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Pod quality of snap bean as affected by Nitrogen fixation, cultivar and climate zone under dryland agriculture

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Snap bean (*Phaseolus vulgaris* L.) is one of the major vegetable crops in Ethiopia grown for export and local markets. The crop is mainly produced during the dry season under irrigation. Snap bean has higher price than other vegetables in local markets in Ethiopia; however, the high cost of production under irrigation restricts the majority of local farmers from taking this opportunity. The main objective of this research was to investigate the influence of nitrogen (N) treatment, cultivar and contrasting environments on pod quality of snap bean under rain fed conditions. Three N treatments (0 and 100 kg N ha^{-1}, and *Rhizobium etli*[HB 429]) and eight snap bean cultivars were evaluated in a factorial experiment arranged as a randomized block design with three replications. The experiment was conducted at three locations (DebreZeit, Hawassa and Ziway) in 2011 and 2012. Applied N and rhizobium inoculant increased marketable pod yield by 43 and 18%, respectively. Cultivar Melkassa 1 had the greatest marketable yield, but had lower pod physical qualities than other cultivars. The highest zinc concentration in pods was obtained at Hawassa location. In conclusion, viable option for the production of high quality snap bean can be realised under rain fed condition using rhizobial inoculant as N source. These results open new opportunity for resource limited farmers in Ethiopia to produce snap bean with acceptable quality using rhizobial inoculation as N source under rain fed condition.

Key words: Snap bean, cultivars, quality, rhizobium, nutrient concentrations.

INTRODUCTION

Snap bean cultivars are specific cultivars of common bean (*Phaseolus vulgaris* L.) grown for their green pods used as vegetable and serve as an important source of protein. The pod physical quality of snap bean is a combination of appearance and physical condition. Acceptable snap bean quality includes well-formed and straight pods, and pods should be bright in color with a fresh appearance, free of defects, and tender, not tough or stringy and firm (Cantwell and Suslow, 1998). The quality of snap bean pods can also be expressed in terms

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of nutrient concentrations because of their importance in human nutrition. Over two billion people are affected by micronutrient malnutrition in the developing world (Cakmak et al., 2010). Iron (Fe) and zinc (Zn) deficiencies are leading micronutrient deficiencies affecting preschool children that impaired physical growth and mental development (Fe), hampered growth and development (Zn), and weaken the immune system (Zn) (Cakmak et al., 2010). Consumption of common bean which its pods are rich in quality protein, fibre, micronutrients such as iron, zinc and vitamin A may help to alleviate micronutrient malnutrition (Ugen et al., 2012). Common bean also contains high protein that contains the essential amino acid lysine (Baudoin and Maquet, 1999). Although information is lacking for direct comparison, independent research results showed that snap bean immature pods on a dry weight basis contain a similar range of protein concentration as dry seeds of common bean (Abubaker, 2008; Pereira et al., 2009). Report also showed that snap bean possesses relatively high bio available calcium when compared to other vegetables (Quintana et al., 1999a).

Protein and mineral concentrations of snap bean pods can be affected by cultural practices including N fertilizer (Abubaker, 2008; Ahmed et al., 2010). Further, yield and quality of snap bean plant were significantly improved by organic fertilizers (Salinas-Ramírez et al., 2011) and by both macro and micro nutrient applications (Tantawy et al., 2009; Abdel-Mawgoud et al., 2011).

The use of synthetic N for improvement of snap bean pod quality has been well documented and extensively studied. However, dependency on synthetic fertilizers needs to be minimized due to some reasons including high fertilizer cost. Synthetic fertilizers may also release greenhouse gases and may loss in the field resulting from less effective application strategy (Reid et al., 2011; Ferguson et al., 2010; Ferguson, 2013). Extensive reports are available on the use of rhizobium inoculation for increasing yield of chickpea (Bhuiyan et al., 2008), soybean (Sall and Sinclair, 1991), field bean (Bildirici and Yilmaz, 2005; Otieno et al., 2009), and many other legumes. However, the use of rhizobium inoculant for improving the quality of snap bean is lacking. Some reports also argued the effectiveness of using rhizobium inoculation for vegetable legume production including snap bean because nitrogen fixation may not produce adequate N early in the season to support pod production (Rubatzky and Yamaguchi, 1997).

The productivity and quality of a given crop species or cultivarare determined by crop management and agro-meteorological variables such as soil properties, rainfall and temperature (Dapaah, 1997; Hoogenboom, 2000). Individual legume species or cultivars often require specific ecological niches for maximum production (Masaya and White, 1991), which should be considered when selecting the production site suitability whether at local, national or international levels (Valentine and Matthew, 1999). Knowledge of the developmental and environmental factors contributing to yield and quality variation is, therefore, required to maximize yield and quality of agricultural crops. Yield variation was observed among different *P. vulgaris* genotypes along different locations in Tanzania (Giller et al., 1998). Nutrient concentration in seeds of common bean was also influenced by genotype (Beebe et al., 2000; Gregorio, 2002; Nchimbi-Msolla and Tryphone, 2010; Prolla et al., 2010) and environment (Quintana et al., 1999b; Nchimbi-Msolla and Tryphone, 2010).

However, studies are lacking on the influence of climatic zones (environment) on the physical properties and nutrient concentrations of snap bean pods. The interactive effects of environments and cultivars on pod quality of snap bean also need investigation. We hypothesized that rhizobium inoculation can be the main N source to produce quality snap bean under low input production system. Further, rhizobium inoculation, selection of suitable climatic zone (location) and cultivar can improve pod physical qualities and nutrient concentrations in the pods of snap bean.

The objectives of the study were first to assess the possibility of using rhizobium inoculation as the main source of N to produce quality snap bean pods relative to the use of synthetic N fertilizer, and second to evaluate the cultivars of snap bean for their marketable yield, physical pod qualities and nutrient concentrations in the pods under different N treatments across different agro-ecologies in the Rift Valley of Ethiopia.

MATERIALS AND METHODS

Site characteristics

The study was conducted at three sites across different agro-ecologies in the Rift Valley of Ethiopia. The three sites were DebreZeit, Hawassa and Ziway. DebreZeitis found at 8°44’52’’N, 38°05’53’’E, in a tepid to cool sub-moist climate zone characterized by moderate temperature and a definitive rainfall patterned between July to September (Table 1). It is situated at higher altitude in the transitional region of the Rift Valley and associated mountain ranges. The area is dominated by clay soils with higher copper and cation exchange capacity, and a neutral pH (Table 2).

Hawassa is situated at 7°4’ N, 38°31’ E and it is in a hot to warm sub-moist humid climate zone with warmer temperature especially during the dry season (February to April) (Table 1). It has a longer growing season and a less definitive pattern of rain fall during the growing season (Table 1). It is a mid-highland area in the Rift Valley zone. The soil is loam characterized by slightly acidic pH and higher concentrations of micronutrients such as manganese, iron and zinc (Table 2).

Ziway is found at 8°00’ N, 38°45’E in a tepid to cool semi-arid climate zone with erratic rainfall and unpredictable climate (Table 1). The area is in the Rift Valley zone with a mid-altitude. It has warmer temperature particularly during the dry season. The soil is sandy loam with a very high pH and relatively higher exchangeable sodium (Table 2). Ziway is located at a distance of around100 km equidistant between DebreZeit and Hawassa.

Experimental design and crop management

The field experiments were conducted under rain fed conditions in

Table 1. Average rainfall, maximum and minimum temperature during 2011 and 2012 growing seasons atDebreZeit, Hawassa and Ziway, Ethiopia. Ten year normal climate, altitude and climate zone of each location are presented.

Year		DebreZeit			Hawassa			Ziway		
		Rainfall	Max. T‡	Min. T§	Rainfall	Max. T‡	Min. T§	Rainfall	Max. T‡	Min. T§
		mm	°C	°C	mm	°C	°C	mm	°C	°C
	July	134.6	26.9	13.5	129.6	25.7	12.8	133.7	25.8	14.8
2011	August	241.7	25.0	14.9	157.3	25.3	13.0	114.8	24.6	15.1
	September	82.6	25.0	14.9	113.3	25.7	13.3	56.2	25.5	13.3
	Annual	724.1	26.4	11.3	776.1	28.0	12.1	598.3	29.1	13.0
	July	197.4	25.0	13.5	232.5	24.9	14.7	326.3	23.2	15.0
2012	August	256.5	24.5	12.6	72.7	24.4	14.5	171.4	24.3	14.7
	September	103.0	25.6	12.5	139.8	27.0	15.3	136.6	27.8	9.7
	Annual	726.3	26.7	10.4	884.8	28.1	12.7	856.8	28.6	12.4
10 years	Normal	747.0	26.4	10.7	786.5	27.9	12.3	763.9	27.5	13.9
Altitude (m above sea level)			1950			1700			1645	
Climate Zone †			Tepid to cool sub-moist			Hot to warm sub-moist Humid			Tepid to cool Semi arid	

Data collected by DebreZeit Agricultural Research Center (DebreZeit), South Agricultural research Center (Hawassa), and Adame Tulu Agricultural Research Center (Ziway). †According Ethiopian Ministry of Agriculture (2000); ‡Maximum temperature; § Minimum temperature.

2011 and 2012 during the main rainy season from June to September (normal planting season in the region). In 2011 seeding occurred on June 27, July 6 and 19 at Ziway, DebreZeit and Hawassa, respectively. In the second year, crops were seeded on July 1, 2 and 4, 2012, at Hawassa, Ziway and DebreZeit, respectively. At each of the three sites, eight snap bean cultivars (six commercial: Andante, Boston, Contender Blue, Lomami, Paulista and Volta; and two locally recommended cultivars from Melkassa Agricultural Research Center: Melkassa 1 and Melkassa 3) were tested against three N treatments (0kg N ha^{-1}, *Rhizobium etli* [strain HB 429] and 100 kg N ha^{-1}). The rhizobium strain used in the experiment was developed by the National Soil Testing Center at Addis Ababa, Ethiopia. The strain is being used by local farmers for dry bean production. Seeds of snap bean cultivars for rhizobium inoculation treatment were coated with charcoal based rhizobium inoculum (*R. etli* [HB 429]) at a concentration of 1 × 10^{9} cells g^{-1} material. Fresh inoculum impregnated in charcoal was taken from National Soil Testing Centre, Addis Ababa, Ethiopia, one week before seeding date. On the date of seeding, the snap bean seeds for inoculation were wetted with water with a spoon of sugar in it as a sticker solution. The charcoal base rhizobium inoculum was mixed thoroughly with seeds with sticker for proper coating. Then the coated seeds were put under shade for approximately 20 to 30 min and then seeded immediately. The detailed procedure is summarized in N2Africasite (http://www.n2africa.org/). The 100 kg N ha^{-1}is the average rate of commonly used N fertilizer by commercial snap bean producers in Ethiopia.

The treatments were applied as factorial combinations in a Completely Randomized Block Design with three replications at each location and year. The size of the plot was 2.5 m × 2.0 m. Each plot had five rows. Row length was 2.0 m with 0.1 m between plants within each row and 0.5 m between rows. The two outer rows were considered as border rows. Plant population was maintained by planting two seeds per hill and thinned to one upon appearance of trifoliate leaves.

The recommended rate of phosphorus fertilizer (21 kg P ha^{-1}) was applied at the time of seeding in the form of triple super phosphate for all locations. Weeds were controlled by hand weeding and hoeing. Fungicide (Mancozeb) was also sprayed to protect from fungal diseases at three week intervals until the pod setting stage.

Measurements

Marketable yield and other physical qualities

Pods at optimum maturity (firm, bright green, and tender fleshy pods with small green immature seeds at60 to 70 days after planting) were harvested. Three to four rounds or passes of harvesting were made depending on the cultivar. The weights of marketable pods from the total harvest were calculated as tonnes per hectare. The length and diameter of pods from four randomly selected sample plants per plot were measured with a tape measure and sieve, respectively. Pod texture (1= very fine, 2 = fine, 3 = reasonably fine, 4 = coarse/rough, 5 = very coarse/rough) and pod appearance (1 = excellent, 2 = good, 3 = acceptable, 4 = poor, 5 = rejected) were rated visually using the scale modified from Proulx et al. (2010) and Martinez et al. (1995). Pod texture and appearance were rated by five experts who grade and pack snap bean for export markets. For titrate be acidity, aliquots (10.0 g) of juice were diluted with 50 mL distilled water and acidity was determined by titration with 0.1 N NaOH end point (pink color). The results were converted into percentage malic acid, which is the main organic acid in snap bean (Martinez et al., 1995) using the formula (1) of Proulx et al. (2010).

$$TA = \frac{\text{mL NaOH} * 0.1\text{ N} * 0.067\text{ meq}}{10.0\ g} \times 100 \quad (1)$$

Where TA = Titratable acidity, mL = milliliter, NaOH = Sodium hydroxide, N = Normal (normality of NaOH), meq = milli-equivalent (molecular weight of malic acid = 67), and g = gram (juice).

The total soluble solids (TSS) of pods were measured using a hand-held refractometer for Brix (TBT, RHB0-80, Jiangsu, China).

Nutrient concentration

Total N and phosphorus in green pods of snap bean were measured by a sulfuric acid-hydrogen peroxide digestion using a temperature-controlled digestion block (Thomas et al., 1967), followed by determination of total N and phosphate concentration in

Table 2. Soil physicochemical characteristics at DebreZeit, Hawassa and Ziway, Ethiopia during the 2011 and 2012 growing seasons.

Profile code	DebreZeit 2011	Hawassa 2011	Ziway 2011	DebreZeit 2012	Hawassa 2012	Ziway 2012
Sand (%)	13.59	47.03	83.62	15.57	51.69	74.17
Silt (%)	14.75	29.66	14.33	10.30	30.20	17.22
Clay (%)	71.65	23.31	2.05	74.14	18.12	8.61
Texture class†	Clay	Loam	Sandy loam	Clay	Loam	Sandy loam
pH-H_2O (1:2.5) ‡	6.98	6.10	8.38	6.98	6.10	8.20
pH-KCl (1:2.5) ‡	5.96	5.31	7.61	6.02	5.22	7.58
EC (ms cm^{-1}) (1:2.5)	0.16	0.17	0.15	0.26	0.17	0.26
Exch.Na (cmolc kg^{-1} soil) §	0.44	0.65	1.19	0.70	0.60	1.35
Exch.K (cmolc kg^{-1} soil) §	0.36	1.50	1.84	0.32	2.41	2.20
Exch.Ca (cmolc kg^{-1} soil) §	32.32	12.93	18.58	28.28	12.93	21.82
Exch.Mg (cmolc kg^{-1} soil)§	15.35	11.31	6.87	12.12	8.08	0.81
sum of cations (cmolc kg^{-1} soil)	52.70	36.01	34.69	44.35	36.01	37.77
CEC (cmolc kg^{-1} soil)	48.47	26.39	28.48	41.42	24.01	26.18
Organic Carbon (%) ¶	1.5	1.59	0.96	1.47	1.55	1.15
Nitrogen (%) ††	0.11	0.11	0.10	0.08	0.10	0.07
Available P (mg P_2O_5 kg^{-1} soil) #	43.66	49.32	43.81	41.89	91.68	83.46
Available K (mg K_2O kg^{-1} soil) §	158.22	620.7	778.91	141.18	973.64	864.11
$CaCO_3$ (%)						
Exchangeable sodium % (ESP) §	0.83	1.80	3.42	1.58	1.66	3.58
Micronutrients ‡‡						
Cu (mg kg^{-1} soil)	2.04	0.30	0.33	1.47	0.39	0.32
Fe (mg kg^{-1} soil)	12.46	28.96	3.13	10.64	25.93	4.58
Mn (mg kg^{-1} soil)	9.27	20.76	2.70	7.82	27.03	4.63
Zn (mg kg^{-1} soil)	0.86	3.61	1.08	0.86	3.78	1.50

Methods: †Hydrometer; ‡Acid neutralization; §Ammonium acetate; #Olsen; ¶Walklay and Black; ††Kjeldahl; ‡‡ Instrumental.

the digest (Wall et al., 1975; Watanabe and Olsen, 1965), using automated colorimetry (Technicon Instruments Corporation, New York, USA). Protein was estimated by multiplying total N by 6.25 (Imran et al., 2008). The zinc and iron concentrations were analyzed on a novAA®330 Atomic Absorption Spectrometer (Analytikjena, Jena, Germany) using an air/acetylene flame. The calcium and potassium concentrations were analyzed using the same NovAA330 Atomic Absorption Spectrophotometer using nitrous oxide as the oxidant for the acetylene.

Statistical analysis

Data analysis was done using the PROC MIXED procedure of the SAS software version 9.3 (SAS Institute Inc., 2012). The assumptions of ANOVA for normality of distribution and homogeneity of variance were checked. The two years data were combined for analysis. The covariance parameter estimate showed there was year by location by cultivar interactions for protein and calcium concentrations. Therefore, a separate analysis was done for each year to identify the effect of location by cultivar interaction on these response variables. The TSS and acidity data were available only in 2012. Nitrogen treatments, cultivar and locations (agro-ecology) were considered as fixed effects. Year, block nested in year, the interaction of each of main plot factors (N treatment, cultivar and location) with year and the two-way and three-way interactions of main plot factors with year were considered as random. The non-significant covariance parameters were eliminated starting from the higher level of interaction from the model according to AIC values to simplify the model for better model fit (Littell et al., 2005). Interaction effects between main effects (cultivar by location, cultivar by N treatment, N treatment by location, and three way interaction cultivar by location by N treatment) were presented only when statistically significant. The absence of significant interaction shows no particular reaction of one main effect (for example cultivar)at another specific main effect (for example location). Means were separated according Fisher's protected LSD at $P < 0.05$.

RESULTS

Pod marketable yield and other physical qualities

The combined analysis showed that N treatment significantly affected marketable yield, pod appearance and titratable acidity (Table 3). Cultivar significantly affected marketable yield and all other pod physical quality parameters (Table 3).Location significantly affected marketable yield and titratable acidity (Table 3). Cultivar by location interaction significantly ($P < 0.05$) affected TSS of snap bean pods but did not significantly

Table 3. *P*-values from mixed model ANOVA F-test for marketable yield, pod length, pod diameter, pod texture, pod appearance, titratable acidity (TA) and total soluble solids (TSS) of snap bean affected by nitrogen treatment, cultivar and location in 2011 and 2012 under rain fed conditions.

Source	Marketable yield	Pod length	Pod diameter	Texture	Appearance	TA	TSS
	t ha^{-1}	mm	mm	1-5	1-5	%	^{o}Brix
Nitrogen treatment (N)	0.0001***	0.3794	0.1192	0.0986	0.0054**	0.002**	0.0727
Cultivar (V)	<.0001***	<.0001***	<.0001***	0.0316*	0.0046**	0.0072**	0.0225*
Location (L)	0.0173*	0.0868	0.3865	0.6253	0.6626	0.0016**	0.5567
L*V	0.473	0.3774	0.292	0.272	0.5378	0.2464	0.0001***
L*N	0.1543	0.2169	0.9079	0.0078**	0.9636	0.1993	0.8423
V*N	0.6966	0.2525	0.8376	0.0299*	0.0226*	0.6749	0.4801
L*V*N	0.7419	0.4971	0.8746	0.6752	0.6962	0.0567	0.8689

*,**,***, denote significant at the 0.05,0.01,0.001 probability levels respectively.

Table 4. Pod marketable yield, length, diameter, texture, appearance, titratable acidity and total soluble solids (TSS) of snap bean affected by nitrogen treatment, cultivar and location (combined 2011 and 2012).

Nitrogen treatment	Marketable yield (t ha^{-1})	Pod length (mm)	Pod diameter (mm)	Texture (1-5)†	Appearance (1-5)‡	Titratable acidity (%)§	TSS (^{o}Brix)§
100 kg N ha^{-1}	20.54^{a}	125.0	7.56	1.21	1.21^{c}	0.0769^{a}	5.54
Rhizobium etli (HB 429)	16.92^{b}	122.0	7.49	1.91	1.81^{b}	0.0747^{a}	5.50
Zero N	14.39^{c}	120.2	7.38	1.98	2.13^{a}	0.0701^{b}	5.46
Cultivar							
Andante	11.70^{c}	106.4^{e}	6.01^{e}	1.42^{b}	1.57^{b}	0.0765^{a}	5.44^{b}
Boston	17.94^{b}	123.1^{bc}	7.11^{d}	1.44^{b}	1.54^{b}	0.0768^{a}	5.41^{b}
Contender Blue	16.94^{b}	112.8^{d}	7.38^{cd}	1.55^{b}	1.56^{b}	0.0747^{ab}	5.47^{ab}
Lomami	18.14^{ab}	122.7^{c}	7.44^{cd}	1.59^{b}	1.63^{b}	0.0775^{a}	5.51^{ab}
Melkassa 1	20.60^{a}	125.8^{bc}	8.68^{a}	2.26^{a}	2.26^{a}	0.0668^{c}	5.49^{ab}
Melkassa 3	16.95^{b}	133.8^{a}	8.32^{b}	2.15^{a}	2.15^{a}	0.0726^{abc}	5.56^{a}
Paulista	17.98^{b}	126.5^{bc}	7.36^{cd}	1.57^{b}	1.5^{b}	0.0700^{bc}	5.57^{a}
Volta	18.00^{b}	128.1^{b}	7.48^{c}	1.61^{b}	1.54^{b}	0.0763^{a}	5.56^{a}
Location							
DebreZeit	18.45^{a}	122.2	7.22	1.77	1.70	0.0789^{a}	5.54
Hawassa	21.23^{a}	129.2	7.81	1.69	1.71	0.0782^{a}	5.50
Ziway	12.17^{b}	115.8	7.39	1.65	1.74	0.0647^{b}	5.47

Means followed by the different letters in a treatment grouping column differ significantly based on LSD, *P*<0.05. Absence of letter in a grouping column denotes non significance. % determined on the basis of g 100 g^{-1} of pod dry weight. †Score (1 = very fine, 2 = fine, 3 = reasonably fine, 4 = coarse/ rough, 5 = very coarse/rough). ‡Score (1 = excellent, 2 = good, 3 = acceptable, 4 = poor, 5 = rejected). § Data only 2012.

affect marketable yield, pod length, pod diameter, texture, and pod appearance. Location by N treatment significantly (P < 0.05) affected pod texture but had no effect on other pod physical quality parameters considered in this section (Table 3). Cultivar by N treatment interaction significantly affected pod texture and appearance but had no significant effect on other physical quality parameters (Table 3). The three ways interaction (N treatment by cultivar by location) had no effect on all of the parameters considered (Table 3).

Nitrogen treatments, cultivars and locations significantly affected marketable pod yield (Table 3). The highest marketable pod yield was produced using 100 kg N ha^{-1} (Table 4). Rhizobium inoculation resulted in significantly higher marketable pod yield than the no N application (control). The greatest and the least marketable yield were obtained from Melkassa 1 and Andante, respectively (Table 4). Hawassa and DebreZeit were found to be suitable areas to produce snap bean and both had significantly greater marketable yield than Ziway

Table 5. Nitrogen treatment by cultivar interaction for snap bean pod texture and pod appearance. Nitrogen treatment by location interaction for snap bean pod texture. Location by variety interaction for total soluble solids (TSS). (Combined2011 and 2012).

Cultivar	Texture (1-5)†			Appearance (1-5)‡			TSS (°Brix)§		
	Nitrogen treatment			Nitrogen treatment			Location		
	0 kg N ha^{-1}	*Rhizobium Etli* (HB 429)	100 kg N ha^{-1}	0 kg N ha^{-1}	*Rhizobium etli* (HB 429)	100 kg N ha^{-1}	DebreZeit	Hawassa	Ziway
Andante	1.61^{cde}	1.67^{de}	1.00^{e}	1.83^{bcd}	1.78^{bcd}	1.11^{e}	5.6^{ab}	5.57$^{a\text{–}d}$	5.16^{f}
Boston	1.61^{cde}	1.67^{de}	1.06^{e}	1.83^{bcd}	1.78^{bcd}	1.00^{e}	5.6^{ab}	5.2^{ef}	5.42^{bcd}
Contender Blue	1.83^{bcd}	1.83^{bcd}	1.00^{e}	1.94^{bcd}	1.67^{cd}	1.06^{e}	5.52$^{a\text{–}d}$	5.53$^{a\text{–}d}$	5.35^{de}
Lomami	1.83^{bcd}	1.94^{abcd}	1.00^{e}	1.94^{bcd}	1.89^{bcd}	1.06^{e}	5.42^{bcd}	5.5$^{a\text{–}d}$	5.61^{ab}
Melkassa 1	2.61^{a}	2.33^{abc}	1.83^{bcd}	2.83^{a}	2.06^{b}	1.89^{bcd}	5.51$^{a\text{–}d}$	5.38^{cde}	5.59^{abc}
Melkassa 3	2.5^{ab}	2.17^{abcd}	1.78^{bcd}	2.78^{a}	2.11^{b}	1.56^{cd}	5.53$^{a\text{–}d}$	5.6^{ab}	5.53$^{a\text{–}d}$
Paulista	1.89^{bcd}	1.83^{bcd}	1.00^{e}	1.94^{bcd}	1.56^{d}	1.00^{e}	5.57$^{a\text{–}d}$	5.62^{ab}	5.53$^{a\text{–}d}$
Volta	2^{bcd}	1.83^{bcd}	1.00^{e}	1.94^{bcd}	1.67^{cd}	1.00^{e}	5.54$^{a\text{–}d}$	5.58^{abc}	5.57$^{a\text{–}d}$
Location									
DebreZeit	2.15^{a}	1.92^{abc}	1.25^{bc}						
Hawassa	1.85^{abc}	1.85^{abc}	1.21^{bc}						
Ziway	1.81a^{bc}	1.96a^{bc}	1.17^{c}						

Means followed by different letters in the same interaction groups (nitrogen treatment x cultivar; nitrogen treatment x location; location x cultivar) in the same parameter differ significantly based on LSD, $P< 0.05$. †Score (1= very fine, 2 = fine, 3 = reasonably fine, 4 = coarse/ rough, 5 = very coarse/rough). ‡Score (1 = excellent, 2 = good, 3 = acceptable, 4 = poor, 5 = rejected). § data only 2012.

(Table 4).

Cultivar had significant effects on pod length and pod diameter of snap bean. However, N treatments and locations had no effect on pod length and diameter (Table 3). Melkassa 3 produced the longest pods of all cultivars (Table 4). Among the commercial cultivars, Volta produced longer pods than Andante, Contender Blue and Lomami. In contrast, Andante produced the shortest pods of all cultivars followed by Contender Blue (Table 4). Melkassa 1 produced the largest pod diameter followed by Melkassa 3 (Table 4).Volta produced largest pod diameters among the commercial cultivars (Table 4). Among commercial cultivars, pods of cultivar Volta were similar in diameter to pods from Contender Blue, Lomami and Paulista (Table 4). On the other hand, Andante produced the smallest pod diameters of all cultivars (Table 4).

Cultivar significantly affected the texture of snap bean pods (Table 3). The interactions of N treatment by cultivar, and N treatment by location significantly affected pod texture (Table 3). Commercial cultivars generally had better pod texture than Melkassa cultivars (Table4). Commercial cultivars had smooth and uniform pod texture in contrast to pods from Melkassa cultivars which were rough and lacked uniformity. The cultivar differences in pod texture were enhanced by N as seen in the interaction of N treatment by cultivar (Table 5). The best textures seen in Contender Blue, Lomami, Paulista and Volta were all obtained under 100 kg N ha^{-1} application apart from Andante and Boston which were already at their best regardless of N treatment (Table 5). Nitrogen application also improved the texture of Melkassa 1 (Table 5). The results from the N treatment by location interaction showed that N application at Ziway resulted in better pod texture than the control at DebreZeit (Table 5). Generally, N application improved the texture of snap bean pods at all location (Table 5).

Nitrogen treatment and cultivar had significant effect on the appearance of snap bean pods, while the effect of location was not significant

Table 6. *P*-values from mixed model ANOVA F-test for protein, phosphorus (P), zinc Zn), calcium (Ca) and potassium (K) concentration of snap bean pods affected by nitrogen treatment, cultivar and location in 2011 and 2012 under rain fed conditions.

Source	Protein (%)	P (%)	Zn (ppm)	Ca (%)	K (%)
Nitrogen treatment (N)	0.3093	0.0232*	0.3792	0.4652	0.1106
Cultivar (V)	0.050	0.0131*	0.0132*	0.0178*	0.069
Location (L)	0.9413	0.8254	0.001**	0.0753	0.1482
L*V	0.8561	0.6891	0.1245	0.9281	0.0051**
L*N	0.8768	0.6424	0.2873	0.1451	0.0197*
V*N	0.641	0.162	0.5638	0.7692	0.8836
L*V*N	0.6985	0.6057	0.5623	0.3658	0.693
Year*L*V	0.0469*	-	-	0.0136*	-

*,**,***, denote significant at the 0.05,0.01,0.001 probability levels respectively.

(Table 3). The interaction of N treatment by cultivar also significantly affected snap bean pod appearance (Table 3). Excellent pod appearance was obtained from 100 kg N ha^{-1} (Table 4). Rhizobium inoculation also improved the appearance of snap bean pods as compared to the control (Table 4). Commercial cultivars produced the best pod appearance (Table 4). Pod appearance of Melkassa cultivars were in an acceptable range but not at the level of commercial cultivars (Table 4).

Nitrogen by cultivar interaction significantly affected pod appearance. Pods from commercial cultivars was at their best appearance when they were treated by 100 kg N ha^{-1} (Table 5). Applied N fertilizer resulted in better appearance than rhizobium inoculation for all cultivars except Melkassa 1 (Table 5). Pod appearance of Melkassa cultivars was better under rhizobium inoculation than undercontrol treatment (Table 5). There was no difference between rhizobium inoculation and the zero N control for pod appearance of commercial cultivars (Table 5).

Nitrogen treatment, cultivar and locations significantly affected titratableacidity of snap bean pods (Table 3). N application and rhizobium inoculation in particular increased titratableacidity of snap bean pods (Table 4). For the cultivar response, Lomami hadgreaterpod titratableacidity, though it was not significantly different than Andante, Boston, Contender Blue, Melkassa 3 and Volta (Table 4). Growing snap bean at Hawassa and DebreZeit resulted in higher percentage of titratable acidity in the pods than that grown at Ziway (Table 4).

Cultivar significantly affected the TSS of snap bean pods. Nitrogen treatment and location had no effect on TSS of pods (Table 3). The location by cultivar interaction had also a significant effect on the TSS of snap bean pods. Within cultivars, there was only a slight range of TSS. Cultivars Melkassa 3, Paulista and Volta had greater TSS than Andante and Boston (Table 4). TSS was also affected by the interaction of cultivar and location (Table 5).

Nutrient concentrations

All main factors and their interactions had no significant effect on protein concentrations (Table 6). However, year by cultivar by location interactions significantly affected protein concentration as shown on covariate parameter estimate (Table 6). Nitrogen treatment significantly affected only phosphorus concentrations, and cultivar significantly affected phosphorus, zinc and calcium concentrations (Table 6). Location had significant effect only on zinc concentration. For the interaction effects, both location by cultivar and location by N treatment interactions significantly affected potassium concentration. All other interactions had no significant effect on nutrient concentration of snap bean pods, except calcium concentration and protein, which were affected by year by location by cultivar interaction (Table 6).

Analysis from combined data showed that N treatment, cultivar and location had no significant effect on the protein concentrations of snap bean pods (Table 6). However, year by cultivar by location interaction was significant. This indicates that year had significant influence on the cultivar by location interaction. From separate analyses for each year, 2011 (P = 0.018) and 2012 (P = 0.0001), significant interactions for cultivar by location interactions were seen. Paulista at DebreZeit and Volta at Hawassa produced the highest protein in 2011 and 2012, respectively (Table 6). Melkassa 3 at DebreZeit in 2011 and at Ziway in 2012 produced the lowest protein (Table 8). Protein levels in other cultivars were inconsistent from location to location and from year to year. Generally, most cultivars produced high protein concentration at Ziway in 2011 and at Hawassa in 2012 (Table 8).

The effects of N treatment and cultivar were significant on the phosphorus concentration of snap bean pods (Table 6). Location had no effect on phosphorus concentrations in the pods. Applied N improved

Table 7. Protein, phosphorus, zinc, calcium and potassium concentrations of snap bean pods affected by nitrogen treatment, cultivar and location (combined 2011 and 2012).

Parameter	Protein (%)	Phosphorus (%)	Zinc (ppm)	Calcium (%)	Potassium (%)
Nitrogen treatment					
0 kg N ha^{-1}	17.9	0.399^{b}	28.96	0.68	3.2
Rhizobium etli (HB 429)	18.1	0.406^{ab}	29.42	0.67	3.1
100 kg N ha^{-1}	18.4	0.413^{a}	29.93	0.69	3.2
Cultivar					
Andante	18.6	0.413^{ab}	31.21^{a}	0.76^{a}	3.2
Boston	18.1	0.401^{bc}	30.70^{ab}	0.70^{ab}	3.2
Contender Blue	18.3	0.406^{bc}	30.88^{a}	0.65^{bc}	3.3
Lomami	18.9	0.423^{a}	29.69^{abc}	0.69^{ab}	3.3
Melkassa 1	17.7	0.397^{bc}	28.36^{bc}	0.64^{bc}	3.0
Melkassa 3	16.9	0.400^{bc}	28.13^{c}	0.59^{c}	3.1
Paulista	18.0	0.411^{abc}	29.06^{abc}	0.72^{ab}	3.3
Volta	18.2	0.394^{c}	27.45^{c}	0.68^{ab}	3.2
Location					
DebreZeit	18.3	0.404	27.87^{b}	0.66	2.9
Hawassa	18.3	0.415	36.22^{a}	0.61	3.2
Ziway	17.7	0.399	24.20^{c}	0.77	3.4

Means followed by the different letters in a treatment grouping column differ significantly based on LSD, $P < 0.05$. Absence of letter in a grouping column denotes non significance. % determined on the basis of g 100 g^{-1} of pod dry weight.

phosphorus concentration, but no different in phosphorus concentration from rhizobium inoculation and zero N application (Table 7). Lomami produced the highest phosphorus concentration, significantly more than Boston, Contender Blue, Melkassa 1, Melkassa 3 and Volta (Table 7).

Snap bean cultivars and locations significantly affected zinc concentration inthe pods (Table 6). The N treatment did not significantly change zinc concentration in pods. Numerically, the highest pod zinc concentration was recorded from Andante. Pod zinc concentration among Andante, Boston, Contender Blue and Paulista was similar (Table 7). Snap bean produced the highest zinc concentration when grown at Hawassa followed by DebreZeit and Ziway (Table 7).

The combined data analysis of the two year experiment showed that cultivar had a significant effect on calcium concentration in snap bean pods. Calcium concentration was not affected by N treatment and location (Table 6). Year by cultivar by location interaction was also significant (Table 6). The separate analysis for 2012 indicated that the cultivar by location interaction significantly (P = 0.0008) affected calcium concentrations of snap bean pods. In 2011, the cultivar by location (P = 0.375) interaction was not significant. Combined analysis across two years showed that Andante produced higher calcium concentration than Contender Blue and Melkassa cultivars (Table 7). The cultivar by location interaction in 2012 showed that Andante produced the highest calcium when grown at Ziway (Table 8). Melkassa 3 pods had the lowest calcium concentration at Ziway (Table 6). Cultivars had similar pod calcium concentrations within DebreZeit, except Melkassa 1 at Hawassa (Table 8).

Pod potassium concentration was not affected by N treatment, cultivar or location. But the cultivar by location interaction significantly affected potassium concentration of snap bean pods (Table 6). Numerically, pods from Lomami at Ziway had the highest potassium concentration (Table 9). Overall, Lomami was the most consistent cultivar forpod potassium concentration across all locations (Table 9). Melkassa cultivars had pods with lower potassium at Hawassa than other cultivars group in the same location (Table 9).

The interaction of N treatment by location significantly affected potassium concentration in the pods. Applied N at Ziway resulted in higher pod potassium concentration than rhizobium inoculation and Zero N at DebreZeit (Table 9). Generally, cultivars produced lower potassium concentration at DebreZeit than at Hawassa and Ziway (Table 9).

DISCUSSION

The results demonstrated that applied N and rhizobium

Table 8. Protein (%) and calcium (%) concentrations of snap bean pods affected by cultivar by location interaction in 2011 and 2012.

Cultivar	2011			2012			2012		
	Protein (%)			Protein (%)			Calcium (%)		
	Location			Location			Location		
	DebreZeit	Hawassa	Ziway	DebreZeit	Hawassa	Ziway	DebreZeit	Hawassa	Ziway
Andante	17.54^{a-g}	16.19^{g-j}	18.16^{a-e}	19.93^{a-f}	20.49^{abc}	19.26^{b-g}	0.757^{b-e}	0.632^{f-k}	1.016^{a}
Boston	17.31^{a-g}	16.32^{f-i}	17.13^{b-h}	18.83^{d-j}	20.84^{a}	17.91^{h-l}	0.763^{b-e}	0.616^{g-k}	0.793^{bc}
Contender Blue	17.69^{a-g}	15.18^{ij}	18.90^{abc}	19.81^{a-g}	20.80^{a}	17.41^{j-m}	0.667^{d-i}	0.550^{jl}	0.769^{bcd}
Lomami	18.34^{a-d}	17.05^{d-h}	18.42^{a-d}	20.12^{ab}	21.07^{a}	18.48^{f-i}	0.658^{d-j}	0.551^{ijl}	0.819^{b}
Melkassa 1	16.32^{f-i}	14.88^{ij}	17.19^{b-h}	19.69^{a-g}	20.87^{a}	17.13^{lm}	0.743^{b-f}	0.659^{d-g}	0.697^{e-f}
Melkassa 3	14.38^{j}	15.45^{hij}	18.05^{a-f}	18.97^{c-h}	19.74^{b-g}	15.03^{n}	0.691^{c-h}	0.550^{jl}	0.530^{kl}
Paulista	18.91^{ab}	16.37^{e-i}	17.42^{a-g}	18.87^{d-j}	20.12^{a-e}	16.47^{m}	0.713^{b-g}	0.615^{g-k}	0.804^{bc}
Volta	17.21^{c-h}	15.91^{g-j}	18.17^{a-e}	18.67^{e-k}	21.10^{a}	18.32^{g-k}	0.664^{d-j}	0.562^{ijl}	0.793^{bc}

Means followed by the different letters in the same interaction group (cultivar x location) differ significantly based on LSD, $P < 0.05$. Letters a-g indicate all alphabetical letters included in the range from a to g. % determined on the basis of g 100 g^{-1} of pod dry weight.

Table 9. Potassium (%) of snap bean pods as affected by cultivar by location interaction; and Nitrogen treatment by location interaction in 2011 and 2012.

Parameter	Combined 2011 and 2012		
	Potassium (%)		
	Location		
	DebreZeit	Hawassa	Ziway
Cultivar			
Andante	2.86^{f-j}	3.40^{a-d}	3.20^{d-h}
Boston	2.78^{g-j}	3.26^{a-g}	3.42^{a-e}
Contender Blue	3.02^{b-g}	3.38^{a-f}	3.50^{abc}
Lomami	3.08^{a-f}	3.25^{a-g}	3.58^{a}
Melkassa 1	2.63^{j}	2.95^{e-j}	3.36^{a-f}
Melkassa 3	2.90^{d-h}	3.02^{c-i}	3.32^{b-f}
Paulista	3.02^{b-g}	3.33^{a-f}	3.38^{a-f}
Volta	2.87^{f-j}	3.32^{a-f}	3.25^{b-g}
Nitrogen treatment			
0 kg N ha^{-1}	2.83^{c}	3.29^{abc}	3.39^{ab}
Rhizobium etli (HB 429)	2.87^{bc}	3.24^{abc}	3.28^{abc}
100 kg N ha^{-1}	2.98^{abc}	3.18^{abc}	3.47^{a}

Means followed by different letters in the same interaction group (cultivar x location; nitrogen treatment x location) differ significantly based on LSD, $P < 0.05$. Letters a-g indicate all alphabetical letters included in the range from a to g. % determined on the basis of g 100 g^{-1} of pod dry weight.

inoculation were effective in improving the marketable yield of snap bean pods by 43 and 18%, respectively (Table 3). The result agreed with Mahmoud et al. (2010); El-Awadi et al. (2011) and Salinas-Ramírez et al. (2011) all of whom reported that applied N improved yield and yield components of dry bean. Results also confirmed Bildirici and Yilmaz (2005) who reported significant yield improvement in dry bean by rhizobium inoculation. The current result, however, was in contrast to Otieno et al. (2009) who found no yield response to rhizobium inoculation on dry bean. Most of these reports were focused on grain yield of dry bean. The current finding demonstrated that the benefit of rhizobium inoculation can be realized at earlier crop growth stage at immature pod stage. Our investigation showed the possibility of producing export quality snap bean under reduced inputs that minimizes the reliance of vegetable production on heavy N fertilizer especially for resource limited farmers.

The significant differences among cultivars for marketable yield may be due to size of the plant that attributed to increased photosynthetic area (leaf area index) and relatively more pod sites. Melkassa 1, the best cultivar for marketable yield was characterized by tall plants and a larger leaf area index (data not presented) that determined its high yield capacity. In addition, Melkassa 1 was a well-adapted cultivar to a reduced input production system, especially dry land agriculture as it was developed under Ethiopian conditions. The yield potential of commercial cultivars may be limited by environmental variables; potentially moisture shortage because this experiment was conducted under natural rain fed conditions. The marketable yield of snap bean cultivars was similar at DebreZeit and Hawassa, but it was lower at Ziway. Ziway is characterized by a high soil pH, semi-arid environment with erratic and unpredictable rain fall (Tables 1 and 2). This may limit the productivity and quality of snap bean. The high marketable yield at DebreZeit and Hawassa may be due to suitability of the agro-ecology at these locations for enabling better utilization of soil fertility (Tables 1 and 2).

The length and diameter of snap bean pods were not affected by N treatment and location under rain fed conditions (Table 3). Pod size is therefore highly controlled by genetic factors (additive gene effect) and less affected by environmental factors (Arunga et al., 2010). From our study, cultivars could be grouped into three categories based on pod diameter. Andante is an extra fine cultivar with very small pod diameter ranging from 5.0 mm to 6.2 mm and Melkassa cultivars (Melkassa 1 and Melkassa 3) were at the other extreme, being bobby cultivars with pod diameters ranging from 8.0 mm to 8.7 mm (Tables 3). The remaining cultivars were fine cultivars with pod diameter of 7.0 mm to 7.6 mm (Wahome et al., 2013).

Texture and appearance of snap bean pods are the two most critical parameters that influence their marketability. Snap bean pods are graded into marketable and unmarketable pods depending on texture and appearance. Texture and appearance of pods depend on smoothness, uniformity and overall look of the pods in the absence of disease, insect damage and other defects. The appearance of pods was improved by the application of N fertilizer (Tables 4 and 5).The texture and appearance of all the commercial cultivars were improved by N fertilizer application. Melkassa cultivars responded well for rhizobium inoculations especially pod appearance (Table 5). The result is in agreement with previous studies stating N application increased the quality of green bean (Mahmoud et al., 2010; Kamanu et al., 2012).Our findings demonstrated that rhizobium inoculant can provide sufficient N to improve the appearance of snap bean pods at least for some cultivars. Improved N nutrition turned green pods into well-formed and straight, bright in color and acceptable quality.

Commercial cultivars produced the highest quality pods due to their fine texture, and well-rounded straight pods. Melkassa cultivars lacked some quality characteristics including smoothness and uniformity of pods, particularly for Melkassa 1 which had a high marketable yield. Therefore, breeding work is needed to improve the pod appearance for Melkassa 1 to bring this cultivar to the premium level. Generally, all cultivars had fine texture and acceptable appearance at all locations. This indicates that it is possible to produce snap bean with acceptable texture and appearance for export markets even without N application and inoculation at any of the three sites.

Nitrogen application and rhizobium inoculation increased the titratable acidity of snap bean pods. Studies on tomato (Wright and Harris, 1985; Erdal et al., 2007) and grape (Baiano et al., 2011) fruits indicated that increasing N fertilizer increased titratable acidity of the fruit. As titratable acidity is the prime taste quality determinant in fruit juice (Zagory and Kader, 1989), the authors assumed applied N and rhizobium inoculation would improve the taste quality of pods by increasing titratable acidity. The titratable acidity of the cultivars was in the range for snap bean determined by Proulx et al. (2010). The higher titratable acidity at DebreZeit and Hawassa may be due to favorable growing conditions for snap bean production as reflected in other parameters such as marketable yield. Nitrogen nutrition, cultivar and growing location may additionally affect the taste quality of snap bean in terms of titratable acidity.

Some cultivars had consistent pod TSS from location to location but others did not. Melkassa 3, Paulista and Volta were numerically the most stable cultivars found in the top group of pod TSS at all locations. This may be due to environmental variables of a specific location determining the TSS of a particular cultivar (Hoogenboom, 2000). In soybean, TSS of pods is directly associated with the photo-assimilate manufactured by the plant (Liu et al., 2011), and affects the relative concentrations of soluble sugars in the pod. Generally, factors that affect soluble sugars also influence TSS (Caliman et al., 2010). TSS is another taste quality determinant (Champa et al., 2008), and cultivars with higher TSS have higher taste quality particularly when in combination with high titratable acidity (Al-Jamali and Hani, 2009).

In 2012, a cultivar by location interaction resulted in generally higher pod protein at Hawassa but the reverse was observed in 2011 with numerically better protein at Ziway. The low pod protein concentrations for most of the cultivars at Ziway may be due to unfavorable weather conditions especially erratic and excess rain fall during the early growth periods of these snap bean in 2012 (Table 1). Nitrogen from agricultural fields may be lost by moderate to high rain fall (Scharf and Lory, 2006), an effect which would be magnified by the sandy nature of the soil at Ziway (Table 2). Pod protein concentrations of cultivars were inconsistent from year to year and location to location.

Applied N increased the phosphorus concentration in snap bean pods. This result was supported by Apthorp et al. (1987) who reported that N fertilizer application increased phosphorus uptake by plants. Rhizobium inoculation and applied N were similar in increasing pod phosphorus concentration. However, only the latter was significantly different from the control. The concentrations of phosphorus in green pods of snap bean showed variation among cultivars. Phosphorus shoot tissue concentration and its uptake by the plant were affected by varietal differences in common bean (Mourice and Tryphone, 2012).

Applied N and rhizobium showed a trend of enhanced zinc pod concentrations of snap bean pods numerically (Table 7). The variations among cultivars for zinc are supported by the report from Beebe et al. (2000) and Gregorio (2002) who reported the presence of sufficient variability in zinc concentration among bean cultivars. The authors found that the tested cultivars had pod zinc concentrations close to mean values reported by Beebe et al. (2000). Zinc concentration of pods was highest at Hawassa followed by DebreZeit. The soil analysis from each locations showed that high zinc content in the soil was found at Hawassa followed by Ziway, and DebreZeit had the least (Table 2). This may suggest that a high zinc concentration in pods at Hawassa was due to high zinc content in the soil. However, the pod zinc concentration at DebreZeit was higher than at Ziway. This may indicate that environmental variables other than zinc concentration in the soil may also contribute to zinc concentration in snap bean pods. Studies indicated that higher pH reduced the availability and plant uptake of zinc in the soil solution (Jeffery and Uren, 1983), which may explain the lower zinc concentration in pods at Ziway where high soil pH occurred (Table 2). Both zinc content and pH of the soil affected zinc concentration in snap bean pods. Locations with higher zinc content or slightly acidic soils resulted in pods with higher zinc concentration compared to locations with low zinc content or alkaline soils.

The result from 2012 showed that Andante was the top cultivar in producing calcium in its pod when grown at Ziway. This result is in agreement with reports of cultivars having small pod diameters have higher calcium concentration (Grusak and Pomper, 1999). Generally, snap bean cultivars had numerically, greater pod calcium when grown at Ziway and DebreZeit. Low calcium concentration in pods at Hawassa may be due to lower calcium concentration in the soil (Table 2). Calcium concentration in snap bean pods is influenced by cultivar and environmental conditions such as heat units (temperature), rainfall and water availability for crop uptake, and soil calcium concentration (Quintana et al., 1999b).

Applied N at Ziway improved the potassium concentration of snap bean pods when compared to rhizobium inoculation and no N at DebreZeit. Hirzel and Walter (2008) also reported that NPK fertilizer application increased soil and tissue concentrations of potassium in sweet corn.

Conclusion

Nitrogen application and rhizobium inoculation increased marketable yield and titratable acidity of snap bean compared to no N application. Nitrogen treatments interacted with cultivars to affect pod texture and pod appearance. Nitrogen application was almost always better than rhizobium inoculation for improving pod appearance, and consistently resulted in improved pod appearance compared to a zero N control. However, rhizobium inoculation also improved the appearance, particularly of the two Melkassa cultivars. Melkassa 1 was well-adapted to rain-fed conditions in that it gave numerically the highest overall marketable yield across all locations. Melkassa 1 had the largest pod diameter of any tested cultivar, and it is frequently ranked below commercial cultivars for pod texture and pod appearance. Locations interacted with cultivars and affected the pod traits TSS and concentrations of protein, calcium, and potassium. Snap bean pods produced at DebreZeit and Hawassa were similar in marketable yield and several other traits. Pod zinc concentration was particularly highest at Hawassa. Ziway, with a more arid climate and soil pH above 8.0, was the least favorable location for production of export-quality snap bean as compared to other locations tested. Generally, production of marketable quality snap bean pods can be achieved by using rhizobial inoculation as N source particularly for resource limited farmers. Hawassa, which is characterized by higher soil zinc content, slightly acidic soil and hot to warm sub-moist humid climate, is most suitable to produce snap bean pods with high zinc concentration. Further breeding works are required to improve the pod quality of cultivar Melkassa 1 to gain maximum benefits from its high yielding potential.

Conflict of Interest

The author(s) have not declared any conflict of interests.

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