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Research Article

Acid Soil Resistance of Faba Bean (*Vicia faba* L.) Genotypes in the Highlands of Dawro Zone, Southwest Ethiopia

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Abstract

Soil acidity and its driven soil fertility problems are causing wide gap between actual farmers yield and research yield in faba bean in the highlands of Dawro zone and Ethiopia. Therefore, 11 improved faba bean genotypes were evaluated with and without lime application on the acidic highland soils of Dawro zone at different locations for two cropping seasons to identify high seed yielding and lime responsive and/or acid soil tolerant genotypes. Combined analysis of variance, overall mean seed yield performance, percent seed yield reduction, and Soil Acidity Susceptibility Index (SASI) were used to analyze data. Profitability of producing higher seed yielding genotypes was analyzed using partial budget with dominance. The combined analysis of variance showed that the effects of all sources of variations viz., Genotype (G), Location (L), Year (Y), Lime (M), and their interactions such as GL, GY, GM, LY, LM, YM, GLY, GYM, LYM, and GLYM were highly significant ($p<0.01$). The effects of G, GY, and GM, were 43.43%, 10.32%, and 8.15%, respectively, indicating greater influence of these sources in causing variability among faba bean genotypes for seed yield performance. In overall, genotypes viz., Ashebeka, Hachalu, Numan, and Tumsa, are higher seed yielding, lime responsive, and acid soil tolerant genotypes. Therefore, these genotypes are best for production in the highlands of Dawro zone and Ethiopia with development of optimum lime and fertilizer rates and agronomic practices as their production is profitable both with and without lime with extra net benefit of 21454.60 Birr when lime is applied. These genotypes are also good for breeding to improve seed yield potential and quality traits under acid soil conditions.

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Introduction

Faba bean (*Vicia faba* L.) is the most important pulse crop in Ethiopia. It shares 29.84% area coverage and 33.5% production from total pulse crops [1]. It is a major source of protein and cash for subsistence farmers and foreign currency to the country [2]. It is widely used in rotation with cereals because it improves soil fertility by fixing atmospheric nitrogen. Despite its diverse benefits, the actual yield obtained by farmers is 2.2 ton per hectare, which is about 70.09% lower than actual yield obtained by farmers in Egypt and United Kingdom [3].

This low yield obtained by farmers is attributed to several deficiencies in management of field and the crop but, mainly due to soil acidity and its driven soil fertility problems. These problems are making yield gains achieved in improved varieties unstable and unsustainable [4-6]. For example, the research yield of faba bean in Ethiopia is up to high as 5.7 t ha^{-1}[7]. Thus, there is about 61.40% yield difference between actual farmers yield and research yield. This is because most highland soils of Ethiopia are acidic and hence, crops are less responsive to application of inorganic fertilizers and improved agronomic practices in these soils [8,9] besides other ecological limitations. It is estimated that 43% of the Ethiopian land area and 28% of cultivated land is affected by soil acidity and the measured soil pH is in the range 4.1-5.5 [10]. These soils are poor in exchangeable cations and low in base saturation [11,12].

Soil acidity is caused by processes that lower down soil pH such as removal of crop residue, leaching of basic cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) at excessive rainfall areas, crop removal of essential cations (Ca^{2+}, Mg^{2+}, and K^{+}), continuous use of acid forming fertilizers (diammonium phosphate ($(NH4)_2HPO4$) and urea ($CO(NH_2)_2$)), which produce Hydrogen Ion (H^{+}) through oxidation of ammoniumion ion ($NH4^{+}$) to nitrate ion ($NO3^{-}$), dissociation of weak acids (carboxylic, enolic, and phenolic acids) in organic matter, which release H^{+} ions into soil solution, and buffering capacity of the soil, which is defined as the contact exchange between exchangeable hydrogen ion on root surfaces and the bases in exchangeable form on soils [4,9,13].

At soil pH less than 5.5, soil acidity affects crop yields due to Aluminum (Al^{3+}), Hydrogen (H^{+}), Iron (Fe^{2+}), and Manganese (Mn^{2+}) toxicities and the concurrent deficiencies of plant available Phosphorus (P), Nitrogen (N), Calcium (Ca), Magnesium (Mg), Potassium (K), Molybdenum (Mo), Sulfur (S), and reduced activities of beneficial microorganisms [14,15].

Soil acidity decreased faba bean seed yield by 45-81% [16], 32% [17], 111% [18] and 500% [19]. Similarly, it decreased hundred seeds weight and total biomass yield by 30% and 53.4%, respectively [5], leaf area and nodule quality by 58% and 94 %, respectively [20], and increased photosynthetic rate by 7.1% [20].

Several practices have been recommended to reclaim soil acidity. These recommendations include use of acid tolerant crops, covering the surface with non-acidic soil, use of organic fertilizer, and liming [4,5,9]. Of these practices, liming and the application of organic fertilizers are considered as best measures due to their persistent effects on soil properties. However, farmers in the high lands of Dawro zone did not prefer shifting to production of other crops because faba bean is coexisted with their staple perennial food crop, enset, and is the main source of their dietary protein and cash income. In addition, high population pressure and availability of fewer lands to produce more foods in the highlands of Dawro zone and Ethiopia urges even use of marginal lands [21]. Furthermore, field crops like faba bean need bulky organic materials and, therefore, use of organic fertilizers is impractical for it. In this scenario, evaluation of different genotypes at target production environments for soil acidity tolerance and/or for lime application response provides useful information [18].

In Ethiopia, faba bean is suitably grown in areas of altitude ranging from 1800-3000 meters above sea level, rainfall from 700 to 1100 mm per annuum, and minimum and maximum temperatures 10º and 27º , respectively, from June to October. It needs red brown soil with no water logging [7,17]. Its optimum soil pH is in the range 6.0-7.0 [9], but the measured soil pH of the study sites were 4.7 and 5.3 in Gozobamush site and Kechi site, respectively. In this situation, soil test results based liming is very important to raise the pH of the soil to the desired optimum level recommended for crops [22].

Liming is the application of calcium and/or magnesium rich materials to soil in various forms, including marl, chalk, limestone, or hydrated lime. It raises soil pH and enhances crop yield. Raising of soil pH occurs when the basic cations such as Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Sodium (Na^+) replace acidic cations such as Iron (Fe^{2+}), Manganese (Mn^{2+}), Hydrogen (H^+), and Aluminum (Al^{3+}) on cation exchange sites of soil clay and organic matter particles and are released into soil solutions. Crop yield is enhanced because raising soil pH improves plant availability of Phosphorus (P), Nitrogen (N), Molybdenum (Mo), Calcium (Ca), Magnesium (Mg), Potassium (K), and soil physical and biological properties [9,22].

Faba bean genotypes show differential reaction to lime application and soil acidity. For example, some faba bean genotypes showed variability in the range 3.4% to 22% in days to maturity when lime is applied [18,23]. Height of different genotypes differed in the range 15.2% to 71.9% compared to lime unapplied. By the same works, number of pods per plant performance of genotypes differed in the range 7.3% to 90.5 % whereas hundred seeds weight performance differed in the range 3.7% to 158.9% when lime is applied. These works detected 0.93% to 83.8% variation among the genotypes for seed yield performance compared to lime unapplied control. Another work revealed existence of 650%, 74.9%, 6.1%, 88.4%, 108.3%, 15.3%, 62.8%, and 11.3% differences in root length, leaf area, photosynthetic rate, nodule quantity, nodule quality, chlorophyll concentration, shoot dry weight, and seed production efficiency, respectively, among the genotypes due to lime application [20]. Therefore, evaluation of different faba bean genotypes on acid soils with acidity driven soil fertility problems and identification of acid soils tolerant and/or lime responsive genotypes is important to narrow the gap between actual farmers yield and research yield. Most highland soils of Dawro zone have soil acidity driven soil fertility problems [24,25]. As a result, this research was done with the following objectives.

- To evaluate seed yield performance of faba bean genotypes with and without lime application in highlands of Dawro zone.
- To assess economic profitability of faba bean production with and without lime application in the highlands of Dawro zone.
- To identify high seed yielding, acid soil tolerant and/or lime application responsive, and profitable faba bean genotypes for production in the highlands of Dawro zone and Ethiopia.
- To recommend soil acidity tolerant and/or lime application responsive faba bean genotypes for further breeding.

Materials and Methods

Description of the study area

Field experiment was conducted in two districts of Dawro zone namely Mareka and Kechi in the 2019 and 2020 main faba bean cropping seasons. The specific experimental sites are Gozobamush and Kechi. They are sub research centers of Wolaita Sodo University Dawro Tarcha campus.

Gozobamush site is located at 7.0569º north latitudes and 37.1953º east longitudes with altitude of 2432.2 meters above sea level. It receives an annual rainfall of 1672.8 mm and experiences minimum and maximum temperatures 10º and 25º , respectively. Its soil test result pH was 4.7. The major annual crops grown around this site are faba bean, field pea, wheat, barley, and Irish potato. The major perennial crop that shares largest area than both annual and other perennial crops is enset (*Enset ventricosum* L.). Enset is the main staple starch food whereas faba bean is the main source of dietary protein and cash income for people in the area. They coexisted in the area and supplement each other the diet of people.

Kechi site is located at 7.2030° north latitudes and 36.5930° east longitudes with altitude of 2090.4 meters above sea level. It receives an annual rainfall of 1560.8 mm and experiences minimum and maximum temperatures 12° and 26°, respectively. Its soil test result pH was 5.3. Similar annual and perennial crops are grown here too.

Experimental genotypes and design

Eleven improved faba bean genotypes collected from Holetta and Kulumsa Agricultural Research Centers in the country were used in the study (Table 1). At each site in each year, two trials, one with lime application and the other without lime application, were planted. Both lime applied and unapplied trials contained the same genotypes. The experiments were arranged in Randomized Complete Block Design (RCBD) with three replications. The plot size was 2mx2m ($4m^2$) for all experiments. The spacing used was 40 cm between rows and 10 cm between plants as this is recommended spacing for faba bean production by national research system. The two outer rows were used as border rows and the net harvested area was $2.4m^2$, the central three rows. Two seeds per hill were sown on rows with manual drilling to ensure germination and good stands of the faba bean genotypes and then were thinned to one plant per hill 12 days after emergence to achieve 100 plants per plot. For the trials with lime applications, lime was applied at the rate of 2.42 t ha^{-1} and 2.21 t ha^{-1} at Gozobamush and Kechi sites, respectively, one month a head of planting. These were the lime amounts required to raise the measured soil pH (Table 2) to the target pH recommended for best growth of faba bean, which is in the range 6.0 to 7.0 [8,9]. For all experiments, blended fertilizers

NPS were applied at the rate of 100 kg ha^{-1} during planting. The other agronomic practices were carried out uniformly to all plots as per the recommendations made by the national research system for faba bean.

Genotype	Altitude (m.a.s.l.)	Annual rain fall (mm)	Days to maturity	Seed color	Year of release	Breeder
Ashebeka	1990-2800	900-1000	128-156	Light green	2015	KARC
Didea	1990-2800	900-1000	122-145	Light brown	2014	KARC
Numan	1800-3000	700-1100	137-148	Light green	2016	KARC
Degaga	1800-300	800-1100	125	Light brown	2002	HARC
Gebelcho	1900-3000	700-1000	103-167	Light brown	2006	HARC
Moti	1900-2800	700-1000	108-165	Light brown	2006	HARC
Obse	1900-2800	700-1000	87-166	Light brown	2007	HARC
Dosha	2050-2800	700-1000	120-165	Light brown	2009	HARC
Hachalu	1900-2800	700-1000	122-156	Light brown	2010	HARC
Tumsa	1900-2800	700-1000	121-176	Light brown	2010	HARC
Gora	2000-2800	700-1200	151-158	Light green	2013	KARC

Table 1: Experimental genotypes, their adaptation areas, and some of their agronomic traits.

Source: HARC=Holeta Agricultural Research Center, KARC=Kulmsa Agricultural Research Center, m.a.s.l.= Meter above sea level, and mm=millimeter. Degaga is introduced variety; Dosha is developed from local collection, and others are developed from hybridization.

Parameter	Unit	Values	
		Gozobamush	Kechi
Sand	%	28	20
Clay	%	30	38
Silt	%	42	42
Textural class	-	Clay loam	Clay
Soil bulk density	g(cm3)-1	0.99	1.0
PH-H2O	-	4.7	5.3
Exchangeable Acidity	Meq (100 g soil)-1	1.63	1.47
Exchangeable H+	Meq (100 g soil)-1	0.29	0.75
Exchangeable Al3+	Meq (100 g soil)-1	1.34	0.72
Conductivity	ms cm-1	-	0.02
Organic Carbon (OC)	%	5.3	4.48
Total Nitrogen (TN)	%	0.4	0.44
C:N	Ratio	13.4	10.18
Ava. phosphorous (P)	mg kg-1	4.73	2.74
Sulfur (S)	mg kg-1	9.71	8.24
Calcium (Ca)	cmol(+)(kg soil)-1	5.78	4.33
Magnesium (Mg)	cmol(+)(kg soil)-1	0.86	0.75
Potassium (K)	cmol(+)(kg soil)-1	0.35	0.24
Sodium (Na)	mg kg-1	13.92	1.61
Cation Exchangeable Capacity (CEC)	cmol(+)(kg soil)-1	37.5	37.72
Boron (B)	mg kg-1	0.48	0.02
Iron (Fe)	mg kg-1	231.77	415.6
Manganese (Mn)	mg kg-1	198.75	311.3
Copper (Cu)	mg kg-1	2.8	0.72
Zinc (Zn)	mg kg-1	23.15	4.27

Table 2: Selected physical and chemical properties of the experimental soils.

Gozobamush and Kechi are experimental sites.

Experimental Procedures

Soil sampling, preparation and analysis

Before planting, twelve soil samples from top 20 cm depth were taken randomly from representative spots of the entire 243m^2 experimental field using an auger and composited to one representative sample. The composite sample was air-dried at room temperature, thoroughly mixed and ground to pass through a 2 mm sieve and then analyzed for soil texture, pH, organic carbon, cation exchange capacity, exchangeable bases (Na, K, Ca and Mg), total nitrogen, available Phosphorus, exchangeable acidity, extractable aluminum and micro nutrients (Zn, Fe, Mn and Cu). One soil sample for bulk density analysis at each location was taken by core sampler.

Soil bulk density was determined using a core sampler and soil pH-H_2O was determined by potentiometric method at 1:2.5 soils: water ratio [26]. Cation exchange capacity was determined by 1 M ammonium acetate method at pH 7 [27] whereas organic carbon was determined by the Walkley and Black method [28] and total nitrogen by the micro-Kjeldhal method [29], available Phosphorus (P) was determined by the Olsen method [29]. Soil particle size distribution was determined by the hydrometer method [30]. Exchangeable bases such as Na, K, Mg and Ca and extractable Al, Fe, Zn, Mn and Cu were determined by Mehlich-3 method [31]. Analysis of all the soil parameters was done at Debrezeit agricultural research center soil and plant analysis laboratory.

Treatment application and field activities

All field activities were done with standard production practices developed for faba bean. The land was tilled by tractor at Kechi site and by oxen plough at Gozobamush site. Land pulverization and row making were done using hand tools to plant the seeds. Lime was applied one month ahead of planting to give time for incorporation. It was applied based on the amount required to raise soil pH from 4.7 and 5.3 at Gozobamush and Kechi sites, respectively, to the range in between 6.0 to 6.5. Planting of the experiments was done in July at both locations in both years. Similarly, harvesting was done in November at both locations in both years. The liming material used was calcium carbonate and its rate (LR) was determined based on soil analysis results using the following formula:

$$LR\ (CaCO_3\ kg\ ha^{-1}) = \frac{EA(cmol\ kg^{-1}) * \rho b(gcm^{-3}) * SD(m) * 10^4 m^2)}{2} * 1.5$$

Where, LR=Lime rate, EA=Exchangeable soil acidity, =Soil bulk density, SD=Soil depth, and 1.5 was liming factor determined based on crop response.

Data collection and analysis

The agronomic data recorded were plant height (cm), hundred seeds weight (g), number of pods per plant, number of seeds per pod and seed yield per plot in grams. Plant height, number of pods per plant, and number of seeds per pod were recorded on individual plant basis from ten randomly pre-tagged plants from the central three rows and then averaged. Hundred seeds weight was recorded by taking hundred seeds from each plots threshed and cleaned seed yield randomly and then weighing using sensitive balance. The moisture content of the seed yield was measured before sampling and the net weight of seeds was calculated based on the formula given by [32] to adjust to 14 % moisture content. Seed yield collected on plot basis was the yield in grams of plants in the central three rows obtained by weighing using sensitive balance. It was adjusted to 14 % moisture content using the formula:

$$Y_{adj} = \left[\left(\frac{100 - MC}{100 - 14\%}\right) * Y\right]$$

Where; Y_{adj} was moisture adjusted yield, Y was unadjusted yield, and MC was measured moisture content (%) and then converted to kg ha^{-1}.

Soil acidity resistance

The tolerance of genotypes to soil acidity was analyzed using Soil Acidity Intensity Index (SAII) and Soil Acidity Susceptibility Index (SASI) indices extrapolated from the formulas used for low soil fertility intensity index and low soil fertility susceptibility index [33]. Soil Acidity Intensity Index (SAII) of each environment was calculated as: $SAII = 1 - (\frac{X_{without}}{X_{with}})$ where; $X_{without}$ and X_{with} were the mean of all genotypes under lime untreated and treated environments, respectively. Soil acidity susceptibility index (SASI) for each genotype was calculated as follows: $SASI = \frac{1-(\frac{Y_{without}}{Y_{with}})}{SAII}$ where, $Y_{without}$ and Y_{with} were the mean yields of a given genotype under lime untreated and treated environments, respectively.

Analysis of variance

Data were subjected to analysis of variance (ANOVA) for RCBD using Genstat statistical software package version 17 after test for presence of outliers and normality of residuals [34]. ANOVA for the traits per location/year/lime level were first analyzed separately and then combined after Bartlett's test for homogeneity of error variance.

The combined analysis of variance model used was: $y_{ijkl} = \mu + G_i + Y_j + L_k + M_l + GY_{ij} + GL_{ik} + GM_{il} + YL_{jk} + YM_{jl} + LM_{kl} + GYL_{ijk} + GYM_{ijl} + GLM_{ikl} + GYLM_{ijkl} + \varepsilon_{ijkl}$; where, y_{ijkl} was the mean yield over replicates of i^{th} genotype at k^{th} location and l^{th} lime level in the j^{th} year ; μ was the overall mean, G_i was the effect of i^{th} genotype, Y_j was the effect of j^{th} year, L_k was the effect of k^{th} location, M_l was the effect of l^{th} lime level, GY_{ij}, GL_{ik}, GM_{il}, YL_{jk}, YM_{jl}, LM_{kl}, GYL_{ijk}, GYM_{ijl}, GLM_{ikl}, and $GYLM_{ijkl}$ were the interaction effects and ε_{ijkl} was pooled error assumed to be normally and independently distributed as mean 0 and variance $\frac{\sigma^2}{r}$.

Existence of significant difference among the genotypes, locations, lime level and their interactions was determined using the F-test in all the cases. Mean separation at 5% probability level was done using Duncan's Multiple Range Test (DMRT) following [35], whenever genotype differences were significant.

Economic analysis

The economic analysis such as partial budget, marginal, and sensitivity analysis were carried out as described by [36]. To estimate economic parameters, crop produces were valued based on market price of the year. The concepts used in the partial budget analysis were mean seed yield ha^{-1}; gross field benefit per hectare (GFB ha^{-1}), Total Variable Cost (TVC), and the net benefit per hectare (NB ha^{-1}). Seed yield ($kgha^{-1}$) refers to average seed yield of each genotype across locations and over years for both lime treated and untreated experiments. The GFB ha^{-1} was obtained as the products of real price in birr of a kilogram of seed yield and the mean seed yield in kilogram of each genotype. The TVC in the partial budget analysis refers to the sum of costs of all variable inputs (seed, fertilizer, lime, pesticides) and management practices (tillage and labor costs for planting, fertilizing, weeding, pesticide application, harvesting, threshing, and transporting) whereas the NB ha^{-1} was the difference between the GFB ha^{-1} and the TVC.

The dominance analysis procedure was used to select potentially profitable treatments by ranking of treatments in order of ascending TVC from the lowest to the highest cost to eliminate those genotypes that were costing more but producing a lower NB ha^{-1} than the next lowest cost genotype. For each pair of ranked undominated genotypes, a percentage Marginal Rate of Return (% MRR) was calculated. The MRR (%) was calculated using the equation:

$$MRR\ (\%) = \frac{\Delta NB}{\Delta TVC}$$

Where; ΔNB was change in net benefit, and ΔTVC was change in total variable cost between any pair of undominated treatments.

Results and Discussions

Soil physicochemical properties

Soil physicochemical properties of experimental sites were variable (Table 2). The Gozobamush site soil had clay loam textural class with particle size distribution of 30% clay, 42% silt and 28% sand whereas the Kechi site soil had clay textural class with particle size distribution of 38% clay, 42% silt, and 20 % sand. The pH-H_2O values of soils were 4.7 and 5.3 at Gozobamush site and at Kechi site, respectively. Thus, soil at Gozobamush site is very strongly acidic according to [45] whereas soil at Kechi site is strongly acidic soil based on [18]. This acidity resulted in deficiencies of essential nutrients like Phosphorus (P), Sulphur (S), and Boron (B) and toxicities of cations such as Hydrogen Ion (H^+), Aluminum Ion (Al^{3+}), Iron Ion (Fe^{2+}), and Manganese Ion (Mn^{2+}) as reported by [4] and [8] and affected seed yield performance of faba bean genotypes.

The Organic Carbon (OC) content of experimental soils was 5.3% at Gozobamush site and 4.48% at Kechi site. Similarly, the Total Nitrogen (TN) content was 0.40% at Gozobamush site and 0.44% at Kechi site. Thus, experimental sites have medium OC content and optimum TN content according to [37] and [38] ratings. The available Phosphorus (P), Sulphur (S), and Boron (B) were 4.73, 9.71, and 0.48 mg kg^{-1} at Gozobamush site and 2.74, 8.24, and 0.02 mg kg^{-1} at Kechi site, respectively. Therefore, experimental soils are very low in these essential nutrients based on similar ratings as expected from acidic soils. The concentration of cations was in the order of Calcium Ion (Ca^{2+})> Magnesium Ion (Mg^{2+})> Potassium Ion (K^+)>

Sodium Ion (Na^+) in both sites with slightly higher concentrations at Gozobamush site. The slightly higher concentrations of cations at Gozobamush site could be due to higher organic matter content at the site. Similarly, the concentration of micronutrients was in the sequence of Iron Ion (Fe^{2+})> Manganese Ion (Mn^{2+})> Zinc Ion (Zn^{2+})> Copper Ion (Cu^{2+})> Boron (B^+) at both sites. The concentration of Fe^{2+} and Mn^{2+} were 231.77 and 198.75 mg kg^{-1} in Gozobamush site and 415.6 and 311.3 mg ka^{-1} at Kechi site, respectively. So, the concentrations of both fall in the sufficient III range according to [39] classification. The concentration of Zn^{2+} and Cu^{2+} were 23.15 and 2.8 mg kg^{-1} in Gozobamush site and 4.27 and 0.72 mg ka^{-1} at Kechi site, respectively. This indicates Zn^{2+} is optimum and Cu^{2+} is deficient in experimental soils according to the [38].

Analysis of variance

The combined analysis of variance for seed yield (Table 3) showed that genotypes (G), Locations (L), Year (Y), Lime (M), Genotype X Location Interaction (GL), Genotype x year interaction (GY), genotype x lime interaction (GM), location x year interaction (LY), location x lime interaction (LM), year x lime interaction (YM), Genotype x location x year interaction (GLY), Genotype x year x lime interaction (GYM), location x year x lime (LYM), and genotype x location x Year x lime interaction (GLYM) effects were highly significant ($p < 0.01$). These indicate existence of substantial genetic differences among genotypes and variability of locations and years for seed yield performance. Reports of [40] and [6] are similar to these findings. The highly significant effect of lime also indicated differential seed yield performance of genotypes with and without lime application. Similarly, several studies reported variable seed yield performance of faba bean genotypes to lime applied at different rates compared to control treatments [8,18]. Furthermore, the highly significant effect of genotype x lime interaction (GM) indicated variable response of genotypes to lime application. [21] Evaluated 50 faba bean genotypes for lime response and reported differential reaction of genotypes.

Source of variation	D.F.	Mean square	Explained % within structures	Explained % of TSS
Year (Y)	1	19287921**	32.42	7.43
Location (L)	1	7991622**	13.43	3.08
Lime (M)	1	14306710**	24.05	5.51
Location x Year (LY)	1	8924355**	15.00	3.44
Year x Lime (YM)	1	2659450**	4.47	1.02
Location x Lime (LM)	1	2993168**	5.03	1.15
Location x Year x Lime (LYM)	1	3334600**	5.60	1.28
Rep (Year x Location x Lime)	16	19169		
Genotype (G)	10	11278101**	56.34	43.43
Genotype x Year (GY)	10	2680748**	13.39	10.32
Genotype x Location (GL)	10	958776**	4.79	3.69
Genotype x Lime (GM)	10	2117220**	10.58	8.15
Genotype x Location x Year(GLY)	10	499791**	2.50	1.92
Genotype x Location x Lime(GLM)	10	465458**	2.33	1.79
Genotype x Location x Year x Lime (GLYM)	20	1009164**	10.08	7.77
Residual	160	6904		

Table 3: Analysis of variance for seed yield (kg ha-1) performance of faba bean genotypes evaluated with and without lime at two locations of Dawro zone in the 2019 and 2020 main cropping seasons.

**=Significant at $p<0.01$, D.F.=Degree of freedom, and TSS=Treatment sum of squares.

The effects of sources of variations (Table 3) were in the order of G (43.43%)>GY (10.32%)>GM (8.15%)>GLYM (7.77%)>Y (7.43% >M (5.51% >GL (3.69%)>LY (3.44%)>L (3.08%)>GLY (1.92%)>GLM (1.79%) > LYM (1.28%) > LM (1.15%) > YM (1.02%). This shows that variability between genotypes was greatest compared to variability between other sources of variations similarly as reported by [41].The higher effect of Year (Y) compared to Location (L) showed that temporal variation in environments was higher than spatial variations. In this scenario, it is very important to select genotypes that are specifically adapted to a given production environment than widely adapted genotypes. Similarly, the higher M and GM effects than L and GL effects indicated higher influence of soil acidity related soil fertility problems than other edaphic factors in seed yield performance of faba bean genotypes. This is because when there is soil acidity problem, most plant nutrients became unavailable and genotypes do not respond to applied inorganic fertilizers [4,8]. Furthermore, in acidic soils with soil pH less than 5.5, H^+, Al^{3+} , Fe^{2+}, Mn^{2+} ions become in toxic concentrations and injure plant roots and so that reduce uptake of available nutrients, water, and nodulation that help faba bean genotypes to use atmospheric nitrogen.

Soil acidity tolerance of genotypes

In overall, lime application increased seed yield performance of genotypes in the range 2.83% for genotype Degaga to 23.85% for genotype Gora (Table 4). The average percent seed yield increment due to liming was 12.56%. [42] Reported 17.09% seed yield increment when lime is applied at a rate of 2 t ha^{-1}. Thus, it is within the reported range and similar to this finding. Genotypes viz., Gora, Didea, Numan, Gebelcho, and Dosha showed above average seed yield increment. They also had soil acidity susceptibility index (SASI) values above unity. Thus, they are reactive with line and are sensitive to acid soils. Other genotypes viz., Ashebeka, Tumsa, Hachalu, Obse, Moti, and Degaga showed below average percent seed yield increment and had lower SASI values. As a result, they seem less reactive with lime and are tolerant to acid soils. Acid soil tolerant genotypes should give higher seed yield compared to other genotypes when grown in acid soils. However, the genotypes selected as acid soil tolerant genotypes using percent seed yield increment and SASI values contained both higher and lower seed yielding genotypes.

In Gozobamush site, percent seed yield increment due to liming ranged from 3.87% for genotype Degaga to 21.54% for genotype Gora. In this site, the average percent seed yield increment due to liming was 14.48%. Liming increased seed yield of faba bean by 32% [5] and 45-81% [8] in Ethiopia. These reports are similar to present report in yield increment but, different in magnitude of increment. The difference in magnitude may be because of variation in sites and test genotypes used. Genotypes viz., Gora, Dosha, Didea, Gebelcho, and Tumsa, which showed above average seed yield increment and had higher SASI values, are sensitive to acid soils. Genotypes viz.,

	Gozobamush				Kechi				Combined			
Genotype	With	Without	PR	SASI	With	Without	PR	SASI	With	Without	PR	SASI
Ashebeka	5470.45	4842.40	12.97	0.91	5327.50	4923.55	8.20	0.79	5398.98	4882.98	10.57	0.86
Degaga	4467.10	4300.75	3.87	0.29	4289.45	4214.50	1.78	0.18	4378.28	4257.63	2.83	0.25
Didea	4829.65	4017.15	20.23	1.33	4762.85	3944.70	20.74	1.80	4796.25	3980.93	20.48	1.52
Dosha	4872.50	4012.75	21.43	1.39	3803.10	3673.95	3.52	0.36	4337.80	3843.35	12.87	1.02
Gebelcho	3890.65	3240.56	20.06	1.32	3439.40	3088.24	11.37	1.07	3665.03	3164.40	15.82	1.22
Gora	4308.60	3545.75	21.51	1.40	4114.30	3255.00	26.40	2.18	4211.45	3400.38	23.85	1.73
Hachalu	5209.10	4632.85	12.44	0.87	5218.95	4903.90	6.42	0.63	5214.03	4768.38	9.35	0.77
Moti	4579.70	4116.15	11.26	0.80	3716.15	3551.00	4.65	0.46	4147.93	3833.58	8.20	0.68
Numan	4884.10	4341.10	12.51	0.88	5253.20	4324.95	21.46	1.85	5068.65	4333.03	16.98	1.30
Obse	3755.45	3396.90	10.56	0.75	3418.64	3194.75	7.01	0.69	3587.05	3295.83	8.84	0.73
Tumsa	5028.75	4360.35	15.33	1.05	4473.75	4171.70	7.24	0.71	4751.25	4266.03	11.37	0.92
Mean	4663.28	4073.34	14,48	-	4347.03	3931.48	10.57	-	4505.15	4002.41	12.56	-
ASII				0.13				0.10				0.11

Table 4: Soil Acidity Intensity Index (SAII), Soil Acidity Susceptibility Index (SASI), and percent seed yield reduction (PR) of faba bean genotypes evaluated at two locations of Dawro zone in the 2019 and 2020 main cropping seasons.

SAII = Soil acidity intensity index and SASI = Soil acidity susceptibility index, without = Seed yield (kg ha-1) in lime untreated experiment and With = Seed yield (kg ah-1) in lime treated experiment, and PR = Percent seed yield reduction.

Ashebeka, Numan, Hachalu, Moti, Obse and Degaga, which showed below average percent seed yield increment and had lower SASI values, are tolerant to acid soils.

Similarly, in Kechi site, seed yield increment with lime application ranged from 1.78% for genotype Degaga to 26.40% for genotype Gora. Here, the average seed yield increment was 10.57%. [6] Evaluated 50 faba bean genotypes and reported 43.9 % seed yield increment due to liming. Percent seed yield increment is higher in this report may be because they used a single four meter row as a plot. Other possible causes may be variation in experimental sites. Genotypes namely, Gora, Numan, Didea, and Gebelcho showed above average seed yield increment and had SASI values above unity. Thus, they are sensitive to acid soils. Unlike ways, genotypes viz., Ashebeka, Tumsa, Obse, Hachalu, Moti, Dosha, and Degaga showed below average seed yield increment and had SASI values below unity. So, they are tolerant to acid soils.

The Soil Acidity Intensity Index (SAII) was 0.13 at Gozobamush site and 0.10 at Kechi site (Table 5). This reveals more acidity of experimental soil at Gozobamush site than Kechi site (Table 3). These results also suggest presence of moderately high soil acidity stress at both sites. In overall, the soil acidity susceptibility index (SASI) values of genotypes ranged from 0.25 for genotype Degaga to 1.73 for genotype Gora. At Gozobamush site, it ranged from 0.29 for genotype Degaga to 1.40 for genotype Gora. It ranged from 0.18 for genotype Degaga to 2.18 for genotype Gora at Kechi site. These SASI values indicated existence of considerable variability among improved faba bean genotypes studied for acid soil tolerance. [38] Reported similar variable reaction of faba bean genotypes to acid soils in Ethiopia.

In overall, the rankings of genotypes based on Soil Acidity Susceptibility Index (SASI) from most acid soil tolerant genotype to least acid soil tolerant genotype were Degaga (0.25)>Moti (0.68)>Obse (0.73)>Hachalu (0.77)>Ashebeka (0.86)>Tumsa (0.92)>Dosha (1.02)>Gebelcho (1.22)>Numan (1.30)>Didea (1.52)>Gora (1.73) (Table 5). Therefore, genotypes with SASI values below unity are acid soil tolerant genotypes whereas genotypes with SASI values above unity are acid soil sensitive genotypes.

In Gozobamush site, the rankings of genotypes based on soil acidity susceptibility index (SASI) from most tolerant genotype to least tolerant genotype was Degaga (0.29)> Obse (0.75)> Moti (0.80)> Hachalu (0.87)>Numan (0.88)> Ashebeka (0.91)> Tumsa (1.05)> Gebelcho (1.32)> Didea (1.33)> Dosha (1.39)> Gora (1.40) (Table 5). Similarly, in this site also genotypes with SASI values below unity are acid soil tolerant genotypes and with SASI values above unity are acid soil sensitive genotypes.

In Kechi site, the ranking of genotypes based on soil acidity susceptibility index (SASI) from most tolerant genotype to least tolerant genotype was Degaga (0.18)> Dosha (0.36)> Moti (0.46)> Hachalu (0.63)> Obse (0.69)> Tumsa (0.71)> Ashebeka (0.79)> Gebelcho (1.07)> Didea (1.80)> Numan (1.85)> Gora (2.18) (Table 5). Here again, acid soil tolerant and sensitive genotypes can be identified similarly as that of Gozobamush site.

In lime applied experiment, when averaged over years and locations, seed yield performance of genotypes ranged from 3587.1 kg ha^{-1} for the genotype Obse to 5399.0 kg ha^{-1} for the genotype Ashebeka (Table 4). The average seed yield of genotypes was 4505.2 kg ha^{-1} with lime application. Genotypes viz., Ashebeka, Hachalu, Numan, Didea, and Tumsa performed above average seed yield when lime was applied. As a result, they are lime responsive genotypes. Other genotypes viz., Degaga, Dosha, Gebelcho, Gora, Moti, and Obse performed below average seed yield when lime was applied. Therefore, they are lime unresponsive genotypes. In overall, genotypes tested are variable in their response to applied lime. Similarly, [6] reported existence of substantial genetic variability among faba bean genotypes in response to lime.

In lime unapplied experiment, when averaged over years and locations, seed yield performance of genotypes ranged from 3164.4 kg ha^{-1} for the genotype Gebelcho to 4883.0 kg ha^{-1} for the genotype Ashebeka (Table 4). The average seed yield of genotypes was 4002.4 kg ha^{-1} without lime application. Genotypes viz., Ashebeka, Hachalu, Numan, Tumsa, and Degaga, which performed above average seed yield when lime was not applied, are acid soil tolerant genotypes.

Gozobamush				Kechi				Combined				Overall Mean	
Genotype	With	Genotype	Without	Genotype	With	Genotype	Without	Genotype	With	Genotype	Without	Genotype	Mean
Ashebeka	5470.5a	Ashebeka	4842.4a	Ashebeka	5327.5a	Ashebeka	4923.6a	Ashebeka	5399.0a	Ashebeka	4883.0a	Ashebeka	5141.0a
Hachalu	5209.1b	Hachalu	4632.9b	Numan	5253.2a	Hachalu	4903.9a	Hachalu	5214.1b	Hachalu	4768.4b	Hachalu	4991.2b
Tumsa	5028.8c	Tumsa	4360.4c	Hachalu	5219.0a	Numan	4324.9b	Numan	5068.7c	Numan	4333.0c	Numan	4700.8c
Numan	4884.1d	Numan	4341.1c	Didea	4762.8b	Degaga	4214.5bc	Didea	4796.2d	Tumsa	4266.1c	Tumsa	4508.6d
Dosha	4872.5d	Degaga	4300.8c	Tumsa	4473.7c	Tumsa	4171.7c	Tumsa	4751.3d	Degaga	4257.6c	Didea	4388.6e
Didea	4829.6d	Moti	4116.2d	Degaga	4289.5d	Didea	3944.7d	Degaga	4378.3e	Didea	3980.9d	Degaga	4318.0f
Moti	4579.7e	Didea	4017.2d	Gora	4114.3e	Dosha	3673.9e	Dosha	4337.8e	Dosha	3843.4e	Dosha	4090.6g
Degaga	4467.1e	Dosha	4012.8d	Dosha	3803.1f	Moti	3551.0e	Gora	4211.5f	Moti	3833.6e	Moti	3990.8h
Gora	4308.6f	Gora	3545.7e	Moti	3716.1f	Gora	3393.6f	Moti	4147.9f	Gora	3469.7f	Gora	3817.5i
Gebelcho	3890.7g	Obse	3396.9f	Gebelcho	3439.4g	Obse	3194.7g	Gebelcho	3665.0g	Obse	3295.8g	Obse	3441.4j
Obse	3755.4h	Gebelcho	3240.6g	Obse	3418.6g	Gebelcho	3088.2g	Obse	3587.1h	Gebelcho	3164.4h	Gebelcho	3414.7j
Mean (0.05)	4663.28a		4073.35b		4347.02a		3944.07b		4505.15a		4008.71b		4254.8
SED	47.97		47.97		47.97		47.97		36.56		36.56		23.99

Table 5: Mean seed yield (kg ha-1) performance of faba bean genotypes evaluated with and without lime at two locations of Dawro zone in the 2019 and 2020 main cropping seasons.

Means followed by the different letters down columns and across rows are significantly different at $p < 0.05$, with = with lime application averaged over years, without = without lime application averaged over years, Combined = averaged over years and locations, Overall = averaged over years, locations, and management (lime levels), SED = Standard error of differences of means and SED for lime is 17.04.

Therefore, genotypes viz., Ashebeka, Hachalu, Numan, and Tumsa, both lime responsive and acid soil tolerant, are good genotypes for both subsistence and commercial farmers. Genotypes viz., Didea, Dosha, Gebelcho, Gora, Moti, and Obse, which performed below average seed yield when lime was not applied, are acid soil sensitive genotypes. Genotype, Didea, responsive to lime but, sensitive to soil acidity, is good genotype for production in highly acidic soils with lime application. Genotype, Degaga, unresponsive to lime but, tolerant to acid soils, is good for production in marginal lands without lime application. Remaining genotypes viz., Dosha, Gora, Gebelcho, Moti, and Obse, both unresponsive to lime and sensitive to acid soils, are less suitable for production in study sites and similar areas because they are less responsive to soil amendment and sensitive to changes in the soil.

In Gozobamush site, in lime applied experiment, when averaged over years, seed yield performance of genotypes ranged from 3755.4 kg ha^{-1} for genotype Obse to 5470.5 kg ha^{-1} for genotype Ashebeka (Table 4). The average seed yield of genotypes with lime application at Gozobamush site was 4663.28 kg ha-1. As a result, genotypes viz., Ashebeka, Hachalu, Tumsa, Numan, Didea, and Dosha, which performed above average seed yield when lime was applied, are lime responsive genotypes whereas genotypes viz., Moti, Degaga, Gora, Gebelcho, and Obse, which performed below average seed yield when lime was applied, are lime unresponsive genotypes.

In Gozobamush site, in lime unapplied experiment, when averaged over years, seed yield performance of genotypes ranged from 3240.6 kg ha^{-1} for the genotype Gebelcho to 4842.4 kg ha^{-1} for the genotype Ashebeka (Table 4). In this site, when lime was not applied, the average seed yield of genotypes was 4073.34 kg ha^{-1}. Therefore, genotypes viz., Ashebeka, Hachalu, Tumsa, Numan, Degaga, and Moti, which performed above average seed yield when lime was not applied, are acid soil tolerant genotypes whereas Didea, Dosha, Gora, Obse, and Gebelcho, which performed below average seed yield when lime was not applied, are acid soil sensitive genotypes. Therefore, genotypes viz., Ashebeka, Hachalu, Tumsa, and Numan, both lime responsive and acid soil tolerant genotypes at Gozobamush site, are good genotypes for both subsistence and commercial production in Gozobamush and similar sites. Genotypes, Didea and Dosha, lime responsive but, sensitive to soil acidity, are good genotypes for cultivation with lime application in highly acidic soils. Genotypes, Degaga and Moti, lime unresponsive but, tolerant to acid soils, are good for production in marginal lands without lime application. Other genotypes viz., Gora, Gebelcho, and Obse, both lime unresponsive and acid soil sensitive, are less good genotypes for production in this and similar sites.

In Kechi site, in lime applied experiment, when averaged over years, seed yield performance of genotypes ranged from 3418.6 kg ha^{-1} for the genotype Obse to 5327.5 kg ha^{-1} for the genotype Ashebeka (Table 4). The average seed yield with lime application at Kechi site was 4347.03 kg ha^{-1}. Genotypes viz., Ashebeka, Numan, Hachalu, Didea, and Tumsa which performed above average seed yield when lime was applied, are lime responsive genotypes whereas genotypes viz., Moti, Degaga, Gora, Gebelcho, Dosha, and Obse, which performed below average seed yield when lime was applied, are lime unresponsive genotypes. In Kechi site, in lime unapplied experiment, when averaged over years, seed yield performance of genotypes ranged from 3088.4 kg ha^{-1} for the genotype Gebelcho to 4923.6 kg ha^{-1} for the genotype Ashebeka (Table 4). Here, average seed yield without lime application was 3931.48 kg ha^{-1}. Genotypes viz., Ashebeka, Hachalu, Tumsa, Numan, Degaga, and Didea which performed above average seed yield when lime was not applied, are acid soil tolerant genotypes whereas Dosha, Gora, Obse, Moti, and Gebelcho which performed below average seed yield when lime was not applied, are acid soil sensitive genotypes. As a result, genotypes viz., Ashebeka, Hachalu, Tumsa, Numan, and Didea, both lime responsive and acid soil tolerant, are good genotypes for both subsistence and commercial production in Kechi and similar sites. In this site, no genotype is exceptionally well for production with lime application. Genotype, Degaga, lime unresponsive but, tolerant to acid soils, is good for production in marginal areas without lime application.

Seed yield performance of genotypes

The overall mean seed yield performance of genotypes ranged from 3414.7 kg ha^{-1} for genotype Obse to 5141.0 kg ha^{-1} for genotype Ashebeka (Table 5). The overall mean seed yield averaged across management (lime levels) and over genotypes was 4254.8 kg ha^{-1}. Genotypes viz., Ashebeka, Hachalu, Numan, Tumsa, Didea, and Degaga, which performed above the overall mean, are higher seed yielded genotypes whereas the remaining genotypes viz., Dosha, Moti, Gora, Obse, and Gebelcho, which performed below the overall mean, are lower seed yielding genotypes. Similarly, several researchers [6,7,18,43] reported variability of faba bean genotypes for seed yield performance. Therefore, these higher seed yielding genotypes are good for production in the highlands of Ethiopia with development of appropriate soil amendment and agronomic practices. They can also be used in faba bean improvement programs as parents to improve seed yield potential and quality traits in Ethiopia and elsewhere. Among the locations, when averaged over lime levels and genotypes, higher seed yield performance of genotypes was observed at Gozobamush site (4368.31 kg ha^{-1}) than Kechi site (4145.55 kg ha^{-1}). Therefore, Gozobamush site has higher faba bean seed yield potential than Kechi site. Similarly, [18] reported variability among locations for faba bean seed yield performance.

In Gozobamush site, when averaged over years and lime levels, seed yield performance of genotypes ranged from 3565.6 kg ha^{-1} for genotype Gebelcho to 5470.5 kg ha^{-1} for genotype Ashebeka (Table 5). Genotypes viz., Ashebeka, Hachalu, Tumsa, Numan, Didea, Dosha, and Degaga performed above average whereas Moti, Gora, Gebelcho, and Obse performed below average. Thus, genotypes viz., Ashebeka, Hachalu, Tumsa, Numan, Didea, Dosha, and Degaga, are higher seed yielding genotypes and good for production at this site with development of optimum soil management and agronomic practices.

Similarly in Kechi site, when averaged over years and lime levels, seed yield performance of genotypes ranged from 3263.8 kg ha^{-1} to 5125.5 kg ha^{-1} for similar genotypes as to Gozobamush site. Again, the same genotypes performed above and below average as that of Gozobamush site except Dosha which performed below average in this site. Therefore, the genotypes selected for production in Gozobamush site are also good for production in Kechi site with development of appropriate soil and agronomic management technologies.

In overall, the higher seed yielding genotypes viz., Ashebeka, Hachalu, Numan, Tumsa, Didea, and Degaga showed significantly different seed yield performance among one another and from the remaining lower seed yielded genotypes (Table 5). Ashebeka was the first top higher seed yielding genotype while Degaga was the sixth top higher seed yielding genotype. Similarly, the lower seed yielding genotypes viz., Dosha, Moti, Gora, Obse, and Gebelcho showed significantly different seed yield performance among one another and from higher seed yielding genotypes except Gebelcho and Obse which exhibited statistically similar lowest seed yield performance.

In lime applied experiment, comparing means averaged over years and locations, among the higher seed yielding genotypes viz., Ashebeka, Hachalu, Numan, Didea, and Tumsa, the first three showed significantly different seed yield performance among one another whereas Didea and Tumsa showed statistically similar seed yield performance. In the same way, among the lower seed yielded genotypes, Degaga and Dosha and again Gora and Moti showed statistically similar seed yield performance within themselves. The remaining lower seed yielded genotypes, Gebelcho and Obse, showed statistically dissimilar seed yield performance between themselves and from other lower seed yielded genotypes.

In lime unapplied experiment, when averaged over years and locations, the higher seed yielding genotypes viz., Ashebeka, Hachalu, Numan, Tumsa, and Degaga were divided into three sub groups for seed yield performance. Ashebeka and Hachalu, which formed the first and second groups, showed significantly different performance between themselves and from others. Numan, Tumsa and Degaga, which formed the third group, showed statistically similar seed yield performance. The lower seed yielded genotypes viz., Didea, Dosha, Moti, Gora, Obse, and Gebelcho, all showed dissimilar seed yield performance among one another, but Dosha and Moti, which showed statistically similar seed yield performance.

In lime applied experiment, in Gozobamush site, when averaged over years, higher seed yielding genotypes, Ashebeka, Hachalu, Tumsa, and Numan showed dissimilar seed yield performance among themselves. But, other higher seed yielding genotypes, Didea, and Dosha, showed similar seed yield performance between them and with Numan. The lower seed yielding genotypes viz., Moti, Degaga, Gora, Gebelcho, and Obse again showed dissimilar seed yield performance except Moti and Degaga that showed similar seed yield performance.

In lime unapplied experiment, in Gozobamush site, when averaged over years, genotypes viz., Ashebeka, Hachalu, and Tumsa showed significantly dissimilar seed yield performance among themselves but, the performance of Tumsa was not different from that of Numan and Degaga. Moti, Didea, and Dosha again showed similar seed yield performance. Other lower seed yielding genotypes viz., Gora, Obse, and Gebelcho showed significantly different performance among themselves and from others.

In lime applied experiment, in Kechi site, when averaged over years, genotypes viz., Ashebeka, Numan, and Hachalu showed similar seed yield performance among them, but significantly different seed yield performance from other genotypes. Other higher seed yielding genotypes, Didea and Tumsa, showed significantly variable seed yield performance between them and from others. Among the lower seed yielding genotypes viz., Moti, Degaga, Gora, Gebelcho, Dosha, and Obse, the two genotypes, Moti and Dosha, showed dissimilar seed yield performance between themselves and among others. Degaga and Gora as well as Gebelcho and Obse showed similar seed yield performance between themselves, but significantly different from others.

In lime unapplied experiment, when averaged over years, genotypes viz., Ashebeka and Hachalu were first, Numan was second, and Tumsa and Degaga were third higher seed yielding genotypes. Among the lower seed yielding genotypes, Dosha and Moti and again Obse and Gebelcho showed similar seed yield performance within themselves, but significantly different from other genotypes.

Seed yield component traits performance

The seed yield component traits viz, plant height, hundred seed weight, number of pods per plant, and number of seeds per pod performance of genotypes was variable (Table 6). The height of genotypes ranged from 122.11 cm for genotype Dosha to 152.77 cm for genotype Gora with average height of 141.41 cm. Genotypes viz., Gora, Ashebeka, Didea, Degaga, and Hachalu, which measured above average height, are taller genotypes. Their tallness was statistically similar. Other genotypes viz., Moti, Numan, Tumsa, Obse, and Dosha, which measured below average height, are shorter genotypes. Among shorter genotypes, Moti, Numan, and Tumsa measured similar shorter heights within themselves. Similarly, Obse and Dosha measured statistically similar heights.

Genotype	PH	Genotype	HSW	Genotype	PPP	Genotype	SPP
Gora	152.77a	Numan	107.08a	Tumsa	22.49a	Gebelcho	3.50a
Ashebeka	150.50a	Gora	100.06b	Dosha	22.11a	Ashebeka	3.47a
Didea	149.57ab	Ashebeka	92.35c	Didea	21.35ab	Numan	3.40a
Degaga	148.29ab	Gebelcho	91.48c	Degaga	21.30ab	Didea	3.33ab
Hachalu	147.00ab	Tumsa	86.40d	Gora	19.94bc	Hachalu	3.33ab
Gebelcho	144.89bc	Didea	86.00d	Numan	19.17cd	Degaga	3.10ab
Moti	140.00cd	Hachalu	85.76de	Hachalu	17.78d	Obse	2.98bc
Numan	139.39cd	Obse	85.61de	Ashebeka	17.10de	Gora	2.90cd
Tumsa	135.01d	Dosha	85.35de	Moti	15.21ef	Dosha	2.77cd
Obse	125.95e	Moti	82.60e	Gebelcho	14.17fg	Moti	2.77cd
Dosha	122.11e	Degaga	63.53f	Obse	12.94g	Tumsa	2.67d
Mean	**141.41**		**87.84**		**18.51**		**3.11**
SED	2.04		1.09		0.70		0.14
DF	40.00		80.00		40.00		40.00

Table 6: Mean plant height, hundred seeds weight, number of pods per plant, and number of seeds per pod performance of faba bean varieties evaluated at two locations of Dawro zone in the 2019 and 2020 main cropping seasons.

Means followed by the same letters down columns are not significantly different at $p < 0.05$, SED = Standard error of difference of means, DF = degree of freedom, PH = Plant height in cm, HSW = Hundred seeds weight, PPP = number of pods per plant, SPP = Number of seeds per pod.

Hundred seeds weight performance of genotypes ranged from 63.53 gram for genotype Degaga to 1007.08 gram for genotype Numan with average hundred seeds weight of 87.84 gram (Table 6). Genotypes viz., Numan, Gora, Ashebeka, and Gebelcho, which measured above average weight, are larger seeded genotypes. Therefore, they can be used as parents in breeding for large seed size. Genotypes viz., Tumsa, Didea, Hachalu, Obse, Dosha, Moti, and Degaga, which measured below average weight, are small seeded genotypes. Among the larger seeded genotypes, Numan and Gora showed statistically dissimilar hundred seeds weight performance between them and from others. Other larger seeded genotypes, Ashebeka and Gebelcho, showed similar hundred seeds weight performance. The small seeded genotypes showed similar hundred seeds weight performance except Moti and Degaga, which showed dissimilar hundred seeds weight performance between them and from others.

Number of pods per plant performance of genotypes ranged from 12.94 for genotype Obse to 22.49 for genotype Tumsa with mean number of pods per plant 18.51 (Table 6). Genotypes viz., Tumsa, Dosha, Didea, Degaga, Gora, and Numan, which bore above average number of pods, are higher pod bearing genotypes whereas genotypes viz., Hachalu, Ashebeka, Moti, Gebelcho, and Obse, which bore below average number of pods, are lower pod bearing genotypes. Among the higher pod bearing genotypes, Tumsa, Dosha, Didea, and Degaga were similar in pod bearing ability whereas lower pod bearing genotypes were dissimilar in their bod bearing ability.

Number of seeds per pod performance of genotypes ranged from 2.67 for genotype Tumsa to 3.50 for genotype Gebelcho with mean number of seeds per pod 3.11 (Table 6). Genotypes viz., Gebelcho, Ashebeka, Numan, Didea, and Hachalu, which produced above average seeds per pod, are higher number of seeds per pod producing genotypes. The remaining genotypes, viz., Degaga, Obse, Gora, Dosha, Moti, and Tumsa, which produced below average seeds per pod, are lower number of seeds per pod producing genotypes. Both higher numbers of seeds per pod producing and lower numbers of seeds per pod producing genotypes showed similar performance for number of seeds per pod performance within themselves, but dissimilar between groups.

Economic performance of genotypes

Gross field benefit per hectare (GFB ha^{-1}) of genotypes ranged from 242955.00 Birr from production of genotype Ashebeka with lime application to 142398.45 Birr from production of genotype Gebelcho without lime application (Table 7). Similarly, the net benefit per hectare (NB ha^{-1}) of genotypes ranged from 203405.75 Birr from production of genotype Ashebeka with lime application to 107025.14 Birr from production of genotype Gebelcho without lime application.

In lime applied experiment, GFB ha^{-1} of genotypes ranged from 242955.00 Birr from production of genotype Ashebeka to 161417.25 Birr from production of genotype Obse. The average GFB ha^{-1} of genotypes with lime application was 202731.91 Birr. Genotypes viz., Ashebeka, Hachalu, Numan, Didea, and Tumsa returned above average GFB ha^{-1} whereas genotypes viz., Degaga, Dosha, Gora, Moti, Gebelcho, and Obse returned below average GFB ha^{-1}.

In lime applied experiment, NB ha^{-1} of genotypes ranged from 203405.75 Birr from production of genotype Ashebeka to 123226.96 Birr from production of genotype Obse. The average NB ha^{-1} of genotypes with lime application was 163853.05 Birr. Similar genotypes those returned above average GFB ha^{-1} viz., Ashebeka, Hachalu, Numan, Didea, and Tumsa provided above average NB ha^{-1}. Therefore, production of these genotypes is more profitable than production of remaining genotypes, which provided below average NB ha^{-1}. [42] Reported a net benefit of 60610.00 Birr from production of faba bean when lime is applied at a rate of 2 t ha^{-1}. This is lower amount and may be due to lower seed yield potential of faba bean genotype used and variability of production site.

In lime unapplied experiment, GFB ha^{-1} of genotypes ranged from 219735.00 Birr from production of genotype Ashebeka to 142398.45 Birr from production of genotype Gebelcho. The average GFB ha^{-1} of

With lime application										
Genotype	GY	UP	GFB	TVC	NB	Dominance	Incremental cost	Incremental benefit	MRR (%)	BC ratio
Obse	3587.05	45.00	161417.25	38190.29	123226.96	Undominated				3.23
Gebelcho	3665.03	45.00	164926.35	38248.77	126677.58	Undominated	58.49	3450.62	5900	3.31
Moti	4147.93	45.00	186656.85	38610.95	148045.90	Undominated	362.18	21368.33	5900	3.83
Gora	4211.45	45.00	189515.25	38658.59	150856.66	Undominated	47.64	2810.76	5900	3.90
Dosha	4337.80	45.00	195201.00	38753.35	156447.65	Undominated	94.76	5590.99	5900	4.04
Degaga	4378.28	45.00	197022.60	38783.71	158238.89	Undominated	30.36	1791.24	5900	4.08
Tumsa	4751.25	45.00	213806.25	39063.44	174742.81	Undominated	279.73	16503.92	5900	4.47
Didea	4796.20	45.00	215829.00	39097.15	176731.85	Undominated	33.71	1989.04	5900	4.52
Numan	5068.65	45.00	228089.25	39301.49	188787.76	Undominated	204.34	12055.91	5900	4.80
Hachalu	5214.05	45.00	234632.25	39410.54	195221.71	Undominated	109.05	6433.95	5900	4.95
Ashebeka	5399.00	45.00	242955.00	39549.25	203405.75	Undominated	138.71	8184.04	5900	5.14
Without lime application										
Genotype	GY	UP	GFB	TVC	NB	Dominance	Incremental cost	Incremental benefit	MRR (%)	BC ratio
Gebelcho	3164.41	45.00	142398.45	35373.31	107025.14	Undominated				3.03
Obse	3295.83	45.00	148312.35	35471.87	112840.48	Undominated	98.56	5815.34	5900	3.18
Gora	3469.65	45.00	156134.25	35602.24	120532.01	Undominated	130.37	7691.53	5900	3.39
Moti	3833.58	45.00	172511.10	35875.19	136635.92	Undominated	272.95	16103.90	5900	3.81
Dosha	3843.35	45.00	172950.75	35882.51	137068.24	Undominated	7.33	432.32	5900	3.82
Didea	3980.95	45.00	179142.75	35985.71	143157.04	Undominated	103.20	6088.80	5900	3.98
Degaga	4257.63	45.00	191593.35	36193.22	155400.13	Undominated	207.51	12243.09	5900	4.29
Tumsa	4266.05	45.00	191972.25	36199.54	155772.71	Undominated	6.31	372.58	5900	4.30
Numan	4333.00	45.00	194985.00	36249.75	158735.25	Undominated	50.21	2962.54	5900	4.38
Hachalu	4768.40	45.00	214578.00	36576.30	178001.70	Undominated	326.55	19266.45	5900	4.87
Ashebeka	4883.00	45.00	219735.00	36662.25	183072.75	Undominated	85.95	5071.05	5900	4.99

Table 7: Partial budget with dominance and marginal analysis of faba bean genotypes evaluated with and without lime application at two locations of Dawro zone in the 2019 and 2020 main cropping seasons.

GY = Seed yield (kg ha-1), UP = Unit price in Birr kg-1 of seed yield, GFB = Gross field benefit in Birr ha-1 (GY*UP), TVC = Total variable cost (sum of variable costs) in Birr ha-1, NB = Net benefit in Birr ha-1 (GFB ha-1-TVC ha-1), and MRR = Marginal rate of return (incremental benefit /incremental cost), and BC ratio = Net benefit /TVC.

genotypes without lime application was 180392 [43].11 Birr. Genotypes viz., Ashebeka, Hachalu, Numan, Tumsa, and Degaga returned above average GFB ha^{-1} whereas genotypes viz., Didea, Dosha, Moti, Gora, Obse, and Gebelcho returned below average GFB ha^{-1}.

In lime unapplied experiment, NB ha^{-1} of genotypes ranged from 183072.75 Birr from production of genotype Ashebeka to 107025.14 Birr from production of genotype Gebelcho. The average NB ha^{-1} of genotypes without lime application was 144385.58 Birr. Similar genotypes those returned above average NB ha^{-1} with lime application viz., Ashebeka, Hachalu, Numan, Didea, and Tumsa provided above average NB ha^{-1} when lime was unapplied [44]. Therefore, production of these genotypes is more profitable than production of remaining genotypes, which provided below average NB ha^{-1}. However, production of them with lime application provides 21454.60 Birr extra net benefit per hectare than production of them without lime application.

Dominance analysis revealed that in both lime applied and unapplied experiments all genotypes were undominated (Table 8). Therefore, the same marginal rate of return (MRR %), which was 5900%, was observed from production of all genotypes in both lime applied and unapplied experiments. This is because production of all genotypes in the same one hectare of land incurred similar costs except transportation cost of seed yield produced from each genotype, which varied according to amount of seed produced by each genotype [45]. The MRR was 5900% means that investment of one Birr in production of faba bean genotypes returns a net benefit of 59 Birr. However, net benefit to cost ratio (BC) of genotypes ranged from 3.02 from production of Gebelcho when lime was unapplied to 5.14 from production of Ashebeka when lime was applied. BC values were higher for more profitable genotypes than less profitable genotypes. Therefore, production of genotypes viz., Ashebeka, Hachalu, Numan, and Tumsa is more profitable both with and without lime application in highlands of Ethiopia but, lime application provides 21454.60 Birr extra net benefit per hectare. MRR% better revealed a net benefit return from investment of unit Birr than net benefit to cost ratio (BC), which indicated net benefits from investment of unit Birr in the range 3.02 from production of Gebelcho when lime was unapplied to 5.14 from production of Ashebeka when lime was applied.

In sensitivity analysis, with the concurrent changes in prices of seed yield (-10%) and TVC (+10%), again the same MRR with value 4809.09 was recorded from all genotypes in both lime applied and unapplied experiments (Table 8). GFB ha^{-1} ranged from 218659.50 Birr from production of genotype Ashebeka when lime applied to 128158.61 Birr for genotype Gebelcho when lime unapplied. The NB ha^{-1} ranged from 175155.33 Birr from production of genotype Ashebeka when lime applied to 89247.97 Birr from production of

With lime application										
Genotype	GY	UP	GFB -10%	TVC +10%	NB	Dominance	Incremental cost	Incremental benefit	MRR (%)	BC ratio
Obse	3587.05	45.00	145275.53	42009.32	103266.21	Undominated				2.46
Gebelcho	3665.03	45.00	148433.72	42073.65	106360.07	Undominated	64.33	3093.86	4809.09	2.53
Moti	4147.93	45.00	167991.17	42472.04	125519.12	Undominated	398.39	19159.06	4809.09	2.96
Gora	4211.45	45.00	170563.73	42524.45	128039.28	Undominated	52.40	2520.16	4809.09	3.01
Dosha	4337.80	45.00	175680.90	42628.69	133052.22	Undominated	104.24	5012.94	4809.09	3.12
Degaga	4378.28	45.00	177320.34	42662.08	134658.26	Undominated	33.40	1606.04	4809.09	3.16
Tumsa	4751.25	45.00	192425.63	42969.78	149455.84	Undominated	307.70	14797.58	4809.09	3.48
Didea	4796.20	45.00	194246.10	43006.87	151239.24	Undominated	37.08	1783.39	4809.09	3.52
Numan	5068.65	45.00	205280.33	43231.64	162048.69	Undominated	224.77	10809.45	4809.09	3.75
Hachalu	5214.05	45.00	211169.03	43351.59	167817.43	Undominated	119.95	5768.75	4809.09	3.87
Ashebeka	5399.00	45.00	218659.50	43504.18	175155.33	Undominated	152.58	7337.89	4809.09	4.03
Without lime application										
Genotype	GY	UP	GFB -10%	TVC +10%	NB	Dominance	Incremental cost	Incremental benefit	MRR (%)	BC ratio
Gebelcho	3164.41	45.00	128158.61	38910.64	89247.97	Undominated				2.29
Obse	3295.83	45.00	133481.12	39019.06	94462.06	Undominated	108.42	5214.09	4809.09	2.42
Gora	3469.65	45.00	140520.83	39162.46	101358.36	Undominated	143.40	6896.31	4809.09	2.59
Moti	3833.58	45.00	155259.99	39462.70	115797.29	Undominated	300.24	14438.92	4809.09	2.93
Dosha	3843.35	45.00	155655.68	39470.76	116184.91	Undominated	8.06	387.62	4809.09	2.94
Didea	3980.95	45.00	161228.48	39584.28	121644.19	Undominated	113.52	5459.28	4809.09	3.07
Degaga	4257.63	45.00	172434.02	39812.54	132621.47	Undominated	228.26	10977.28	4809.09	3.33
Tumsa	4266.05	45.00	172775.03	39819.49	132955.53	Undominated	6.95	334.06	4809.09	3.34
Numan	4333.00	45.00	175486.50	39874.73	135611.78	Undominated	55.23	2656.24	4809.09	3.40
Hachalu	4768.40	45.00	193120.20	40233.93	152886.27	Undominated	359.21	17274.50	4809.09	3.80
Ashebeka	4883.00	45.00	197761.50	40328.48	157433.03	Undominated	94.54	4546.76	4809.09	3.90

Table 8: Sensitivity analysis of faba bean genotypes production evaluated with and without lime application at two locations of Dawro zone in the 2019 and 2020 main cropping seasons based on a 10% raise in total variable cost (TVC) and a 10% faba bean seed yield price (GFB) fall.

GY = Seed yield (kg ha-1), UP = Unit price in Birr kg-1 of seed yield, GFB – 10% = Gross field benefit in Birr ha-1 (GY*UP) minus 10%, TVC +10% = Total variable cost (sum of variable costs) in Birr ha-1 minus 10%, NB = Net benefit in Birr ha-1 ((GFB -10%) ha-1-(TVC+10%) ha-1), and MRR = Marginal rate of return (incremental benefit /incremental cost), and BC ratio = Net benefit /TVC.

genotype Gebelcho when lime unapplied. The average reductions in NB ha^{-1} were 17.29% when lime applied and 17.63% when lime unapplied. The net benefit (NB ha^{-1}) to Total Variable Cost (TVC) ratio was also higher for the same genotypes. These results revealed that the same genotypes are more profitable under risky market situations. Therefore, production of genotypes viz., Ashebeka, Hachalu, Numan, and Tumsa in the highlands of Dawro zone and Ethiopia is certainly profitable.

Conclusion

There is wide gap between actual farmers yield and research yield in faba bean in Ethiopia. This is mainly due to soil acidity and its driven soil fertility problems in the highlands. Soils of this experiment sites are strongly acidic. They have medium content of organic carbon and are optimum in total nitrogen and zinc content. However, they are deficient in cupper and very low in available phosphorus, sulphur, and boron. Therefore, determination of optimum rates of blended fertilizers containing Nitrogen (N), Phosphorus (P), Sulphur (S), and Boron (B) for these soils is important. They have high concentration of iron and manganese which again indicate need for interventions that can bring their concentration to nontoxic level.

Faba bean genotypes studied have substantial genetic variability for seed yield performance. Similarly, test environments are very variable with greater variability in seasons than locations. Again, the influences of soil acidity and its related soil fertility problems are higher than other edaphic factors in causing variability among faba bean genotypes for seed yield performance. Mean seed yield performance above overall mean enabled identification of higher seed yielding genotypes and soil acidity intensity index enabled identification of more acidic site. Soil acidity susceptibility index and percent seed yield reduction analysis enabled identification of acid soil tolerant genotypes but, less clearly than overall mean.

Higher seed yielding genotype is defined as a genotype that performs above overall mean in a set of test environments. Genotypes viz., Ashebeka, Hachalu, Numan, Tumsa, Didea, and Degaga, are higher seed yielding genotypes.

Liming is application of calcium- and magnesium-rich materials to acidic soils to raise soil pH to the optimum level for crops. It increased seed yield of genotypes variably for different genotypes. Lime responsive genotype is defined as a genotype that gives higher seed yield compared to other genotypes when lime is applied to acidic soils based on soil test results. Genotypes viz., Ashebeka, Hachalu, Numan, Didea, and Tumsa are lime responsive genotypes.

Acid soil tolerant genotype is defined as a genotype that gives higher seed yield compared to other genotypes in acid soils. Acid soil tolerant genotypes are very important as they enable cultivation of marginal lands without the need to take costly reclamation measures. Genotypes viz., Ashebeka, Hachalu, Numan, and Tumsa, are acid soil tolerant genotypes. Their production is also very profitable in the highlands of Dawro zone and Ethiopia.

Therefore, genotypes viz., Ashebeka, Hachalu, Numan, and Tumsa, both lime responsive and acid soil tolerant, are good genotypes for both subsistence and commercial production in the highlands of Dawro zone and Ethiopia. They can also be used in future breeding programs to improve seed yield potential and quality traits under acid soil conditions. Genotype, Didea, responsive to lime but, sensitive to soil acidity, is good genotype for production in highly acidic soils with lime application. Genotype, Degaga, unresponsive to lime but, tolerant to acid soils, is good for production in marginal lands without lime application. Genotypes viz., Dosha, Gora, Gebelcho, Moti, and Obse, both unresponsive to lime and sensitive to acid soils, are less suitable for production in study sites and similar areas.

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