Response of Snap Bean Genotypes to Rhizobium Inoculation and Nitrogen Fertilizer under Different Agroecological Zones of Ethiopia

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In Ethiopia, snap beans are one of the economically important vegetable crops grown for both export and local markets. It is mostly grown in the Rift Valley region, especially for export. In 2008, Ethiopia exported close to 8000 tonnes of snap bean mainly to Europe and Middle East bringing the total revenue of 10.5 million dollars to the country (FAOStat, 2011).

Snap bean production in Ethiopia is being increasing from time to time both for export and local market. In addition to large commercial vegetable farms which produce snap bean for export, the number of small scale vegetable producers are also increased for local market. Snap bean producers for export market are restricted their production during the dry season under irrigation (October to April). The potential of snap bean production during the main rainy season is not studied under Ethiopian condition. In Ethiopia only limited number of varieties are introduced and used for production. The varieties under current production are not studied for their yield responses and quality characteristics under rain fed condition of Ethiopia. This will help to have idea for potential production of snap bean under different seasons depending on the capacity of the farmers and suitability of the varieties.

Snap bean producers used high rate of nitrogen regardless of the varieties, environmental impact, production cost and nutritional value of the snap beans. Excessive nitrogen fertilizer application reduces vaitamin C and Ca concentrations on snap beans. High rate of nitrogen is also not affordable by small scale farmer. On the other hand snap beans belongs to the legume family that fix nitrogen from the atmosphere. The possibility of using rhizobia inoculation as source of nitrogen is not studied under different agroecologies of Ethiopia for different varieties.

The protein and mineral content of snap bean is affected by the cultural practices applied to the crop. The report by Abubaker (2008) indicated that planting density significantly affect yield, quality, protein and mineral content of snap bean pods. However, the effect of different agroecologies and planting season on these parameters are not well studied.

In order to solve the above problems the following objectives were set:-

1. To determine pod yield potential and quality of commercial and locally

developed varieties of snap bean under different agro-ecologies of Ethiopia

2. To see nodulation pattern of commercial and locally developed varieties as a response of Rhizobium inoculation (HB-429)
3. To investigate the pod yield and quality response of snap bean varieties to applied nitrogen and Rhizobium inoculation under different agroecologies of Ethiopia
4. To determine the impact of agroecologies on pod yield and quality of snap bean varieties
5. To investigate the potential of snap bean production under low cost production system suited for small scale farmers that results improved nutrition and cash income in Ethiopia
6. To investigate the impact of drought stress at different growth stages of snap bean in greenhouse conditions

To attain these objectives eight varieties of snap bean were tested at three different agro-ecologies (Debrezeit, Zeway and Hawassa) under natural and irrigated conditions. The varieties also were tested for their response to rhizobium inoculation at the different agro-ecologies. Further the response of these varieties to moisture stress at different growth stages were also investigated under greenhouse conditions at Hawassa University.

Methodology

The actual experiment was started in June 2011 even though the preparation went back March 2011 under rain fed condition. The field experiment was conducted at three sites Hawassa, Zeway and Debrezeit. At Hawassa site planting was done June 10, 2011, however, replanting was done on July 19, 2011due to damage by bean stem maggot. Planting was done on June 26 and 27, 2011 at Zeway. Debrezeit site was planted on July 6, 2011. The trail under irrigated condition was planted in February 2012. The beans were sown 8, 9, and 12 of February at Zeway, Debrezeit and Hawassa respectively. Irrigation water was applied for the experiment conducted under irrigation. The second year experiment under rain fed condition were planted on July 1, 2 and 4, 2012 at Hawassa, Zeway and Debrezeit respectively. All management practices were applied from planting to harvesting according to season and other requirements. Vegetative, flowering and nodulation data were collected at flowering period and yield and other postharvest parameters including quality were collected during harvesting time. Dried pod and straw samples were sent to University of Saskatchewan, Canada, for nutrient analysis from the first experiment.

Most of the results are incorporated in this report. The collected data were analyzed using SAS software. The results from the two seasons experiment are presented as follow.

The greenhouse experiment was also conducted using the same varieties with the field experiment. These varieties were tested for drought at three growth stages namely at vegetative, flowering and pod setting including continuous supply of water during the whole growth period as a control. At the three stages of growth drought was introduced for five days maintaining at 50% field capacity. The experiment was laid out as completely randomized factorial design replicated three times. Each replicated treatment consisted of four pots with two plants in each pot. Vegetative, yield and quality data were collected and analyzed using SAS software.

Result

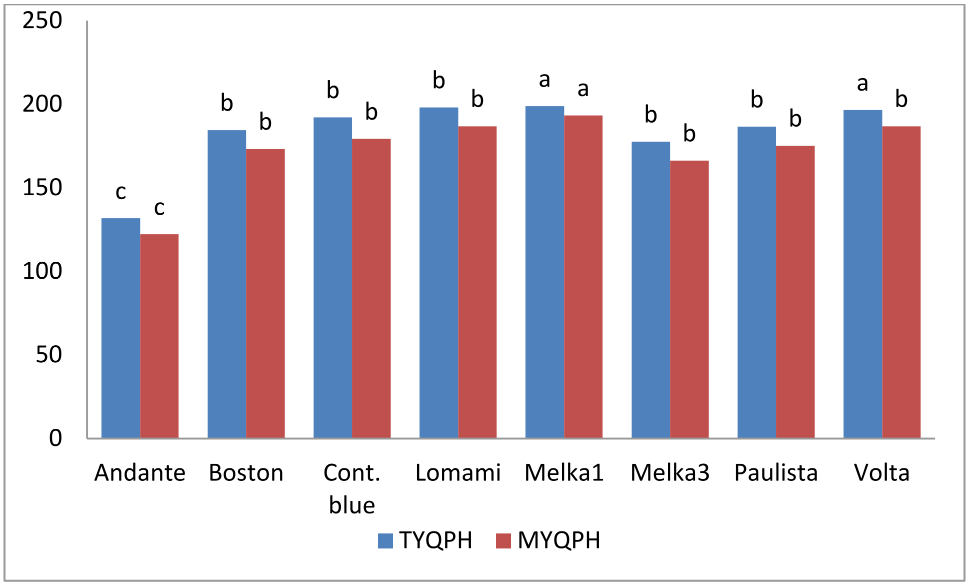
Experiment Under Rain Fed Conditions in two seasons (June to September 2011 and 2012)

Yield and Yield components

The perusal of data presented on Figure 1 indicated that there was significant difference on yield and yield components of snap bean as influenced by agroecologies (locations), nitrogen sources and varietal differences. Among the eight varieties considered Volta and Melkassa 1 produced the highest total yield and there was no statistical difference between them. However, as a fine variety Andante yielded significantly less than the other varieties. The other five varieties are in between these extremes and they are statistically at par between each other. With regard to marketable yield, Andante remains the lowesst and Melkassa 1 ranked the highest and others are in between with no differences among them. Melkassa 1 and Volta produced the highest pod dry matter per plant but were not statiscally different from Boston, Contender blue, Lomami and Melkassa 3. Whereas, Andante produced the lowest pod dry matter per plant followed by Paulista. In other case, Andante, Boaton, Lomami and Volta produced the largest pod number per plant which were not statistically different from each other. Melkassa 3 was the lowest in pod number per plant followed by Melkassa 1.

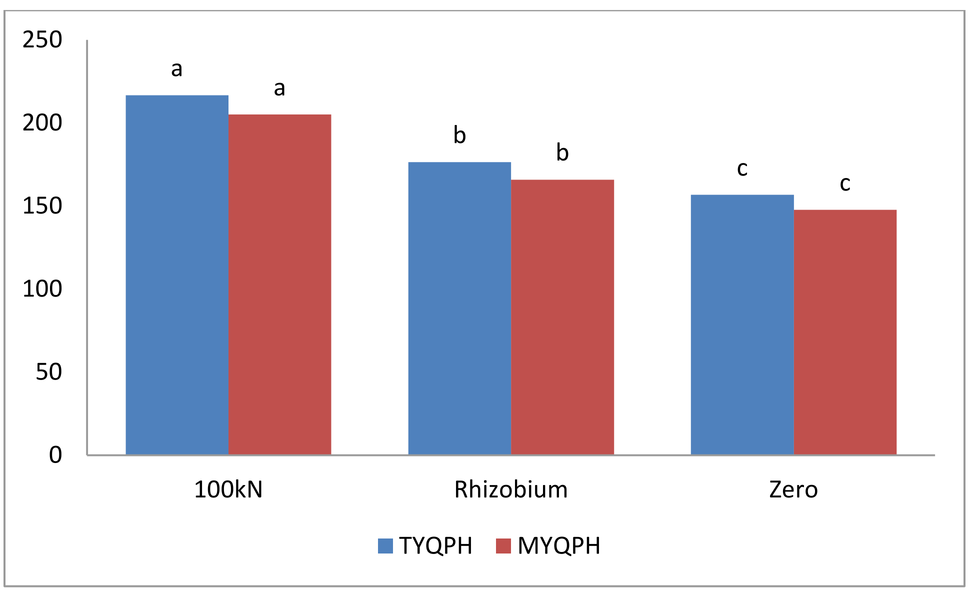
The results of the experiment presented on Figure 2 also revealed that applied nitrogen increased the total yield, marketable yield, dry matter per plant and pod number per plant followed by inoculation by Rhizobium strain (HB 429). The control treatment was the least for those parameters.

Locations exerted significant influence on total yield, marketable yield, dry matter per plant and pod number per plant of snap bean varieties (Figure 3). The highest yield and yield components were observed at Hawassa site followed by Debrezeit and Zeway was the least of all.



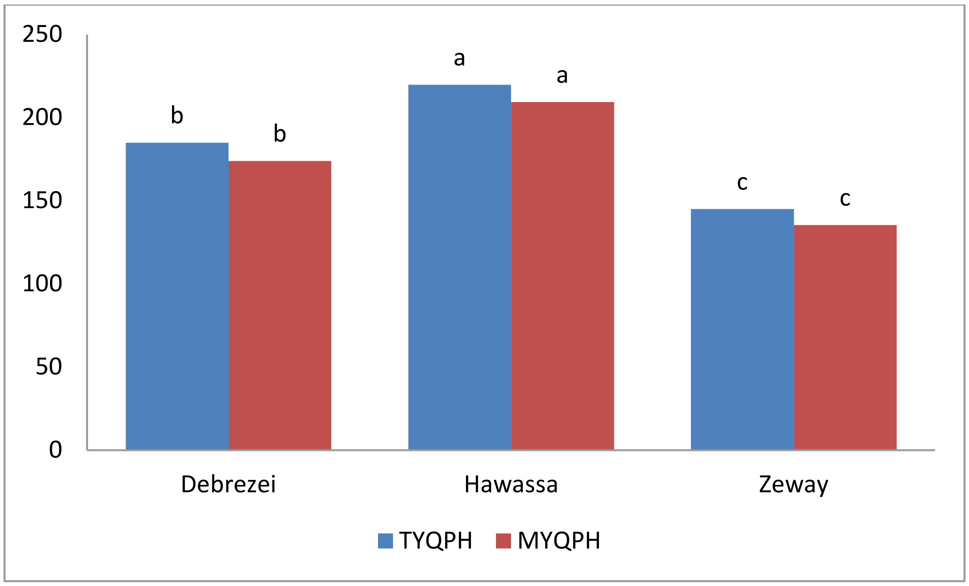
TYQPH=total yield quintal per hectare, MYQPH=Marketable yield quintal per hectare

Figure 1. Effect of varietal differences on total and marketable yields of snap bean under rain fed conditions in quintals per hectare ((α=0.05)



TYQPH=total yield quintal per hectare, MYQPH=Marketable yield quintal per hectare

Figure 2. Influence of applied nitrogen (100kgN/ha) and Rhizobium inoculation (HB 429) on total and marketable yields of snap bean under rain fed conditions in quintals per hectare ((α=0.05)



TYQPH=total yield quintal per hectare, MYQPH=Marketable yield quintal per hectare
Figure 3. Agroecology (Location) on total and marketable yields of snap bean under rain fed conditions in quintals per hectare ((α=0.05)

Flowering, Maturity, and Vegetative Growth

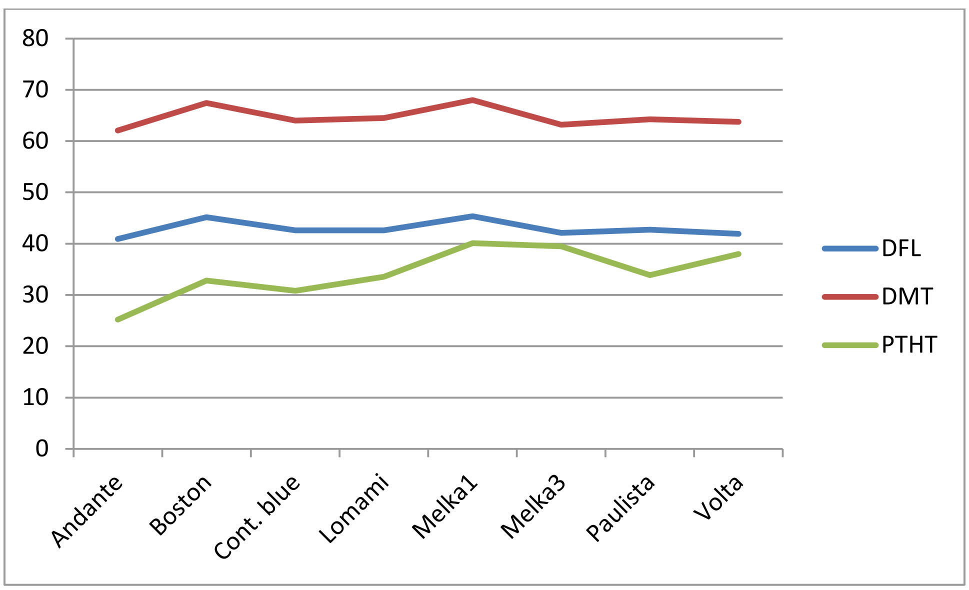
Data presented on Figure 4 showed that there was significant difference among varieties, nitrogen sources and locations on days to flowering, days to maturity and vegetative growth of snap bean.

Melkassa 1 and Boston were the latest to flower but they differ in maturity. Andante was the earliest to flower and mature followed by Melkassa 3 and Volta (Figure 4). The other varieties were found in between these two extremes for days to flowering and maturity. Generally it can sort out that Andante, Melkassa 3 and Volta were in the earliest group, however, Melkassa 1 and Boston could be regarded as late group and Lomami, Contender blue and Paulista as intermediate group.

Further Melkassa 1 was found to be the tallest variety which was statistically at par with Melkassa 3 and these were followed by Volta. Whereas, Andante was the shortest followed by Contender blue. Further Boston, Lomami, and Paulista were in intermediate plant height (Figure 4. Melkassa 1 extended its superiority with leaf area index followed by Melkassa 3 and Andante produced the least leaf area index too.

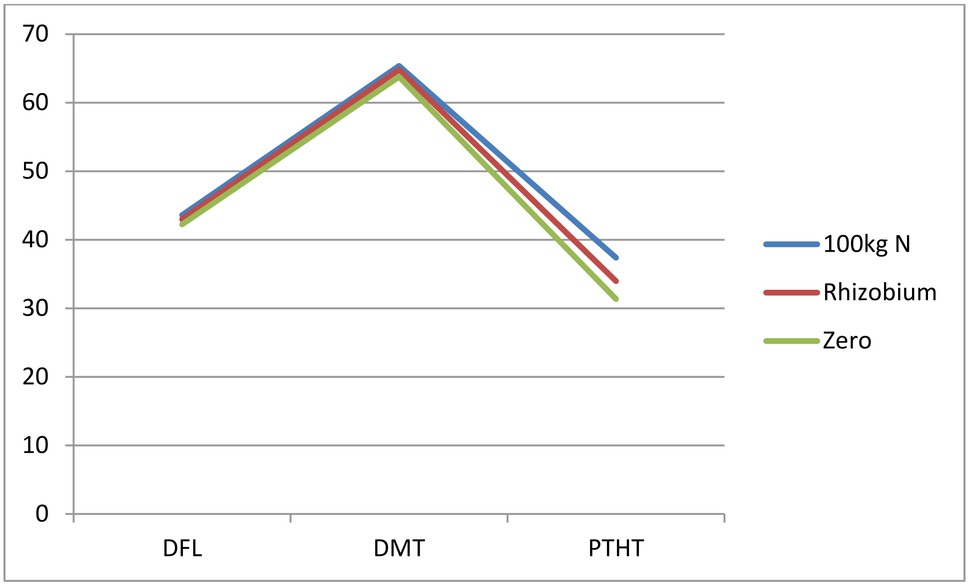
Applied nitrogen and Rhizobium inoculation delayed flowering and maturity of snap bean varieties and the delay in flowering due to applied nitrogen was significantly more than Rhizoboum inoculation (Table 2). The same trend was observed on plant height and leaf area providing the tallest plant height and largest leaf area due to applied nitrogen and Rhizobium inoculation.

Snap bean varieties flower early at Zeway site followed by Debrezeit and latest at Hawassa (Table 2),however, they mature latest at Debrezeit remaining the earliest at Zeway. Maximum leaf area index and tallest plant height was observed at Hawassa ever if plant height is not statistically significant from Debrezeit and Zeway remain the least for these parmeters too.



DTF= Days to flower, DTM=Days to maturity, PtHt= Plant height,

Figure 4. Effect of varietal differences on days to flower, days to maturity and plant height (cm) of snap bean under rain fed conditions in quintals per hectare ((α=0.05)



DTF=Days to flower, DTM=Days to maturity, PtHt=Plant height

Figure 5. Influence of applied nitrogen (100kgN/ha) and Rhizobium inoculation (HB 429) on days to flower, days to maturity and plant height (cm) of snap beans under rain fed conditions (α=0.05)

Pod Quality Parameters

The analysis of variance showed that quality differences were observed among varieties, nitrogen sources and across locations. The largest pod diameter was recorded on Melkassa 1 followed by and Melkassa 3 where as the smallest pod diameter was shown on Andante. Hence, Andante was found to be very fine and followed by other commercial varieties. However, the two Melkassa varieties have larger pod size. Volta was found to be the variety with the longest pod length and short pod length was observed on Andante. Commercial varieties were also superior in texture and appearance of pods over the Melkassa varieties in general.

Pod diameter and curvature were not affected by nitrogen application and rhizobium inoculation. However, applied nitrogen resulted the longest pod than Rhizobium inoculation and the control. Moreover, applied nitrogen and Rhizobium inoculation improved the texture and appearance of snap beans. Further, applied nitrogen improved the pod appearance of snap bean varieties at significant level even better than Rhizobium inoculation. On the other hand it reduced TSS and increased acidity of fresh snap bean pods. Curvature was not affected by varieties and nitrogen but by location, indicated that pods from Hawassa were more curved.

Pod diameter and pod length were highest at Hawassa and pod diameter at Zeway was larger at Zeway and Debrezeit was the least. However, pod length at Debrezeit follows Hawassa the least at Zeway. Pod diameter was also not affected by applied nitrogen and Rhizobium inoculation.

Nutritional Quality

The collected data showed that varieties Andante and Contender blue were found to be highest zinc concentration in the pod which were also statistically at par with Boston and Lomami. In other cases Contender blue, Andante, Boston and Lomami had the highest iron and they were also statistically not different from each other. On the other hand Andante and Paulista had the highest calcium concentration in their edible pod, whereas, Contender blue and Lomami were superior for potassium concentrations.

Snap bean pods produced in Hawassa provided higher Zn concentration followed by Debrezeit, and Zeway was to be the most suitable for higher concentration of iron and calcium in snap bean pods. However, nutrient concentration in snap bean pods were found to be unaffected by applied nitrogen and Rhizoboum inoculation.

Nodulation

The data analyzed from two season rain fed experiment showed that Melkassa 1 was superior to other varieties for all nodulation parameters including nodule number, nodule diameter and nodule dry weight under rain fed conditions. Volta and Paulista were statistically at par with Melkassa 1 with nodule diameter. In contrary Andante was the least performing on all of the nodulation parameters.

It was also clearly indicated that applied nitrogen inhibit nodulation of snap bean. However, inoculation of snap bean with Rhizobium inoculums (HB 429) provided successful nodulation as evidenced by all nodulation parameters.

Large sized and high nodule dry weight were observed at Debrezeit followed by Hawassa. However, nodule number was insignificant between locations

Experiment Under Irrigated Conditions (February to April 2012)

Yield and Yield components

The data presented on Table 6 showed that there was significant difference among varieties for yield and yield components of snap bean. However, most of the varieties considered lie on the same level of productivity with total and marketable yields. As a fine variety Andante provided lower yield followed by Melkassa 3 under irrigated conditions across the locations. All other varieties considered produced similar level of green pods. Further Boston, Lomami, Melkassa 3, Paulista and Volta provided higher level of pod dry matter per plant which were statistically at par with each other. Lomami and the two Melkassa varieties produced lower number of pod number per plant. As shown on Table 6 Volta was superior for all yield and yield components presented.

The highest yield and yield components of snap bean varieties were obtained at Hawassa site, however, there was no significant difference between Debrezeit and Zeway sites on these parameters except dry weight per pod.

Table 1. Effect of varietal differences and locations on yield and yield components of snap bean under
Irrigated conditions in 2012

Variety	**Treatment**	**TYQPH**	**MYQPH**	**PDMPP (gm)**	**NPPP**
	Andante	212.9d	192.47c	12.67b	37.28a
	Boston	271.09abc	252.89ab	15.01ab	36.04a
	Contenderblue	281.62abc	262.83ab	13.62b	33.39ab
	Lomami	264.24bc	246.01ab	14.51ab	29.47bc
	Melkassa 1	275.04abc	251.07b	12.74b	31.72bc
	Melkassa 3	258.29c	240.56ab	14.5ab	28.2c
	Paulista	291.1ab	274.16ab	14.31ab	33.49ab
	Volta	301.47a	274.41a	16.54a	37.02a
	CV	20.35	20.64	28.08	21.68
Locations (Agroecologies)	Debrezeit	245.76b	228.48b	14.81a	30.58b
	Hawassa	335.14a	307.41a	15.54a	40.93a
	Zeway	227.52b	212.02b	12.56b	28.47b
	CV	20.35	20.64	28.08	21.68

TYQPH=total yield quintal per hectare, MYQPH=Marketable yield quintal per hectare, PDMPP= Pod dry matter per plant, NPPP=Number of pods per plant

Flowering, Maturity and Vegetative Growth

Perusal of data on Table 7 showed that Boston and Melkassa 1 were the latest flowering and maturity varieties. However, Andante was the earliest of all varieties. Melkassa 1 was the tallest plant followed by Melkassa 3 and Andante was the shortest of all. The other varieties were intermediate between these two extremes. Melkassa 1 and Melkassa 3 provided largest leaf area index and Melkassa 1 also produced highest number of leaves per plant. However, there was no significant difference among varieties for harvest index.

Flowering and maturity were late at Hawassa followed by Debrezeit and plants at Zeway were early to flower and mature. Plant height was larger at Debrezeit and was small at Zeway. Other vegetative growth was abundant at Hawassa. Large harvest index was obtained from Zeway and Debrezeit.

Table 2. Effect of varietal differences and locations on days to flowering, days to maturity and vegetative growth of snap bean under irrigated conditions in 2012

Variety	**Treatment**	DTF	DTM	PtHt	LA	NLPP	LAI	HI
	Andante	42.78e	63.96d	29.21f	647.1e	39.4c	1.294e	0.456
	Boston	50.48a	71.67a	37.77de	1073bcd	44.41b	2.147bcd	0.379
	Contenderblue	46.93bc	67.63bc	36.42e	975.9d	40.19c	1.952d	0.409
	Lomami	46.74bc	67.93bc	37.85de	1133b	45.03b	2.266b	0.43
	Melkassa 1	50.37a	71.48a	42.99a	1348a	53.65a	2.696a	0.374
	Melkassa 3	47.48b	68.44b	41.06b	1421a	47.63b	2.843a	0.388
	Paulista	46.3cd	67.7bc	38.77cd	1112bc	46.86b	2.224bc	0.412
	Volta	45.74d	67c	39.92bc	989.9cd	39.44c	1.98cd	0.419
	CV	3.47	2.42	7.5	20.45	16.82	20.45	12.85
Location (Agroecologies)	Debrezeit	47.17b	69.82b	42.5a	847.2c	37c	1.695c	0.425a
	Hawassa	48.83a	70.75a	38.57b	1468a	56.84a	2.935a	0.369b
	Zeway	45.31c	64.11c	32.92c	947.7b	39.88b	1.895b	0.43a
		3.47	2.42	7.5	20.45	16.82	20.45	12.85

DTF= Days to flower, DTM=Days to maturity, PtHt= Plant height, LA=leaf area NLPP=Number of leaves per plant, LAI= leaf area index, HI=Harvest index

Pod Quality Parameters

It is clear from Table 8 that Melkassa 3 produced the longest pod followed by Boston and Volta. However, Andante produced pods with the shortest length of all. Further the two Melkassa varieties produced pods with the largest diameter, and in contrary Andante was the smallest. Commercial varieties produced pods with better texture and appearance than the two Melkassa varieties. There was no significant difference among varieties for curvature and TSS. However, Andante and Volta pods contain more titrable acidity although these were not significantly different from other varieties except Melkassa 3 which was less acidic than the other varieties.

Longer pods were produced at Debrezeit followed by Zeway and larger pod diameter was obtained from Zeway and Debrezeit. Pod texture and appearance were better at Zeway and acidity was higher at Debrezeit and Hawassa. However, curvature and TSS were not affected by locations.

Table 3. Effect of varietal differences and locations on pod quality of snap bean under irrigated conditions in 2012

Variety	Treatment	Pod-Lth (cm)	Pod-dia (mm)	Curv	Texture	Pod-App	TSS	Acidity
	Andante	10.77e	5.904e	1.0	1.04d	1.185ef	6.185	0.61a
	Boston	12.42b	7.18d	0.99	1d	1.11f	5.982	0.569ab
	Contender blue	11.41d	7.289cd	1.0	1.11cd	1.33de	6	0.583ab
	Lomami	12.1bc	7.221cd	0.99	1.296b	1.41d	6.13	0.587ab
	Melkassa 1	12c	8.508a	0.99	2.259a	2.593a	6.204	0.571ab
	Melkassa 3	13.17a	8.005b	1	2.148a	2.37b	6.019	0.519b
	Paulista	12.16bc	7.463cd	1.0	1.26bc	1.593c	6.093	0.567ab
	Volta	12.45b	7.549c	0.99	1d	1.259def	6.226	0.609a
	CV	5.36	7.97	4.69	23.38	20.26	7.95	20.26

Location (Agroecologies)	Debrezeit	12.37a	7.372ab	1.0	1.319b	1.569b	6.16	0.604a
	Hawassa	11.88b	7.282b	1.0	1.319b	1.458c	6.02	0.61a
	Zeway	11.93b	7.516a	0.99	1.528a	1.792a	6.13	0.517b
	CV	5.36	7.97	4.69	23.38	20.26	7.95	20.26

Pod-lth=Pod length, Pod dia=Pod diameter, Curv=Curvature, Pod-App=Pod appearance, TSS=Total soluble solids

Effect of Nitrogen Sources under irrigated conditions at Debrezeit 2012

Yield and Yield components at Debrezeit under irrigation

Data presented on Table 9 showed that applied nitrogen improved yield and yield components of snap bean varieties followed by Rhizobium (HB 429) inoculation. Further applied nitrogen and Rhizobium inoculation improved vegetative growth. However, Rhizobium inoculation did not improved significantly plant height and number of leaves per plant as compared to the control treatment. There was also no significant difference among the nitrogen sources for harvest index.

Table 4. Effect of Nitrogen sources on yield and other associated parameters of snap bean under irrigated conditions in 2012 at Debrezeit

Treatments	TYQPH	MYQPH	PDMPP	NPPP	PtHt	LA	LNPP	LAI	HI
100kg/haN	281.38a	264.1a	17.27a	34.13a	45.8a	1034a	39.72a	2.067a	0.435
Rhizobium (HB 429)	246.48b	228.42b	15.11b	30.84b	40.85b	810.5b	36.89b	1.621b	0.428
Zero	209.4c	192.92c	12.04c	26.77c	40.87b	697.6c	34.39b	1.395c	0.413
CV	17.91	17.85	22.94	16.85	5.65	22.77	12.27	22.77	11.45

TYQPH=total yield quintal per hectare, MYQPH=Marketable yield quintal per hectare, PDMPP= Pod dry matter per plant, NPPP=Number of pods per plant, PtHt=Plant height, LA=leaf area, LNPP=leaf number per plant, Leaf area index, Harvest index, 100k/haN= applied nitrogen 100kilo gram per hectare

Days to flower, Days to maturity and Nodulation at Debrezeit under irrigation

It is clear from Table 10 that applied nitrogen and Rhizobium inoculation delayed flowering and maturity of snap bean varieties.

It was also revealed that applied nitrogen inhibited nodulation including nodule number, nodule diameter and dry weight of nodule. However, inoculation with Rhizobium strain (HB 429) significantly improved nodulation and associated parameters.

Table 10. Effect of Nitrogen sources on nodulation, flowering ate and maturity of snap bean under
irrigated conditions in 2012 at Debrezeit

Treatments	NNPP	NDia (mm)	NDMPP (gm)	DTF	DTM
100kg/haN	14.72c	1.686c	0.02c	47.96a	70.58a
Rhizobium (HB 429)	48.29a	2.826a	0.105a	47.5a	70.33a
Zero	30.33b	2.464b	0.064b	46.04b	68.54b
CV	62.59	23.02	70.85	2.05	1.60

NNPP=Nodule number per plant, NDia=Nodule diameter, NDMPP=Nodule dry matter per plant, DTF=Days to flower, DTM=Days to maturity
100k/haN= applied nitrogen 100kilo gram per hectare

Data presented on Table 11 indicated that Melkassa 1 was found to be superior on all nodulation parameters followed by Boston. However, Andante showed poor performance on nodulation. Abundant nodulation in Melkassa 1 was across locations and seasons under irrigated and rain fed conditions. Following Melkassa 1, Boston nodulated higher number of nodules and larger nodule size. The other varieties were found intermediate between these two top varieties and Andante on the other end for nodulation.

Table 5. Effect of varietal differences on nodulation of snap bean under irrigated conditions in 2012 at
Debrezeit

Varieties	NNPP	NDIa (mm)	NDMPP
Adante	17.63c	1.709b	0.029b
Boston	39.93ab	2.353a	0.066b
Contender blue	26bc	2.271a	0.051b
Lomami	32.48abc	2.164ab	0.056b
Melkassa 1	51.89a	2.682a	0.127a
Melkassa 3	27.37bc	2.551a	0.064b
Paulista	26.41bc	2.236ab	0.047b
Volta	27.22bc	2.636a	0.063b
CV	62.59	23.02	70.85

NNPP=Nodule number per plant, NDIa= Nodule Diameter, Nodule dry Matter per plant

Pod Quality at Debrezeit under irrigation

Data presented on Table 11 showed that applied nitrogen and Rhizobium inoculation improved most of the quality parameters. However, pod diameter and pod curvature were not affected by nitrogen application.

Table 6. Effect of Nitrogen sources on pod quality of snap bean under irrigated conditions in 2012

Treatments	Pod lth (cm)	Pod Dia (mm)	Curv	Texture	Pod App	TSS	Acidity
100kg/haN	12.81a	7.41	0.997	1.208b	1.292b	5.979b	0.664a
Rhizobium (HB 429)	12.11b	7.303	1.007	1.208b	1.375b	6b	0.62a
Zero	12.19b	7.402	1.007	1.542a	2.042a	6.504a	0.528b
CV	5.35	10.73	2.22	21.31	15.26	7.53	21.93

Pod-lth=Pod length, Pod dia=Pod diameter, Curv=Curvature, Pod-App=Pod appearance, TSS=Total soluble solids, 100k/haN= applied nitrogen 100kilo gram per hectare

Greenhouse Experiment

The analyzed data indicated that moisture deficit at vegetative stage significantly delayed flowering of snap bean varieties. However, maturity was most delayed by moisture deficit at pod development stage followed by vegetative and flowering stage moisture deficit. Further, moisture deficit at flowering stage affect plant height than other stages.

Moisture deficit at flowering and pod development stages most critically affect the total and marketable yields per plants and still these were also affected by moisture deficit at vegetative stage. On the other hand lowest harvest index was recorded when moisture deficit was induced at flowering stage followed by at pod development stage.

Number of pods and pod dry matter per plant were critically affected by moisture deficit at flowering period followed by at pod development and vegetative stages of moisture deficit. However, the later were statistically at par to each other.

The collected data showed that green pod quality was highly affected by moisture deficit especially at flowering and pod development stages. Green pods were curved the most and resulted rough texture due to moisture deficit at flowering followed by at pod development stages. However, pod curvature and texture were not affected by moisture deficit at vegetative stages. Pod length of snap bean varieties was also affected most critically by moisture deficit at pod development stage followed by moisture deficit at flowering and least affected at vegetative stages. Further, green pod appearance was worsen by moisture deficit at flowering and pod development stages. Our result also showed that moisture deficit at any stages of growth did not affect TSS and acidity of snap bean green pods.

Summary and Conclusion

- Agroecology exerted significant influence on the performance and productivity of snap bean varieties and high productivity was observed at Hawassa site followed by Debrezeit. The former extended high productivity under irrigated conditions too.
- The locally developed varieties especially Melkassa 1 resulted outstanding yield performance and productivity across the three agroecologies. However, commercial varieties were superior in most of pod quality parameters. Further, commercial varieties showed high productivity under irrigated conditions.
- Varieties Andante, Boston, Contender blue and Lomami were found to be good sources of Zn and Fe and Andante and Lomami were also true for Calcium.
- Snap bean produced at Zeway was found to be higher in Fe, Ca, K and acidity under rain fed conditions. However, Hawassa site was highest for Zn.
- Applied nitrogen increased the performance and productivity of snap beans even better than Rhizobium inoculation and Rhizobium inoculation improved these parameters as compared to the control.
- Rhizobium inoculation improved nodulation parameters and applied nitrogen suppressed nodulation of snap beans.
- Rhizobium inoculation was effective at all sites during rain fed experiment, however, this was true only at Debrezeit under irrigated experiment. In general, nodulation at Debrezeit was abundant and also with large sized nodules.
- Melkassa 1 was found superior in nodulation under rain fed experiment across locations and also under irrigation at Debrezeit.
- Nodulation was absent at Zeway and Hawassa during irrigated experiment.
- In general, quality snap bean can be produced under low input production system using rain water and Rhizobium inoculation as a nitrogen source.

- The greenhouse experiment showed that productivity and quality of snap bean varieties were most critically affected by moisture deficit at flowering and pod development stages and the former was the worst. However, moisture deficit at vegetative stage did not show significant effect on most pod quality parameters but it reduced productivity.
- Moisture deficit at flowering stage resulted most curved green pods, whereas, it resulted more deformed and irregular shaped pods at pod development stages.

Remaining activities

1. Repeat the greenhouse experiment at University of Saskatchewan
2. Formulate at least one hypothesis based on the current result and conduct an experiment to test the hypothesis at university of Saskatchewan.
3. Complete the required courses and comprehensive exam and thesis write up.