F., Cheema, M. A., & Ahmad, S. (2006). Effect of phosphorus application on growth, yield and quality of soybean (Glycine max L.). *Pakistan Journal of Agricultural Sciences*, 43(1–2), 21–26.
30. Shubhashree, K. S. (2007).Response of field bean (Lablab purpureus L.) to phosphorus fertilization under rainfed conditions. *Karnataka Journal of Agricultural Sciences*, 20(2), 289–292.
31. Veeresh. (2003). Response of field bean (Lablab purpureus L.) to phosphorus levels and biofertilizers. M.Sc. Thesis, *University of Agricultural Sciences, Dharwad*, India.
32. Beebe, S. E., Rao, I. M., Blair, M. W., & Acosta-Gallegos, J. A. (2008). Genetic improvement of common bean (Phaseolus vulgaris L.) for drought tolerance. *Crop Science*, 48(2), 545–556.
33. Fenta, B. A., Abebe, G., & Tesfaye, K. (2020).Phosphorus use efficiency and yield performance of common bean (Phaseolus vulgaris L.) genotypes under variable soil fertility conditions. *Agriculture & Food Security*.44

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