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1. New Sesame (*Sesamum indicum* L.) Varieties (*BaHa*-zeyit and *BaHa*-necho) Recommended for Cultivation in eastern Ethiopia

Amare Kebede

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Abstract: *BaHa*-zeyit and *BaHa*-necho are the common names for the sesame (Sesamum indicum L.) improved varieties. The varieties were improved through selection from 14 sesame genotypes which were evaluated across locations over seasons in eastern Hararghe. *BaHa*-zeyit and *BaHa*-necho had the original accession name W-119/WSM and W-109/WSS, respectively. The varieties were evaluated at three locations over two cropping seasons for seed yield, oil content, seed color and reaction to diseases in complete randomized block design with three replications, inter-row and intra-row spacing of 0.4 and 0.10 meter, respectively. *BaHa*-zeyit (1.3 t ha^{-1}) and *BaHa*-necho (1.2 t ha^{-1}) were found to be superior in seed yields by 26.21 and 16.50%, respectively, over the commercial check variety, Abasena. *BaHa*-necho has white seed color which is preferred for export while *BaHa*-zeyit has gray seed color. *BaHa*-zeyit had high protein (27.1%) and oil content (56%) in which the oil content was by far greater than other sesame varieties registered in Ethiopia. Both varieties were moderately tolerant to bacterial leaf blight. In addition to seed yield, oil content and seed color, the varieties had other desirable traits. The varieties were approved to be cultivated as commercial varieties in eastern Ethiopia in 2016 considering their contribution to the improvement of sesame seed and oil yields in the region. Therefore, the varieties could be cultivated by smallholder farmers and large scale commercial farms in eastern Ethiopia and in other areas with similar agroecology.

Keywords: Eastern Ethiopia; Oil content, Seed yield and Seed color

1. Introduction

Ethiopia has suitable climate for annual and perennial oil plants and the country is among the five countries identified as center of diversity for sesame (Hernán and Petr, 2006). Ethiopia's oilseed sector provides income to millions of growers, plays a vitally important economic role in generating foreign exchange earnings and income for the country. Among the oilseed crops, sesame is Ethiopia's main exported product after

coffee. Increasingly, sesame seed is taking a significant role in the oilseeds sector and has become the most relevant commodity. For instance, from 2000 to 2016, the total quantity exported annually increased more than tenfold (Musba, 2017). Crop improvement for desirable traits such as seed and oils yields has paramount importance for sustainable sesame (*Sesamum indicum* L.) production in Ethiopian. The presence of great genetic diversity among Ethiopian sesame landraces and cultivars (Daniel and Parzies, 2011) is an advantage for breeders to develop varieties through selection. However, the genotypes need to be evaluated over locations and seasons to be recommended for cultivation since the seed yield and other traits are affected by the environment (Abate *et al.*, 2015).

Haramaya University has initiated sesame variety development for eastern Ethiopia and subsequently executed research activities to develop two sesame varieties. During the multilocation seed yield test, 14 elite sesame genotypes were evaluated in 2013 and 2014 main cropping seasons at three locations (Babile, Iffa and Likale) in East Hararghe. The six environments data were sufficient to progress to verification of the candidate varieties (*BaHa-zeyit and BaHa-necho*) were evaluated for seed yield, oil content and other desirable traits in comparison with *Abasena* and *Adi* varieties at different stages of evaluation. The two release varieties were found to be superior over the commercial varieties for seed yield, oil content, seed color and reaction to diseases and approved for cultivation by the National Variety Release Committee with the local name '*BaHa-zeyit' and 'BaHa-necho'*. The common names '*BaHa-zeyit' and 'BaHa-necho'* were coined from "*Ba'* stands for Babile, and '*Ha'* stands for Haramaya, indicating the main research station used for the varieties development and institution executed the variety improvement research activities, respectively (Kebede and Bushra, 2012). *Baha* in Oromifa (Ethiopian language) expresses situation in the east, conveying where the technologies were developed, i.e. eastern parts of Ethiopia. On the other hand, '*zeyit'* and *'necho'* in Amharic (Ethiopian language) indicating oil content and seed color, respectively.

Agronomic and Morphological Characteristics

The released varieties *BaHa-zeyit* (Figure 1) and *BaHa-necho* (Figure 2) were gray and white seeded, respectively. The seed size of *BaHa-zeyit* was comparatively larger than *BaHa-necho*. Except in seed color and size, the two released varieties seem morphologically similar. The seed yield of *BaHa-zeyit* and *BaHa-necho* in the three test locations over a period of two years were consistent. *BaHa-zeyit* has had seed yield advantages of 26.21 and 34.02% over the check varieties *Abasena* and *Adi*, respectively, while *BaHa-necho* showed superiority over *Abasena* and *Adi*, respectively, by about 16.5 and 23.71% for seed yield (Table 1).

Figure 1. *BaHa-zeyit*

Figure 2. *BaHa-necho*

Table 1. Seed yield of *BaHa-zeyit, BaHa-necho* and two released varieties *(Abasena* and *Adi*) used as checks in three locations over two years.

	Babile			Likale			Iffa		
Variety	2013	2014	Mean	2013	2014	Mean	2013	2014	Mean
BaHa-zeyit	1.39	1.17	1.28	2.07	1.02	1.54	1.02	1.17	1.09
Abasena (Check)[a]	0.88	1.02	0.95	1.48	0.93	1.20	0.81	1.06	0.93
BaHa-necho	1.24	1.19	1.21	1.78	0.72	1.25	1.06	1.22	1.14
Adi (Check)[b]	0.95	1.02	0.98	1.37	0.56	0.96	0.86	1.09	0.97

'a' and 'b' were released varieties and served as check for BaHa-zeyit and BaHa-necho, respectively.

Both *BaHa-zeyit* and *BaHa-necho* had near to 64 and 125 days to flowering and maturity, respectively. The plant height of the two released varieties was short as compared to the commercial varieties used as checks. *BaHa-zeyit* and *BaHa-necho* had 2.6 and2.57g, while *Abasena* and *Adi* 2.6 and 2.62g thousand seed weight, respectively (Table 2). Moreover, the newly released varieties seem stable since the seed yields variations of these varieties over locations and years were low. *BaHa-zeyit* and *BaHa-necho* were recommended for altitudes range from 560 to 1650 meters above sea level, which include the vicinities of Babile, Bisidimo, Kile, Error Guda, Gursum and other similar agro-ecologies.

Table 2. Agronomic and morphology description of *BaHa-zeyit*, *BaHa-necho* and two released varieties *(Abasena* and *Adi*) used as checks

Variety	Seed yield (t ha^{-1})	TSW (g)	DF	DM	PH (cm)	NPPP
BaHa-zeyit	1.31	2.60	64.22	124.61	113.68	73.69
Abasena[a]	1.03	2.60	66.11	124.44	114.20	78.80
BaHa-necho	1.20	2.57	64.44	123.17	110.39	65.21
Adi[b]	0.97	2.62	63.39	124.94	113.73	65.72

TSW=Thousand seed weight, DF=days to flowering, DM=days to maturity, PH=plant height, NPPP= number of pods per plant. 'a' and 'b' were released varieties and served as check for BaHa-zeyit and BaHa-necho, respectively.

Other Attributes

The newly released variety *BaHa-zeyit* had seed oil content of 56% which was greater than the commercial varieties used as checks (Table 3). *BaHa-necho* had white seed color. The high oil content and white color of the seeds are both desirable traits preferred by edible oil processors and exporters. In addition, the seed protein content of *BaHa-zeyit* was greater than the two checks and *BaHa-necho* produced seeds with protein content comparable to *Abasena* and *Adi.* In eastern Hararghe, Ethiopia, diseases and pest pressure on sesame are less compared to other sesame growing regions. The newly released varieties and commercial varieties used as checks showed moderately tolerant to bacterial leaf blight with disease reaction score ranged from 3.3 (*BaHa-zeyit*) and 4.7 (*Adi*).

Table 3. Seed oil and protein contents as well as reaction to bacterial leaf blight of *BaHa-zeyit, BaHa-necho* and two released varieties *(Abasena* and *Adi*) used as checks.

Variety	Seed oil content (%)	Seed protein content (%)	Reaction to bacterial leaf blight (score)
BaHa-zeyit	56	27.1	3.3
Abasena[a]	52	23.63	4
BaHa-necho	52	23.8	4
Adi[b]	50.8	24.24	4.7

'a' and 'b' were released varieties and served as check for BaHa-zeyit and BaHa-necho, respectively.

2. Conclusion

The results of this study demonstrated that the newly released varieties *BaHa-zeyit* and *BaHa-necho* are superior to the commercial *Abasena* and *Adi* sesame varieties in terms seed yield and stability for seed yield over environments. *BaHa-zeyit* is superior over commercial varieties both for seed oil and protein content. The *BaHa-necho* has white seed color to be preferred by exporters. The newly released varieties have also other desirable traits preferred by growers. The high seed production potential of the varieties

implies that the growing of these varieties in eastern Ethiopia would contribute for the increase of production and subsequently the income of smallholder farmers and foreign currency earnings of the country. Therefore, it is possible to make conclusion that the newly released varieties *BaHa-zeyit* and *BaHa-necho* could be cultivated profitably and sustainably in the low to mid altitudes (560 to 1650 meters above sea level) of eastern Ethiopia and other areas with similar agroecolgy to enhance the income of smallholder farmers.

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2. Effects of In-situ Rain Water Harvesting Techniques on Soil Moisture Conservation and Grain Yield of Maize (*Zea mays* L.) in Fedis District, eastern Ethiopia

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Abstract: In the drier farming regions of the world, mainly with arid and semi-arid environments, crop production is heavily dependent on rainfed agriculture. The main constraints in these areas are short growing period, short term rainfall with high run-off and moisture deficit. In such area, in-situ rainwater **harvesting** techniques are vital. This study was conducted under rain-fed conditions for two years (2015 and 2016) to investigate the effects of in-situ rainwater harvesting techniques (Ridge Furrow (RF), Contour Ridge (CR), and Tied Ridge (TR)) on soil moisture conservation and grain yield of maize in Fedis district, which is one of the moisture stressed areas in eastern Hararghe, Ethiopia. The experiment was conducted by using spilt-plot design. Data collection on soil moisture content was conducted from three depths (0-20cm, 20-40cm and 40-60cm) at three periods (viz. early, mid and late vegetative growth stages) during growing season. The yield and yield component data of maize was collected. ANOVA at $p<0.05$ were done by using SAS software version 9.1. Accordingly, moisture content means of 174.05mm/m, 170.90mm/m, 168.05mm/m and 115.65mm/m were observed for RF, CR, TR and FBF(control), respectively. The results showed that water harvesting techniques brought statistically significant effect on soil moisture conservation compared to control. In general, CR, TR and RF treatments resulted in 147.77 %, 145.31 % and 150.50 % more soil moisture conservation than FBP, respectively. The study also revealed that in-situ rainwater harvesting structures brought statistically significant effect on the yield of maize compared to the control. TR resulted in (143.14%), FR (131.47%) and CR (121.16%) higher grain yield compared to FBP. Therefore, in drier environment like Fedis, in-situ rainwater harvesting techniques can be recommended for better moisture retention and subsequent crop production.

Keywords: Contour ridge; Tied ridge; Rain-Fed and Ridge furrow

1. Introduction

Agriculture is the major economic activity for Sub-Saharan Africa countries, and it is strongly considered as the backbone of these countries' economic development and their people's wellbeing in the future (Giller *et al.*, 2009). Rapid population growth occurs in developing countries with a significant proportion still depending on a predominantly rain fed-based economy. Unfortunately, in several regions, including Africa in general and Ethiopia in particular, rain fed agriculture has generally been associated to low yield levels, and high on-farm water losses. As result the majority of the people are not able to ensure their food security. Low crop productivity, food insecurity, hunger and malnutrition characterize poor rural smallholder agriculture based community.

From the 41% of semi-arid region of Sub-Saharan Africa farming land, only about 2% of the arable lands are irrigated, that is, rain fed agriculture is the dominant crop production system to meet the food demand (Zougmoré *et al.*, 2002). However, the unreliability in rainfall and recurrent droughts lead to subsequent production failures and puts great pressure on the food self-sufficiency of the region. The low soil water retention capacity or the high potential evapotranspiration rate is the major problem.

Among the environmental problems people in eastern lowlands of Ethiopia are vulnerable to soil moisture stress problem and there have been notable droughts in this part of the country throughout human history (Tadesse *et al.*, 2008; UNEP, 2006; Gebre-Michael and Kifle, 2009). Some studies have been done on the effectiveness of micro-basin tillage to improve soil moisture in different parts of the semiarid areas in highlands of Ethiopia (Gebreyesus, 2012; McHugh *et al.,* 2007; Heluf, 2003; Aklilu and Mekiso, 2015). Except, Aklilu and Mekiso (2015), all of the studies were at the highlands. However, the same problem (soil moisture stress) is happening in low lands of Eastern Hararghe. This indicates that there were less or no studies done to identify suitable in-situ rainwater harvesting techniques to solve crop production problem. Hence, this study was carried out in Fedis district, Eastern Hararghe, Ethiopia. The objective of this study was to determine the effect of in-situ rainwater harvesting structures on soil moisture conservations and grain yield of maize.

2. Materials and Methods

2.1. Description of the Study Area

The field experiment was conducted during the main rainy season (May to December) of 2015 in eastern Ethiopia, at Fedis research sub- station of Haramaya University. Fedis is one of the woredas in eastern Hararghe Zone found in the semi-arid belt of the eastern low lands in the Oromiya regional state. The station is located west of Boko town in the semi-arid area of Fedis woreda. Climatically, the district is classified into Woinadega (15%) and kola (85%) agro climatic zones. The area is characterized by bimodal rainy seasons, "Belg" and "Meher". The "Belg" season is between March and May, and the second main rainy season is "Meher" which extends from July to October (Fedis Woreda Office of Agriculture). The site is situated at $9^{0}07'$N Latitude and $42^{0}4'$E Longitude with an altitude of 1702 meters above sea level (GPS measurement). In the

study area, the mean annual maximum and minimum temperature was 27.8^{0}C and 8.8^{0}C, respectively, and the area had annual rainfall of 714.3 mm (Fedis Agricultural Research Centre).

2.2. Treatments and Experimental Design

The experiment was conducted by using spilt-plot design with three replicates. Treatments tested on the main-plot was maize variety (Melkasa 4), and the sub plots consisted of contour ridge (CR), tied ridge (TR), ridge furrow (RF) and Fat bed planting (FBP), which is control. Recommended rates of N and P fertilizers were used. Buffer zones were left between plots and around the experiment area to facilitate crop management operations. Each plot was consists of six (6) rows spaced 75 cm between rows with row length of five meter. The spacing between plants within the row was 30 cm. Ridges with 20-30 cm height; in CR, TR and RF treatments of 0.75 m spacing was constructed using a ridger implement. Cross earth ties in TR, 8-12 cm in height, was manually constructed with hoes at 1.5 m apart. Sowing was done in the furrow.

2.3. Data Collection and Analysis

The soil moisture content data was collected from three depths (0-20cm, 20-40cm and 40-60cm) at three periods (viz. early, mid and late vegetative growth stages) during growing season, and determined in the form of depth (mm) of water stored in the top 0.6 meter soil depth (assumed to be the depth of the root zone). The soil water stored (%) in each 0.2 m incremental depth down to 0.6 m was determined gravimetrically. It was then converted to water depth (mm) by multiplying by the specific bulk density values measured by the core sampler methods from the respective depths as described by Blake (1965). Grain yields and all other desirable data and samples were collected from the three central rows of each plot.

Data analysis was conducted with the help of SAS software version 9.1. Analysis of variance (ANOVA) was computed and mean differences were made by using least significant difference (LSD) at P=0.05. The results were presented by using tables, figures and text.

3. Results and Discussion

3.1. Effect of *In-situ* Rainwater Harvesting Techniques on Soil Moisture Conservations

Amount of mean annual rainfall (mm) measured during the experiment years (2015 and 2016) was 714.3mm. Rainfall was measured at the Fedis meteorology station, which is 2 Km far from the experiment site. Soil of the experimental site has sandy clay loam texture, moderate total nitrogen content (0.18 %), low in organic matter (1.61 %), low organic carbon (0.93 %), low available phosphorus (1.78 mg Kg^{-1}), and moderately alkaline pH (7.76). Soil moisture content (SMC) of the soil profile (60 cm) was measured at three periods, i.e. at early season, mid-season and late season. The effects of the treatments on SMC are shown in Table 1 and Figure 1 below.

In all measurement depths at three vegetative growth stages, the results obtained showed significant (P>0.05) difference in SMC between *in-situ* water harvesting treatments and FBP. Where, *in-situ* water harvesting treatments (RF, TR and CR) recorded SMC values higher than FBP in all depths. This result is in agreement with the findings of Ibrahim and Ismail (2008), Mohammed (2009), Li *et al.* (2000), Tian *et al.* (2003), and McHugh *et al.* (2007).

In this area, using of the conventional tillage method (FBP) may not help to conserve enough water for crop production, mainly due to the erratic rainfall that induces runoff. High intensity rain showers also enhance water losses through runoff. Crop growth conditions may further be hampered by a number of climatic factors such as, low and erratic rainfall, low humidity levels and high temperature during growing season (Botha *et al.*, 2003).

The water harvested is retained and is far from the evaporative effects but within reach of plant roots. This is because of the presence of heavy textured soil at 40-60cm depth (sandy clay) than top 0-20cm (sandy clay loam). Lateral flow through which water harvested in the channels could benefit crops can only take place theoretically in the presence of a flow impeding layer at depth. This means water harvested in the channels feeds the soil until it reaches the impervious layer and starts flowing laterally or rising, thereby providing a reservoir of water to the crop at depth which on clays or heavy textured soils, rises by capillarity during dry spells and ensure the crop benefits.

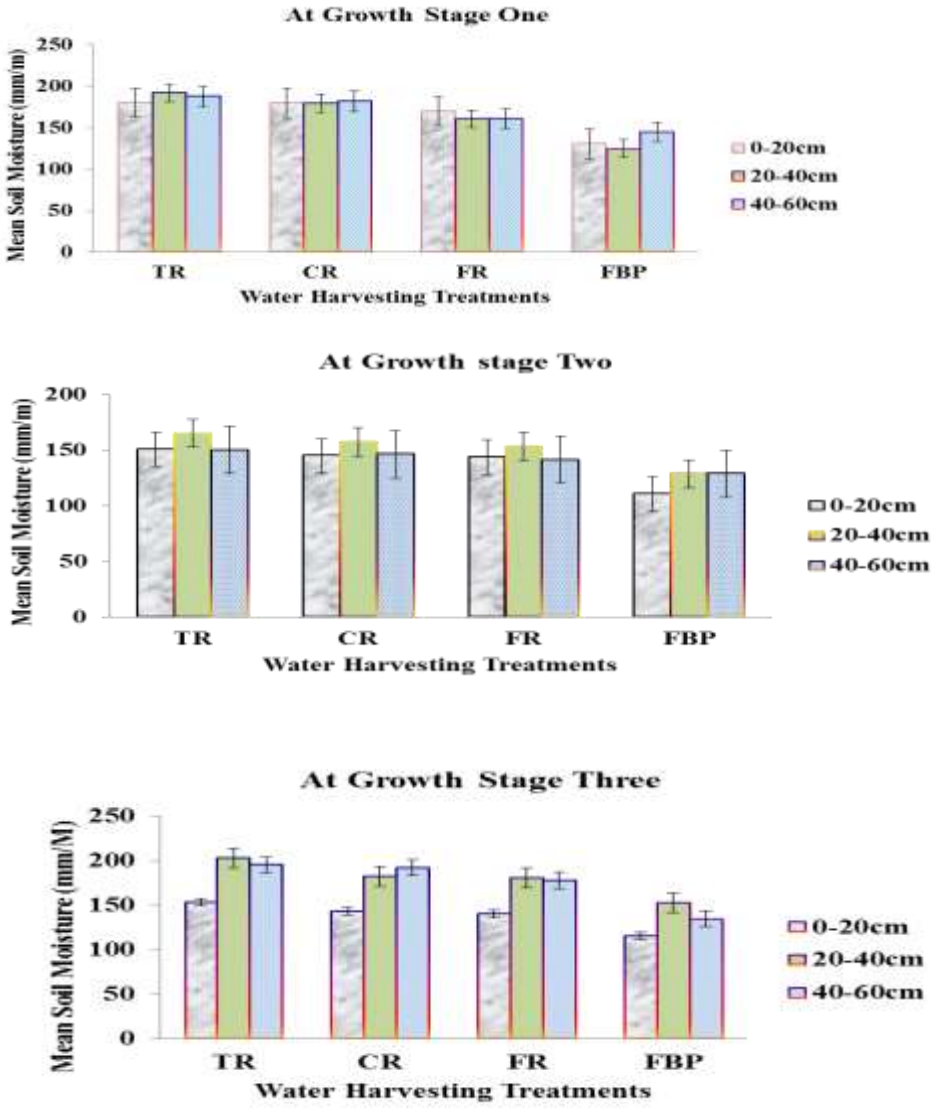

Figure 1. Effect of in-situ rainwatre harvesting treatments on soil moisture conservations (mm/m) at three growth stages from three depths between 2015 and 2016.

Table 1: Analysis of variance for effects of water harvesting treatments on soil moisture conservations (mm/m) at three growth stages from three depths of soil during 2015 and 2016.

Water Harvesting Treatments	Growth Stages								
	Stage One			Stage Two			Stage Three		
	0 – 20cm	20 – 40cm	40 – 60cm	0 – 20cm	20 – 40cm	40 – 60cm	0 – 20cm	20 – 40cm	40 – 60cm
TR	180.06[a]	192.30[a]	187.87[a]	151.09[a]	150.35[a]	165.12[a]	153.15[a]	202.51[a]	195.21[a]
CR	179.59[a]	179.69[b]	181.76[a]	145.15[a]	146.48[ab]	157.59[a]	142.68[b]	182.31[b]	191.77[a]
FR	169.84[a]	160.76[c]	160.58[b]	144.13[a]	141.55[ab]	153.41[a]	140.17[b]	180.16[b]	177.77[b]
FBP	130.41[b]	124.93[d]	145.08[c]	111.01[b]	129.18[b]	128.90[b]	115.22[c]	153.04[c]	134.38[c]
LSD (0.05)	17.56	10.63	12.03	15.28	21.07	12.59	4.26	11.10	8.88

LSD (0.05)= least significant difference at 5% level and means followed by the same letter are not significantly different at P =0.0.

Effect of *In-situ* Rainwater Harvesting Techniques on Grain Yield of Maize

The effect of in-situ rainwater harvesting techniques on grain yield of maize was significantly higher compared to the control at $p<0.05$. The effect of *in-situ* rainwater harvesting structures on the grain yield as presented in Table 2, at $p<0.05$, the grain yield has shown significant difference between treatments with rainwater harvesting structures and flatbed planting, which is control in Melkasa 4 variety. TR has resulted in (143.14%), CR (131.47%) and FR (121.16%) higher grain yield compared to FBP.

All *in-situ* rainwater structure treatments have performed much better than the controlled treatments. This might be due to the fact that the harvesting structures store rainwater in-situ, enhancing infiltration, which provide a reservoir of water to the crop at depth which heavy textured soils (sandy clay), rises by capillarity during dry spells and ensure the crop benefits. This result is in agreement with the finding by Gebreyesus (2012) that tied-ridge and fertilizer, and its interaction significantly influenced the yield and yield components of sorghum and resulted in up to 48% increment. Tied ridges was found to be very efficient in storing the rain water, which resulted in substantial grain yield increase in some of the major dryland crops such as sorghum, maize, wheat, and mung beans in Ethiopia (Georgis and Takele 2000). The average grain yield increase (under tied ridges) ranged from 50 to over 100 percent when compared with the traditional practice. This increase, however, will vary according to the soil type, slope, rainfall and the crop grown.

In the current result, the yield of maize was affected by all in-situ rainwater harvesting structures (Figure 2).The work of Heluf (2003) also supports this finding by the fact that the yield response to water conservation treatments was higher both under fertilized and unfertilized conditions than the control treatments.

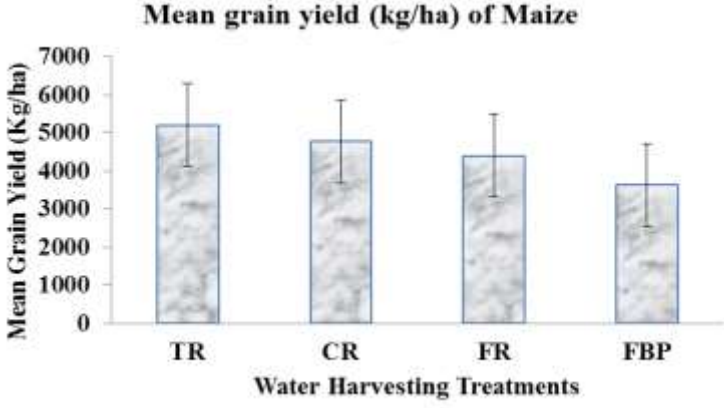

Figure 2. Effect of different in-situ rainwatre harvesting treatments on grain yield of maize during 2015 and 2016 crop seasons.

Table 2: Analysis of variance for effects different *in-situ* rainwater harvesting treatments on mean grain yield (kg/ha) of maize (Melkasa 4) during 2015 and 2016 crop seasons.

Water harvesting treatments	Grain Yield (kg/ha)		Over all mean
	Year I	Year II	
TR	4389	6017	5203[a]
CR	4244	5314	4779[a]
FR	4164	4644	4404[ab]
FBP	3362	3908	3635[b]
LSD (0.05)			1089

LSD (0.05) = least significant difference at 5% level and means followed by the same letter are not significantly different at P =0.05.

4. Conclusion and Recommendations

In conclusion, flat bed planting produced the lowest soil moisture and grain yields of maize in two varieties. Generally, furrow ridge, tied ridge and contour ridge planting produced higher grain yields of maize than flat bed planting. Therefore, in line with results of the research it could be concluded that *in-situ* water harvesting techniques improved soil moisture stored within the root zone as compared to the flat bed planting and the improved varieties of maize responded significantly to *in-situ* water harvesting techniques in which the magnitude of yield response to *in-situ* water harvesting techniques and the relative effectiveness of the different harvesting methods tend to vary with maize varieties. Finally, it could be recommended that *in-situ* water harvesting practices are indispensable agricultural operations for successful maize production in Fedis district and any other moisture stressed areas.

5. Acknowledgement

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3. Native Rhizobia N_2 Fixation in Chickpea (*Cicer arietinum* L.) Potential to Biofertilizer Production

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Abstract: In Ethiopia, chickpea is cultivated in the different areas; however, the yield of pulses in general and chickpea in particular is low mainly due to low soil fertility and limited access to external inputs. Rhizobia N_2 fixation could be considered as one of the options to increase yield of pulses, but the resident rhizobia nodulating pulses vary considerably in size, ranging from, 103 to.108 rhizobia g-1 of soil in Ethiopia. Moreover, the effectiveness of the native rhizobia nodulating Chickpea is not yet well characterized. Hence, this research was initiated to isolate and evaluate the effectiveness of Ethiopian chickpea rhizobia isolates under greenhouse and field condition. The treatments comprised of nine Rhizobium isolates and one uninoculated control, and the experiment was laid out in randomize complete block design with three replications. The result revealed that inoculation significantly increased the nodule number by 300% over the uninoculated treatment at Haramaya site. Inoculating HURCP-29 and most of the tested Rhizobium isolates significantly increased the total biomass and grain yield up to 53% and 99% over the control check, respectively. On top of this consortium, Rhizobium inoculation with Phosphorous fertilizer application resulted significant increase in nodulation and grain yield of chickpea genotypes at Haramaya site. In conclusion, the research demonstrated the effectiveness of native Rhizobium isolates to increase the total biomass and grain yield of chickpea.

Keywords: Effectiveness, Inoculation, Isolates, Nodulating and Pulses

1. Introduction

Chickpea is one of the food legume crops grown in the tropics, sub-tropics and temperate regions of the world. In Ethiopia, chickpea is cultivated mainly in the different areas ranging from mid land up to high land. The production area id extended from drier area with supplement of irrigation. In 2001, chickpea occupied about 23% of the land allocated to the highlands pulses and contributed 21.3% of the total grain production of the highlands pulses (EARO, 2002).

The yield of pulses in Ethiopia is extremely low mainly due to low soil fertility, smallholder farming and limited access to external inputs (EARO, 2002; Amare, 1987).

One of the most important factors of soil fertility is nitrogen (N) deficiency of most Ethiopian soils (Desta and Angaw, 1986). Studies carried out in the past revealed inoculation with rhizobia have improved the yield of legume pulses in Ethiopia (Asfaw and Angaw, 2006; Mitiku, 1990). Therefore, biological nitrogen fixation should be more exploited to increase nitrogen for pulses cultivation in Ethiopia.

In Ethiopian soils, numbers of resident rhizobia nodulating pulses and bean can vary considerably in size, ranging from, 10^3 to.10^8 rhizobia /g of soil (Anteneh, 2007). The size of the soil rhizobial community is dependent on many factors including field history, soil and environmental characteristics and the presence of host plants. Many soil properties including pH, texture, and temperature, as well as management practices such as inoculation, contribute to variation in BNF across the landscape (Drew and Ballard 2010; Toro 1996), with legume genotype and interaction with resident rhizobia being a critical consideration. Hence, we have to enumerate of rhizobia nodulating Chickpea is found in indigenous soil and again have to test soil chemical and physical properties that affected mainly survival of rhizobia, nodulation process and nitrogen fixation of endosymbionts. This study was initiated with the aim to investigate the effectiveness of the native rhizobia and factors affecting the symbiotic N_2 fixation potential and to select rhizobia nodulating Chickpea and characterize its symbiotic effectiveness under control and field conditions.

2. Materials and Methods

The bulk soil samples from major Chickpea growing areas of eastern Ethiopia were collected to evaluate the effectiveness of the native rhizobia nodulating Chickpea their N_2 fixation potential. From each farmer's field, separated soil samples were collected. This experiment was conducted under greenhouse condition using pot experiment. Recently released Chickpea genotypes and local genotypes were used for this experiment. At late flowering and pod setting stage, the nodule number, nodule dry weight, shoot dry weight and plant tissue total were measured.

Nodules and soil samples for rhizobia isolation from each farmer's field which are cultivating Chickpea were collected. This collection was done from major Chickpea growing areas of Ethiopia (Table 1). Nodules obtained from the farmer's fields and/or by induction method from collected soils were first sterilized by soaking in sodium hyper chlorite for 3min and hydrogen peroxide for 3min. and consequently, the nodules were washed five times using sterilized distilled water. Sterilized nodules were crushed in sterilized isotonic salt solution under sterile condition. Loop full of suspension were taken and streaked on yeast extract mannitol agar medium (YEMA).

The field experiments were carried out in Eastern Ethiopia. Filter mud based inoculate were produced at biofertilizer production and research laboratory of Haramaya University. Eight pre-selected isolates (based on the greenhouse experiment) of rhizobia nodulating Chickpea including positive and negative control were included in the treatments of the field experiment. The experiment was laid out as complete randomized block design and replicated three times. Blanket application of phosphorus (46 kg P_2O_5/ha) and nitrogen as starter (20 kg N/ha) were applied before planting the

crop. On top of this experiment, another experiment was conducted in collaboration with the student on the effectiveness of consortium *Rhizobium* inoculation with different rates of P application. The design and other agronomic practices were the same with the above field experiment.

Nodule number, nodule dry weight, shoot biomass yield and shoot height were measured at late flowering stage and early pod setting stage. Number of pods per plant, number of seeds per pod, plant height at harvest, harvest index, total biomass yield, seed yields and 100 seeds weight were measured. All the data collected from greenhouse and field experiments were analyzed by one-way ANOVA using SAS version 9.1. Pair-wise comparison among the mean values was executed using Fisher's Least Significance Differences ($P < 0.05$).

Table 1. The geographical locations of chickpea nodules collection site.

No.	Location	Latitude	Longitude	No.	Location	Latitude	Longitude
1	Akaki kaliti	8.896	38.82877778	26	Chelia	8.970805556	37.48338889
2	Akaki kaliti	8.873916667	38.81794444	27	Toke kutaye	8.978083333	37.60038889
3	Adaa	8.937888889	39.08455556	28	Toke gutayo	8.978666667	37.63294444
4	Adaa	8.91075	39.06227778	29	Toke gutaye	8.989	37.78555556
5	Bishoftu (Adaa)	8.71125	39.01738889	30	Ambo	8.991777778	37.80411111
6	Sebeta	8.849138889	38.51005556	31	Ambo	8.991583333	37.82375
7	Hilu	8.807888889	38.34752778	32	Ambo	8.991583333	37.82375
8	Hilu	8.771888889	38.31452778	33	Ambo	8.968222222	37.89938889
9	Tulubolo	8.738972222	38.28472222	34	Ambo	8.972444444	37.95094444
10	Tulubolo	8.679055556	38.22913889	35	Dandi	8.975138889	38.00569444
11	Tulubolo	8.696361111	38.20747222	36	Dandi	9.024388889	38.16427778
12	Tulubolo	8.695611111	38.19494444	37	Dandi	9.013583333	38.22811111
13	Becho	8.717194444	38.16691667	38	Addis Alem	9.057222222	38.45102778
14	Welesso	8.572861111	37.99791667	39	Akaki	8.897166667	38.82030556
15	Sendafa	9.102638889	38.97944444	40	Denbi	8.767361111	38.93322222
16	Aleltu	9.227944444	39.17688889	41	Adaa	8.81325	39.00486111
17	Kormash	9.261888889	39.22294444	42	Chancho	9.28825	38.75402778
18	Sheno	9.320555556	39.27627778	43	Sululta	9.4135	38.84466667
19	Aleltu	9.172861111	39.14327778	44	Mechale	9.527944444	38.87286111
20	Aleltu	9.130027778	39.17241667	45	Debrelibanos	9.651444444	38.81880556
21	Baco tibe	9.078	37.15347222	46	Debrelibanos	9.675083333	38.82463889
22	Baco tibe	9.022388889	37.22494444	47	Debrelibanos	9.676527778	38.82463889
23	Elu Gelane	9.994	37.35566667	48	Girar jarso	9.737888889	38.78655556
24	Chelia	9.020277778	37.40766667	49	Degem	9.787888889	38.69780556
25	Chelsa Sekondo	9.0385	37.41958333				

3. Results and Discussion

The result showed that significant effect of inoculation on nodulation and yield of chickpea in the study site (Table 2). Inoculating HURCP-18, HURCP-26, HURCP-4, HURCP-12, HURCP-16 and HURCP-31 significantly increased the nodule number of chickpea in the study site over the uninoculated control. The highest nodule number was found in treatment inoculated with HURCP-31 isolate which results 300% increase over the uninoculated treatment. The significant increase in total dry weight was found with HURCP-29 inoculation which caused 53% increase over the uninoculated treatment. Most of the tested isolates except, HURCP-4, HURCP-28 and HURCP-7, resulted in significant increased the grain yield of chickpea over the uninoculated treatment.

Less yield increase due to rhizobium inoculation has been reported by Khurana and Dudeja (1997) which was 10-15% over the uninoculated treatment. However, in this research, it was found that the highest grain yield (2054 kg ha^{-1}) was found with HURCP-18 which results 98.84% yield advantage over the uninoculated treatment. Similarly, Yadav and Verma (2014) reported that a significant increase in chickpea grain yield was obtained by inoculating locally isolated *Rhizobium*. This clearly indicated the need of *Rhizobium* inoculation when chickpea cultivated in the study site.

Table 2. Effect of inoculation on nodulation and yield of chickpea at Haramaya.

Treatment	Number of nodules	Total biomass yield (kg/ha)	Grain yield (kg/ha)
HURCP-18	17.00cd	6145.8ab	2054.6a
HURCP-26	24.67abc	5520.8ab	1892.2a
HURCP-4	16.33d	4062.5b	891.6c
HURCP-29	14.33de	6354.2a	1760.0a
HURCP-12	25.33ab	5416.7ab	1746.9a
HURCP-28	15.33de	5833.3ab	1609.9ab
HURCP-7	14.33de	5677.1ab	1560.3abc
HURCP-16	17.67bcd	4583.3ab	1767.1a
HURCP-31	28.00a	5979.2ab	1993.2a
Control check	7.67e	4145.8b	1033.3bc
LSD (5%)	7.74	2160	682.72
CV (%)	14.82	13.91	14.48

Mean values designated with same letter(s) have nonsignificant difference at P<0.05. LSD (5%) = least significant difference at 5% probability level and CV (%)= coefficient of variation in percent.

Using the tested isolates obtained from the above experiment, the consortium culture based bioinoculant was tested at Haramaya site on different genotypes of chickpea. Number of total nodules per plant in chickpea was highly and significantly (P<0.01) influenced by the three-way interaction effect of variety, phosphorus fertilizer rate and *Rhizobium* inoculants. The variety Ejere supplied with 20 kg P_2O_5 ha^{-1} with *Rhizobium*

seed inoculation produced the highest (40.33) number of total nodules per plant, whereas the variety Habru at 0 and 10 kg P_2O_5 ha^{-1} without *Rhizobium* inoculation produced the lowest (12.67 & 13.33) number of total nodules per plant, respectively (Table 3).

Table 3. Interaction effect of variety, phosphorous fertilizer and *Rhizobium* inoculation on total numbers of nodules per plant of chickpea at Haramaya in 2016/17.

Variety	P_2O_5 rates (kg ha^{-1})	Without Rhizobium	With *Rhizobium* inoculation
Arerti	0	15.00^{hi}	14.00^{i}
Arerti	10	20.00^{fg}	15.33^{ghi}
Arerti	20	30.67^{bc}	13.33^{i}
Arerti	30	26.00^{cde}	28.00^{bcd}
Ejere	0	19.33^{fgh}	13.67^{i}
Ejere	10	29.33^{bc}	24.00^{def}
Ejere	20	40.33^{a}	27.67^{bcd}
Ejere	30	32.33^{b}	14.67^{hi}
Habru	0	15.33^{ghi}	12.67^{i}
Habru	10	16.33^{ghi}	13.33^{i}
Habru	20	28.33^{bcd}	21.83^{ef}
Habru	30	15.33^{ghi}	14.00^{i}
LSD (0.05)			4.91
CV (%)			14.3

Means within a column followed by the same letter(s) are not significantly different as judged by LSD test at 5% level of significance. LSD=least significant difference and CV=coefficient of variation.

The dry weight of total nodules per plant in chickpea was highly and significantly ($P<0.01$) influenced by the three way interaction of variety, phosphorus fertilizer rate and *Rhizobium* inoculants. The highest (0.43 g) dry weight of total nodules per plant was recorded for the variety Ejere grown under 20 kg P_2O_5 ha^{-1} with mixed *Rhizobium* inoculants, which, was statistically at par with the dry weight (0.40 g) of total nodules per plant for the same variety supplied with 10 kg P_2O_5 ha^{-1}, and *Rhizobium* inoculants (Table 4). However, the lowest (0.09 g) dry weight of the total nodules per plant was recorded from the variety Ejere raised under 0 kg P_2O_5 ha^{-1} rate without *Rhizobium* inoculants. The possible reason for this result might be due to the differential response of genotype to the interaction effect of phosphorus fertilizer rate and *Rhizobium* inoculants that eventually led to higher dry weight of total nodules through increased BNF availability. This is also due to the presence of P application with *Rhizobium* strains that individually or in combination affected root development, nodule weight per plant and nitrogen fixation parameters.

Table 4. Mean dry weight (g) of total nodules per plant of chickpea as affected by interaction of varieties, phosphorous fertilizer rates and *Rhizobium* inoculants at Haramaya in 2016/17.

Variety	P_2O_5 rates (kg ha-1)	Without Rhizobium inoculation	With Rhizobium
Arerti	0	0.12^{hij}	0.11^{ij}
Arerti	10	0.21^{cdef}	0.18^{defgh}
Arerti	20	0.28^{b}	0.12^{hij}
Arerti	30	0.27^{bc}	0.16^{efghi}
Ejere	0	0.14^{ghij}	0.09^{j}
Ejere	10	0.40^{a}	0.12^{hij}
Ejere	20	0.43^{a}	0.22^{bcde}
Ejere	30	0.24^{bcd}	0.17^{efghi}
Habru	0	0.14^{fghij}	0.11^{ij}
Habru	10	0.18^{defgh}	0.10^{ij}
Habru	20	0.22^{bcde}	0.20^{cdefg}
Habru	30	0.17^{efghi}	0.15^{efghij}
LSD (0.05)		0.07	
CV (%)		22.2	

Means within a column followed by the same letter(s) are not significantly different as judged by LSD test at 5% level of significance. LSD=least significant difference and CV=coefficient of variation.

The result indicated highly significant (P<0.01) effect of the three-way interaction of variety × phosphorus fertilizer rate × *Rhizobium* inoculant on seed yield of chickpea. The highest (3141 kg ha^{-1}) seed yield was recorded from the variety Ejere treated under 20 kg P ha^{-1} with seed inoculation, followed by the same variety received 30 kg P ha^{-1} with *Rhizobium* inoculant, while the lowest (1013 kg ha^{-1}) seed yield was recorded for the variety Habru grown under 0 kg P ha^{-1} without *Rhizobium* inoculation (Table 5). The highest seed yield from the variety Ejere at rate of 20 kg P ha^{-1} with seed inoculation might be due to the cumulative effect of phosphorus on the processes of cell division, flowering, fruiting, seed setting, and balanced nutrition. In addition to symbiosis between legumes, P and rhizobia resulted in increased nodulation, primary branches, secondary branches and plant height, which contribute for the production of improved number of total pods per plant and number seed per pod that led to high yield through increased supply of nitrogen

Table 5. Seed yield (kg ha-1) of chickpea as affected by interaction of varieties, phosphorous fertilizer rates and *Rhizobium* inoculants at Haramaya in 2016/17

Variety	P_2O_5 rates (kg ha-1)	Without Rhizobium	With Rhizobium inoculation
Arerti	0	1540^{ij}	1387^{ijk}
Arerti	10	1928^{defg}	1585^{hi}
Arerti	20	2060de	1752^{gh}
Arerti	30	2082^{d}	1785^{gh}
Ejere	0	1995^{def}	1757^{gh}
Ejere	10	2071^{d}	1898^{defg}
Ejere	20	3141^{a}	2284^{c}
Ejere	30	2541^{b}	1868^{efg}
Habru	0	1391^{ijk}	1013^{m}
Habru	10	1097^{lm}	1288^{kl}
Habru	20	2017de	1390^{ijk}
Habru	30	1815^{fg}	1361^{jk}
LSD (0.05)	200.2		
CV (%)	6.8		

Means within a column followed by the same letter(s) are not significantly different as judged by LSD test at 5% level of significance. LSD=least significant difference and CV=coefficient of variation.

4. Conclusion

Inoculation increased the number of nodules in chickpea in the study site. On top of this, most of inoculates of isolates increased the grain yield of chickpea. Besides, consortium isolate based bioinoculant increased significantly in different varieties of chickpea in the study site. Hence, the research results suggested the need of *Rhizobium* inoculation in chickpea at the study site in order to increase the chickpea production in sustainable ways without affecting the environment.

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4. New Groundnut (*Arachis hypogaea* L.) Varieties (*Babile-1*, *Babile-2* and *Babile-3*) for Lowland Areas of Ethiopia

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Abstract: Groundnut is produced mainly by small holder farmers in the lowlands of Ethiopia. It is the second important lowland oilseed of warm climate next to sesame. However, the production of the crop is constrained by several biotic and abiotic factors of which lack of improved varieties among the major constraints. Therefore, the national groundnut project coordinated by Haramaya University is thriving to develop varieties with high yield and oil content to increase the production and productivity of groundnut in the country. This project is, therefore, initiated aiming to select genotypes for high yield and oil content to recommend for cultivation in the country. After the yield trial the performance of 15 groundnut genotypes along with one standard check were tested under five locations (Werer, Miesso, Pawe, Asossa and Babile) for three years (2011-2013). The experiment was laid out as randomized block design with three replication all over testing locations and seasons. Depending on yield performance and other agronomic characters, the genotypes with the accession codes of ICGV-98412, ICGV-98404 and ICGV-94100 were identified and proposed as new varieties with local name Babile-1, Babile-2 and Babile-3, respectively, to be cultivated in Ethiopia. The three genotypes were introduced from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India. Babile-1 and Babile-2 out yielded the standard check variety Roba by 33 and 12%, respectively. The seed color of these varieties is red tan. Hundred seed weights of Baile-1 and Babile-2 were 78.07 and 79.5g, respectively, which were significantly higher by about 13.47 and 13.71%, respectively, than check variety Roba with 57.95g hundred seed weight. The two varieties are also better resistant to major diseases such as leaf spots and showed stability for yield over locations and seasons. Babile-3 out yielded the standard check variety Roba by 26%. It also showed moderate resistance to leaf spot which is a major constraint to groundnut production in the study areas. Therefore, the three varieties, Babile-1, Babile-2 and Babile-3 were approved by the

National Variety Releasing Committee in 2016 to be cultivated in lowlands of Ethiopia.

Keywords: Agronomic characters; Genotypes; Oil content; Standard check variety and Yield

1. Introduction

Groundnut (*Arachis hypogaea* L.) is a legume plant that grows to maturity in the ground. It is cultivated in nearly 100 countries, over 90% of which are developing countries. The groundnut is a food staple and valuable cash crop for millions of households (CGIAR, 2004-2005). The 'nuts' are high in edible oil content (40-50%) and protein (25%), and also a good source of a variety of essential vitamins and minerals. They can be consumed directly, processed into oil or cake/meal, or further processed into confectionary products or snack food. Every part of the peanut plant is used in some way: kernels for human consumption, and vines as fodder for cattle. The crop is valued in most countries primarily for its oil, but it has the ability to improve soil fertility, and nitrogen fixed from its roots as nutrients for the soil. This is particularly important when considered in the context of the rising prices of chemical fertilizers which makes it difficult for small scale farmers to purchase the chemical fertilizers (Fredu *et al*., 2015). In livestock farming communities, groundnut can be used as fodder for livestock and increases productivity as the groundnut haulm and seed cake are rich in digestible crude protein content (Simtowe *et al*., nd cited in Fredu *et al*., 2015).

Groundnut was first introduced to Eritrea and then to Hararghe in early 1920s by Italian explorers (Yebio, 1984). Now a day's groundnut is well disseminated in the warm lowlands of the country and it is the second important lowland oilseed of warm climate. The crop is produced mainly by small holder farmers and it play significant role in Ethiopian economy. It provides as raw material for the food oil factory, it has high energy content, and also it is the main source of cash income. Major groundnut producing areas in Ethiopia are Oromia region (East Wollega, West Wollega, West Hararghe, East Hararghe, Illubabor, and KelemWollega zones), Benishangul-Gumuz Region (Metekel, Assosa, Kamashi and Mao Komo zones), SNNP Region (South Omo and Gamo Gofa zones), and Amhara region (Oromiya zone). Moreover, there are pockets of areas in Gambella, Harari and Dire Dawa regions where groundnut is grown. It is also grown under irrigation in middle Awash and Gode. The national average seed yield and area coverage of groundnut were 1.6 t ha^{-1} and 64,649.3 hectares**,** respectively (CSA, 2015).

Groundnuts are becoming increasingly important in Ethiopian agriculture and domestic demand has been on a steady increase. However, the production of the crop is constrained by several biotic and abiotic factors i.e. critical moisture stress especially during flowering and then after, lack of improved varieties and appropriate production and post-harvest practices, and diseases affecting both above-and underground parts of the plant (Fredu *et al*., 2015). Although the national average seed yield of 1.6 t ha^{-1} (CSA, 2015) is by far higher than 1.49 and 0.98 t ha-1 of the world and African countries

average productivity of the crop, respectively (FAOSTAT, 2010), it is low as compared to the attainable yield of 6 t ha-1 unpeeled productivity of groundnut seed at research center (Dandenna *et al.*, 2010). Therefore, the national groundnut project coordinated by Haramaya University is thriving to develop varieties with high yield, disease resistant, high seed oil content and other desirable agronomic traits to increase the production and productivity of the crop in the country. Several groundnut genotypes introduced from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) were evaluated for yield and other desirable agronomic traits aiming to identify genotypes that had better yield than commercial variety to be recommended for cultivation in the country.

2. Materials and Methods

The groundnut genotypes introduced from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India were evaluated for yield and other desirable agronomic traits before the selected genotypes evaluated over locations and seasons. A total of 15 selected genotypes along with the standard check variety (Roba) were evaluated in to two separate experiments laid out as randomized complete block design with three replications at five locations (Werer, Miesso, Pawe, Assosa and Babile) under rain fed condition for three years (2011-2013). All the agronomic practices were applied uniformly across locations and over years. Data were collected for days to flowering, days to maturity, shelling percentage, hundred seed weight and seed yield. Finally, the genotypes with accession codes of ICGV-98412, ICGV-98404 and ICGV-94100 were identified as candidate varieties given the local name as *Babile-1, Babile-2* and *Babile-3*, respectively, to be proposed for release.

3. Results and Discussion

Yield Advantages of New Groundnut Varieties

The three varieties, *Babile-1, Baile-2* and *Baile-3* had significantly higher seed yields of 2.42, 2.03 and 2.43t ha^{-1}, respectively than the standard check variety *Roba* (1.81 and 1.93 t ha^{-1} in the 1st and 2nd sets of experiments, respectively) (Table 1). *Babile-1, Baile-2* and *Baile-3* exhibited seed advantages of 33, 12 and 26%, respectively over the standard check variety *Roba.* The yield advantages of the three new varieties reasonably high to increase the yield of groundnut in the country though the standard check variety *Roba* (ICG-273) was released in 1989 by Werer Agriculture Research Center (MoAN, 2016), but it is found to be high yielding and wide adaptable.

Table 1. Mean seed yield of groundnut varieties at five locations over three years (2011 to 2013).

	First set experiment				Second set experiment			
Location	Year	*Babile-1*	*Babile-2*	*Roba*	Location	Year	*Babile-3*	*Roba*
Assosa	2012	2.66	1.85	1.54	Pawe	2012	1.91	1.23
	2013	2.55	2.64	2.2		2013	1.69	2.11
Babile	2012	1.28	1.32	1.1	Babile	2012	2.65	1.86
	2013	1.32	0.61	0.49		2013	1.89	1.7
Pawe	2013	1.33	1.02	1.16	Assosa	2013	1.58	0.7
Werer	2011	3.85	3.03	3.23	Werer	2011	1.37	0.61
	2012	5.05	5.48	5		2012	5.2	2.89
	2013	3.9	2.74	2.3		2013	5.65	2.8
Miesso	2011	1.68	1.64	1.19	Miesso	2011	1.95	3.95
	2012	1.09	0.6	0.7		2012	1.52	1.9
	2013	1.88	1.44	1.05		2013	1.63	1.46
Mean (t ha^{-1})		2.42	2.03	1.81	Mean (t ha^{-1})		2.43	1.93
Yield advantage (%)		33	12		Yield advantage (%)		26	

Yield Stability of New Groundnut Varieties

Additive Main Effects and Multiplicative Interaction (AMMI) (Zobel *et al*., 1988) model analysis of variance was conducted for 11 (*Babil-1* and *Babile-2*) and 12 (*Babile-3*) environments considering each location and one season as one environment. The result indicated that the mean squares for genotype and environment were significant while the mean square for genotype x environment interaction (GEI) was nonsignificant for the experiment conducted at 11(*Babil-1* and *Babile-2*) environments (Table 2). This implies that the varieties were stable and wide adaptable. The nonsignificant effect of GEI on yields of varieties indicated absence of crossover GEI and consistent yield ranks of varieties over environments since the presence of significant effect of GEI showed the differential yield ranks of varieties due to the presence of crossover GEI (Kang, 2002).

In the case of analysis of variance from AMMI model for 12 (*Babile-3*) environments, the mean squares for genotype, environment and genotype x environment interaction (GEI) were highly significant ($P < 0.01$) (Table 2). This indicated that the differential yield ranks of varieties due to the presence of crossover GEI (Kang, 2002). In such case, evaluation of varieties over environments for mean yield and stability is necessary to select varieties that perform well consistently in all environments or to identify specific varieties for each environment (Gauch, 2006).

Table 2. Analysis of variance (ANOVA) from AMMI model for seed yields of genotypes at 11 (*Babile-1and Baile-2*) and 12 (*Babile-3*) environments

Source	ANOVA for 11(*Babile-1and Baile-2*) environments			ANOVA for 11 (*Baile-3*) environments		
	df	SS	MS	df	SS	MS
Total	479	832.4	1.738	575	2375.6	4.13
Treatments	159	736	4.629	191	2294.1	12.01
Genotypes	15	10.6	0.708*	15	22.8	1.52**
Environments	9	689.8	76.646**	11	2023.1	183.91**
Block	20	7.2	0.358	24	6.7	0.28
Interactions	135	35.5	0.263	165	248.2	1.5**
IPCA 1	23	11.4	0.495	25	124.6	4.99
IPCA 2	21	7.2	0.341	23	50.6	2.2
Residuals	91	17	0.187	117	72.9	0.62
Error	300	89.3	0.298	360	74.8	0.21

**and * *, significant at P < 0.05 and P < 0.01, respectively. df = degree of freedom, SS= total sum square, MS= mean square, Interactions= genotype by environment interaction, IPCA 1 and IPCA 2, interaction principal component axis one and two, respectively.*

Stability parameters of Eberhart and Russell (1966) model i.e. regression coefficient (b_i) and deviation from linear regression (S^2di) were computed for mean seed yield. The result from this model revealed that *Babile-3* had high seed yield mean values, low regression coefficient (0.633) and significant deviation from the regression slope (Table 3). This suggested that the variety and the tested genotypes were sensitive to changed environments but responsive to environments as observed from coefficient determination (R^2) being >0.5 for all genotypes. According to the Eberhart and Russell (1966), regression coefficient (b_i) approximating unity along with deviation from regression (S^2di) near zero indicated the average stability of genotypes. Accordingly, *Babile-3* showed unpredicted yield performance due to its significant deviation from the regression slop. However, the stability alone has not practical utility as far as the varieties have low mean over environments (Dabholkar, 1998). On the other hand, high mean yield of the variety could not be the only criterion for selection unless its high performance is established over wide range of environments since a variety with high mean performance across environments is an advantage for farmers to obtain larger harvest due to large genotypic effect and small genotype x environment interaction (Flis *et al*., 2015). The average yield of genotypes were 2.1 t ha^{-1} in which *Babile-3* had mean seed yields of above or equal to average yield of genotypes at seven environments (Table 1) and suggested to be recommended as variety more preferably in environments (locations) where the variety performed best.

Table 3. Stability parameters from Eberhart and Russells' (1966) model for mean seed yields of genotypes at 12 (*Babile-3*) environments.

Genotype	* Mean	b_i	* S^2di	* R^2
ICGV-94100 (*Babile 3*)	2.412333	0.6333	1.4678	0.5789
ICGV-94105	2.09975	0.7032	0.5127	0.8146
ICGV-96242	2.34525	1.3192	0.0111	0.9895
ICGV-96245	2.39025	1.3076	0.2286	0.9665
ICGV-97150	1.886333	1.0118	0.266	0.9392
ICGV-97153	2.10625	1.095	0.0797	0.9745
ICGV-97157	2.189083	1.0562	-0.0548	0.9945
ICGV-97160	1.978583	1.3172	0.2446	0.9654
ICGV-97163	2.18075	1.0557	0.2855	0.9409
ICGV-97164	2.021083	0.9525	-0.0055	0.9834
ICGV-97165	2.20675	1.2085	0.2904	0.9537
ICGV-98369	1.94775	0.9804	0.447	0.9055
ICGV-98370	2.016	0.9724	0.1266	0.9593
ICGV-98371	2.12025	0.7829	0.0062	0.9722
ICVG-97156	1.710333	1.1539	-0.0493	0.9947
Roba	1.93	0.4502	0.1464	0.8221

b_i=regression coefficient, S^2di= deviation from linear regression and R^2= coefficient determination.

Seed Oil Content and Reaction to Leaf Spot Disease of Varieties

Babile-1 has upright growth habit, whereas *Babile-2* has spreading growth habit and both have sequential branching form; they mature in 131-132 days whereas the standard check matures in 136 days. In addition, they have red tan seed color. *Babile-1* and *Baile-2* had 78.07 and 79.5g hundred seed weight, respectively (Table 4). Babile-1 and Babile-2 are high yielding, large seeded, medium maturing and Spanish type groundnut varieties. Leaf spot is one of the major threats in the groundnut production. Leaf spot incidence was scored on a 1-9 field scale (Faujdar and Oswalt, 1992), and both *Babile-1* and *Babile-2* showed moderate resistance to aforementioned disease throughout the study periods in the study areas. *Babile-3* showed slightly better performance than the check variety, Roba to the leaf spot interaction and it categorized as moderately resistant to leaf spot in the tested locations over seasons. Leaf spots are the most widespread diseases of groundnut that result in severe yield losses in Ethiopia (Solomon and Amare, 2015).

Table 4. Maturity Shelling percentage and hundred seed weight of three groundnut varieties.

No	Genotype	Days to flowering	Days to maturity	Shelling percentage	100 seed weight(g)
1	Babile-1	48	131	67.83	78.07
2	Babile-2	51	132	66.2	79.50
3	ROBA(check variety)	56	136	66.51	57.95

Table 5. Seed oil content of four varieties of groundnut evaluated at 11 and 12 environments.

No.	Variety	Oil content (%)	Remark
1	Babile-1	49.32	
2	Babile-2	51.13	
3	Babile-3	51	
4	Roba (check variety)	47.19	At 11 Environments
5	Roba (check variety)	47.33	At 12 Environments

Other Agromorphology Characteristics of Varieties

All the three new varieties (*Babile-1, Babile-2* and *Babile-3*) are recommended for production in Ethiopia in the altitude range of 750 to 1650 meters above sea level. The varieties were evaluated without application of fertilizers. The description of the varieties is presented in Table 6 as it was registered in variety registry book (MoAN, 2016). Breeder and pre-basic seeds for Babile-1 and Babile-2 will be maintained and multiplied by National Groundnut Research Program of Haramaya University, Ethiopia. In addition, small amount of seed for research purposes may be obtained from collaborating centers (Werer, Pawe and Asossa). Therefore, it is recommended to use the new varieties in the recommended areas of the country to enhance production of groundnut in the country.

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Table 6. Agronomic and morphological characters of three new groundnut varieties.

Characteristics	*Babile-1*	*Babile-2*	*Babile-3*
Adaption area:	Werer, Miesso, Assosa, Pawe & Babile	Same	Same
Altitude (m.a.s.l):	750-1650	Same	Same
Rainfall (mm):	569 - 1100	Same	Same
Planting date:	At the beginning of the summer for rain fed areas, mid-May for Babile	Same	Same
Seed rate (kg/ha):	60-110	Same	Same
Spacing (cm): between plants	10cm	Same	Same
Spacing (cm): between rows	60cm	Same	Same
Days to flowering	48	52	59
Days to maturity	131	132	142
Shelling percentage	67.83	62.2	66.07
Growth habit	Spanish bunch with sequential branching	Same	Same
100 seed weight	78.07	79.5	53.65
Seed color:	Tan	Same	Tan
Flower color	Yellow	Same	Yellow
reaction to leaf spot (1-9 scale)	2.7	2.7	2.67
Oil content (%):	49.32	51.13	51
Seed yield (t/ha) :	Research field: 2.4	2.02	2.43
	Farmers' field: 1.9	1.8	1.65
Year of release:	2016	Same	Same
Breeder/ Maintainer:	Haramaya University	Same	Same

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5. Genetic Variability and Association of Coffee Quality Traits in Hararghe Coffee (*Coffea arabica* L.) Collections

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Abstract: Hararghe coffee has distinct unique aroma and flavor that fetch premium prices in the world market. Therefore, it is necessary to maintain and improve this quality to exploit this good opportunity in the world market. The understanding of the existing variability in the germplasm is the first step to improve the crop. Therefore, this research was conducted to estimate the genetic variability among 60 Hararghe coffee collections maintained at Mechara Agriculture Research Center for coffee bean quality traits. The collections were evaluated for physical and organoleptic coffee quality attributes in three replications of complete randomized design. The collections differed significantly for all the coffee quality traits except acidity. Only one released variety (Mocha) had overall quality (81%) and grade two while 20 collections had >81% and grade two indicating the higher chance of improving Hararghe coffee quality through selection. Genotypic and phenotypic coefficient of variations ranged from 2.46 to 23.39 and 5.25 to 41.47%, respectively. Heritability in broad sense and genetic advance in percent mean also ranged from 35.94 to 99.79 and 5.07 to 85.18%, respectively. Overall coffee quality had lowest values for most of the variability components while the roast bean volume change and coffee physical quality traits had the highest values. The raw and organoleptic coffee quality attributes had low to medium values for both heritability and genetic advance. Overall coffee quality had positive and significant genotypic and phenotypic correlations with most of physical and organoleptic coffee quality attributes of beans. Shape and make, color, cup quality and weight of roast coffee exerted high and positive direct effect on overall coffee in which body and flavor as well most of bean quality traits had strong positive indirect effect through these traits on overall quality at both genotypic and phenotypic levels. This suggested that overall quality of Hararghe coffee could be improved through selection of genotypes for these traits. Euclidean distance ranged from 2.5 to 13.8 which distinctly grouped the Hararghe coffee collections into eight clusters and four subgroups of which Cluster

II, VII, I and III consisted of 29, 9, 7 and 5 out of 60 collections, respectively, while other clusters were constructed with two and three collections. The research results demonstrated the existence of wide genetic variations for quality among the Hararghe coffee collections and the higher chance of developing varieties through selection.

Keywords: Cluster; Cup quality; Euclidean distance and Organoleptic coffee quality

1. Introduction

Ethiopia is the center of origin and genetic diversity of *Coffea arabica* L. which is naturally occurring in country (Anthony *et al*., 2001; Yigzaw, 2005). Coffee is the second most traded commodity after oil in international trade in terms of value which worth an estimated 23.4 billion US dollar in 2013 (Alemseged and Yeabsira, 2014). *Coffea arabica* accounts 75% of the world coffee market (Tadesse *et al*., 2002) which is the significant source of income to several developing countries in Africa, Asia and Latin America. Coffee remains as a backbone of Ethiopian economy contributing 25-30% of foreign exchange, sustaining more than 15 million people and 10% of government revenue (EDRI, 2014). In addition, coffee is the defining feature of the national culture and identity with 50% of the production consumed domestically (Mayne *et al*., 2002).

Coffee physical, organoleptic and bean biochemical quality attributes is an inherent character of coffee genotypes but environment also plays an important role to the expression the traits in genotypes (Leory *et al.,* 2006). Ethiopia is endowed with immense diversity of coffee quality types and contrasting ecological conditions that gives great opportunity to develop very high quality cultivars for sale at exceptionally higher price. However, this potential was not utilized fully and effectively. In Hararghe, farmers grow coffee landraces having their own characteristic features which are produced in highly diversified garden production systems adapted to different ecological conditions (Bayeta *et al.,* 2000; Mesfin and Bayetta, 2003). But this resource is under threat of genetic erosion mainly by the replacement of khat (*Catha edulis*) (Bayeta *et al*, 2007) which needs to be maintained and improved to obtain premium prices in international market.

A lot of effort has been devoted to collect Hararghe coffee and *ex-situ* preserved at research centers to utilize the available diverse coffee genetic materials in breeding activities. Of which more than 200 accessions were collected from East and West Hararghe coffee growing areas and maintained at Mechara Agriculture Research Center. However, there was no extensive coffee quality research conducted on Hararghe coffee collections. For any crop improvement program, a breeder depends on the availability of germplasm collections. The market share for specialty coffees is increasing at a steady rate. Therefore, the first priority in research is on coffee quality, paying much attention to quality improvement and maintenance in the region. Cognizant of this fact, this study was initiated to estimate the extent of variability and genetic divergence in Hararghe coffee collections; estimate heritability and genetic advance under selection, and assess

the association of coffee bean physical and organoleptic traits in Hararghe coffee collections.

2. Materials and Methods

Description of Experimental Area

The study was conducted on Hararghe coffee collections maintained at the Mechara Agriculture Research Center. The center is found in Daro Labu district of West Hararghe Zone. The center is located between latitude of 8°36'38" North and longitude of 40°19'29" East direction and altitude of about 1700 m.a.s.l. The average annual rainfall is 1100 mm and the annual average minimum and maximum temperatures of the center are 14°C and 26°C, respectively. The soil of the center is deep, well-drained and slightly acidic nitsol.

Experimental Materials

The descriptions of four standard check varieties (all varieties released in 2010) and 56 collections are given in Tables 1 and 2, respectively. Hararghe coffees were collected from nine Woredas' of western and eastern Hararghe zone during the year 2002 and planted six plants in single row at the spacing of 2 m both between plants and between rows. The experimental plots maintained under temporary shade tree known as *Sesbania susban*. All the field management practices such as weeding, hoeing, shading and fertilizer application were applied similarly to all plots using the national recommendation.

Table 2. Description of the released Hararghe coffee varieties.

No.	Variety name	Accession code	Collection		Yield (kg ha^{-1})	Resistant to CBD	Recommended
			District	Altitude			
1	Harusa	H-674/98	Mechara	Mid altitude	16.02	Moderate	Low land
2	Mercha-1	H-823/98	Mechara	Mid altitude	13.46	Moderate	Midland
3	Mocha	H-739/98	Mechara	Mid altitude	11.89	Resistant	Mid and high land
4	Bultum	H-857/98	Bultum	Mid altitude	17.06	Moderate	Mid and high land

CBD= coffee berry disease and High, Mid and Low altitude represents ≥2000, 1500 to 1950 and <1500 m.a.s.l., respectively.

Table 3. Description of East and West Hararghe coffee collections.

No.	Acc. Code	District	Altitude	No.	Acc. Code	District	Altitude
1	H-01/02	Deder	High altitude	29	H-636/02	Meta	Mid altitude
2	H-05/02	Deder	Mid altitude	30	H-641/02	Meta	Mid altitude
3	H-10/02	Deder	Mid altitude	31	H-643/02	Meta	Mid altitude
4	H-13/02	Deder	Mid altitude	32	H-644/02	Meta	Mid altitude
5	H-16/02	Deder	Mid altitude	33	H-645/02	Meta	Low altitude
6	H-22/02	Deder	Mid altitude	34	H-648/02	Meta	Low altitude
7	H-25/02	Deder	Mid altitude	35	H-655/02	Meta	Low altitude
8	H-27/02	Deder	Mid altitude	36	H-656/02	Meta	Low altitude
9	H-55/02	Deder	Low altitude	37	H-657/02	Meta	Mid altitude
10	H-160/02	Kombolcha	Mid altitude	38	H-662/02	Meta	Mid altitude
11	H-168/02	Aramaya	Mid altitude	39	H-666/02	Meta	Mid altitude
12	H-203/02	Aramaya	Mid altitude	40	H-668/02	Meta	Mid altitude
13	H-231/02	Aramaya	Mid altitude	41	H-716/02	Kurfa Chele	Low altitude
14	H-236/02	Aramaya	Mid altitude	42	H-717/02	Kurfa Chele	Low altitude
15	H-544/02	Melka Belo	Mid altitude	43	H-719/02	Kurfa Chele	Low altitude
16	H-567/02	Melka Belo	Mid altitude	44	H-734/02	Kurfa Chele	Low altitude
17	H-568/02	Melka Belo	Mid altitude	45	H-735/02	Kurfa Chele	Low altitude
18	H-569/02	Melka Belo	Mid altitude	46	H-743/02	Kurfa Chele	Low altitude
19	H-588/02	Melka Belo	Mid altitude	47	H-744/02	Kurfa Chele	Low altitude
20	H-595/02	Melka Belo	Mid altitude	48	H-749/02	Kurfa Chele	Low altitude
21	H-599/02	Melka Belo	Mid	49	H-759/02	Jarso	Mid altitude

			altitude				
22	H-612/02	Melka Belo	Mid altitude	50	H-761/02	Jarso	Low altitude
23	H-614/02	Mid altitude	Mid altitude	51	H-762/02	Jarso	Low altitude
24	H-623/02	Melka Belo	Mid altitude	52	H-247/02	Doba	Mid altitude
25	H-625/02	Meta	Low altitude	53	H-382/02	Tulo	Mid altitude
26	H-626/02	Meta	Low altitude	54	H-383/02	Tulo	Mid altitude
27	H-627/02	Meta	Low altitude	55	H-387/02	Tulo	Mid altitude
28	H-630/02	Meta	Mid altitude	56	H-402/02	Tulo	Mid altitude

Acc. Code= accession code. High, Mid and Low altitude =≥2000, 1500 to 1950 & <1500 m.a.s.l., respectively.

Sample Preparation and Experimental Design

Selective picking method was applied to collect cherries produced in six trees per collection, i.e., only the red ripe cherries were handpicked from the trees selectively and unripe green beans were left behind to be harvested later. Accordingly, more than three harvests were carried out to collect cherries. The harvested red ripe cherries during each harvesting time were measured and dried on raised bed with mesh wire in a place where there was no any type of shade tree, building, and shade producing material around or near to raised bed. The cherries were dried until the outer shell was become dark brown and brittle in the open sun with regular stirring to promote even drying, prevent fermentation and the growth of mold. At night the cherries were covered with plastic sheet to protect from receiving moisture from the environment. Then after, the sample cherries were hulled with mortar carefully as farmers are practicing. The weight of clean coffee beans were measured and recorded for each accession.

From the total clean coffee beans prepared, 100g in three replicates for each accession was measured. Finally, the green beans were labeled and packed in transparent polyethylene bags where berries stabilize their moisture content and quality attributes. The prepared samples were taken to Coffee Liqouring Unit of Jimma Agriculture Research Center and subjected to physical and organoleptic quality evaluation. Completely randomized design (CRD) with three replications was used, aiming to compare differences between genotypes for quality parameters.

Data Collection

The 60 Hararghe coffee collections as sample bean were subjected to a total of 24 coffee quality traits (Table 3) both at the field and laboratory as per the national and

international coffee quality evaluation procedures. All samples collected from each collection were assigned an arbitrary code (an identity letters) in order to secure an unbiased judgment. The sun dried cherries were hulled and green beans were transferred to coffee quality laboratory at Jimma Agriculture Research Center where the coffee beans quality was evaluated based on the physical, and cup quality attributes.

Defect count was also made for green coffee beans as per International Organization for Standards (ISO, 1991) and national fixed standard (ECX, 2010). Roasting the samples was done by the roaster machine with six cylinders (PROBAT WELKE, VON GIMBORN GMBHAN CO. KJ. Germany) and roast beans analysis was conducted as indicated by Abrar *et al.* (2014). Roasting of sample beans were grounded using electrical coffee grinder (MAHLKONIG, Germany) with middle adjustment and eight gram coffee powder was put into a clean standard cup with 180 ml capacity (Schonwald, Germany) in which the coffee beverages were prepared (ISO, 2000). All physical and cup quality evaluations were carried out by a panel of liquorers at Jimma Agriculture Research Center which was 3 to 5 in number as per the standard recommendation (QSAE, 2000; Wintgens, 2004; CLU, 2007; ECX, 2010).

Table 3. List of coffee quality traits.

No.	Quality trait	No.	Quality trait
1	Moisture content	13	Weight of roasted coffee
2	Over screen	14	Weight lost due to roasting
3	Shape and make	15	Bulk density of green coffee
4	Color	16	Bulk density of roast coffee
5	Defect	17	Bean weight
6	Odor	18	Volume of green coffee
7	Total raw quality	19	Volume of roast coffee
8	Acidity	20	Roast volume change
9	Body	21	Single berry weight
10	Flavor	22	Outturn ratio
11	Cup quality	23	Percent pulp
12	Total quality		

Data Analysis

Analysis of variance (ANOVA) was conducted for data collected at field and laboratory (coffee bean quality attributes) using completely randomized design. DMRT was used for mean separation of field and laboratory (coffee raw bean quality and cup quality attributes) data. Only the coffee bean quality attributes in which the coffee collections exhibited significant differences were used for further genetic analyses.

The phenotypic and genotypic variance and coefficient of variation were estimated according to the methods suggested by Burton and Devane (1953). Heritability (H^2) in broad sense for all characters was computed using the formula adopted by Allard (1960),

while expected genetic advance as part of the mean (GA) for each characters was computed using the formula adopted from Johnson *et al.*, (1955) and Allard (1960). Phenotypic and genotypic correlations among coffee bean quality attributes were estimated using the method described by Miller *et al.* (1958). The direct and indirect effect of beans physical and organoleptic attributes on overall bean quality was analyzed through path coefficient analysis. This analysis was computed as suggested by Dewey and Lu (1959). Genetic distance was estimated based on data collected for all pair-wise combinations of the 60 Hararghe coffee accessions. Euclidean distance (ED) was computed from all phenotype data collected for accessions after standardization (subtracting the mean value and dividing it by the standard deviation) as indicated by Sneath and Sokal (1973). The distance matrix from traits will be used to construct dendrograms based on the Unweighted Pair-group Method with Arithmetic means (UPGMA). The results of cluster analysis was presented in the form of dendrogram. In addition, mean ED was calculated for each accession by averaging of a particular accession to the other 59 accessions. The calculated average distance (ED) was used to estimate which accession is closest or distant to others.

3. Results

Analysis of Variance

The analysis of variance results revealed the presence of significant differences among the Hararghe coffee collections for all the physical and organoleptic quality attributes except for acidity (Table 4). This justifies to carry out further genetic analysis for quality attributes which the collections exhibited significant differences.

Mean Performances of Coffee Collections

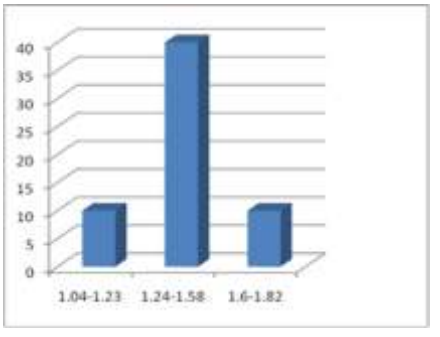
The variations of Hararghe coffee collections for single berry weight and bean weight ranged from 1.04 to 1.82 and 0.136 to 0.202, respectively. The variations for outturn ratio and percent pulp ranged from 12.89 to 24.81 and 19.17 to 52.25%, respectively. The overall mean weight of single berry weight for 60 Hararghe coffee collections was 1.42g with the standard deviation of 0.18. Among the collections, 31, 19 and 10 had significantly low (1.04 to 1.43g), near to equal (1.43 to 1.58g) and significantly higher (1.6 to 1.82g) than the overall mean berry weight of coffee collections (Figure 1). Four collections (H-569/02, H-656/02, H-759/02 and H-743/02) had significantly highest mean single berry & bean weight but with low out turn ratio.

Table 4. Mean squares from analysis of variance for coffee quality traits of 60 Hararghe coffee collections.

Trait	Genotype(59)	Error (118)	CV (%)
Moisture content	0.58**	0.01	0.88
Over screen	76.32**	3.25	1.95
Shape and make	2.21**	1	8
Color	1.56**	0.86	7.41
Defect	6.41**	2.32	6.08
Odor	1.70**	0.2	4.38
Total raw quality	6.56**	2.61	4.61
Acidity	2.30ns	1.74	8.86
Body	1.80*	1.12	7.02
Flavor	2.11*	1.46	8.23
Cup quality	15.30*	10.59	7.28
Total quality	26.48**	14.92	4.85
Weight of roasted coffee	48.90**	0.37	0.74
Weight lost due to roasting	35.16**	0.47	3.71
Bulk density of green coffee	0.01**	0.001	0.85
Bulk density of roast coffee	0.01*	0.001	3.32
Bean weight	4.38**	0.35	4.58
Volume of green coffee	411.16**	0.58	0.46
Volume of roast coffee	912.94**	161.72	6.64
Roast volume change	209.95**	0.31	3.23
Single berry weight	9.64**	0.04	1.48
Outturn ratio	44.47**	1.63	7
Percent pulp	0.04**	0.001	12.38

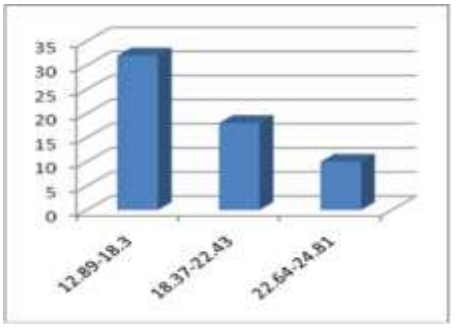
** and ** significant difference at P≤0.05, P≤0.01, respectively, ns= non-significant, and numbers in parenthesis refers to degrees of freedom, CV (%) =coefficient of variation in percent.*

Beans moisture content and bean size ranged from 7.7 to 9.5 and 76.8 to 98.83, respectively. The shape and make ranged from 10.67 to 14.33, color and odor ranged from 11 to 14 and 9.33 to 14% which were evaluated out of 15%. The defects of the coffee samples ranged from 22 to 28. The Hararghe coffee collections had mean total raw quality in the range between 32 and 38% evaluated out of 40%. Among the collections, 22, 27 and 11 had significantly low (76.80 to 92.20%), statistically equal (92.6 to 96.00%) and significantly higher (96.1 to 98.83%) than the overall mean bean size of coffee collections (Figure 2). Six coffee collections had significantly higher mean bean size in the range between 97.57 and 98.83%. These collections also had significantly highest mean shape and make and total raw bean quality but with low color.

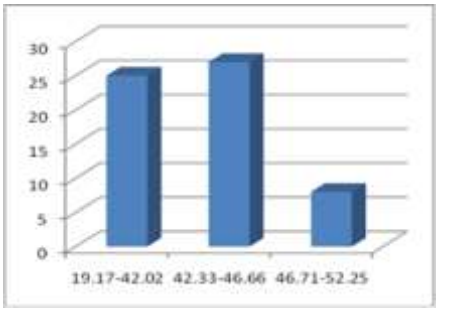


a. Single berry weight

b. Bean weight



c. Outturn ratio

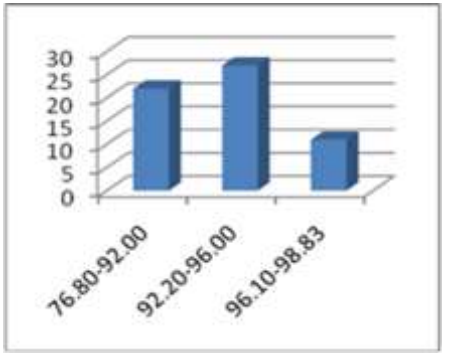


d. Percent pulp

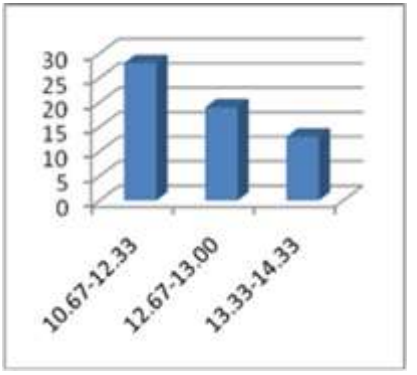
Figure 1a-d. Number of Hararghe coffee collections with mean values lower, near to average and higher than the overall mean performance of collections for berry & bean characteristics.

The overall mean of the collections for bulk density and volume green coffee were 0.61 g/cm^3 and 165.76 g/cm^3, respectively, while weight of roast coffee, weight loss due to roast and volume of roast coffee were 81.46g, 18.37g and 191.57, respectively. Hararghe coffee collections had mean values of 17.23% for roast volume change. The Hararghe coffee collections also exhibited wide range of differences for all roast bean characteristics. However, only 50%, 48.33%, 58.33% and 53.33% collections had significantly higher mean values than overall mean of genotypes for bulk density, volume green coffee, weight of roast coffee, and volume of roast coffee, respectively. Only six

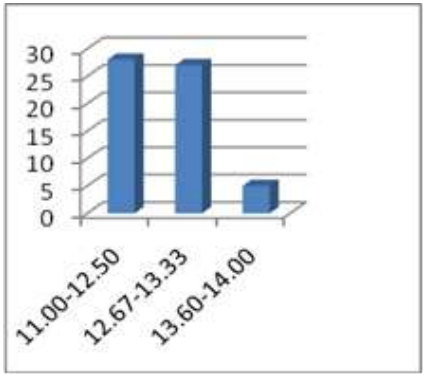
collections had highest roast volume change above the overall mean of collections (Figure 3). Most of the collections had either lower than or statistically equal to the mean performances of collections for all the roast bean characteristics.



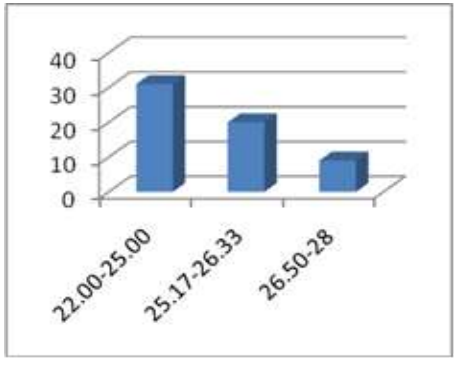
a. Bean size



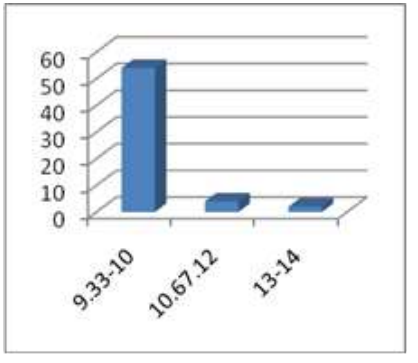
b. Shape and make



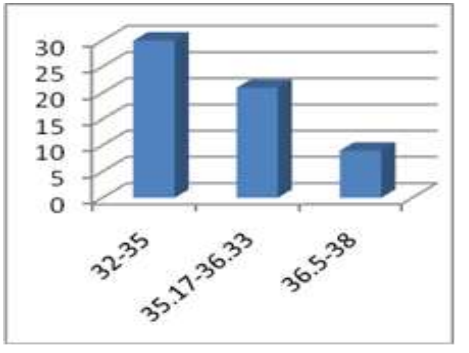
c. Color



d. Defect



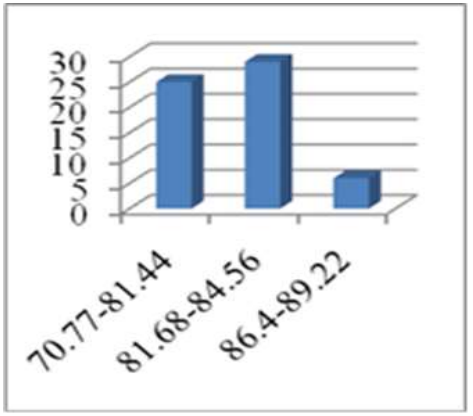
e. Odor



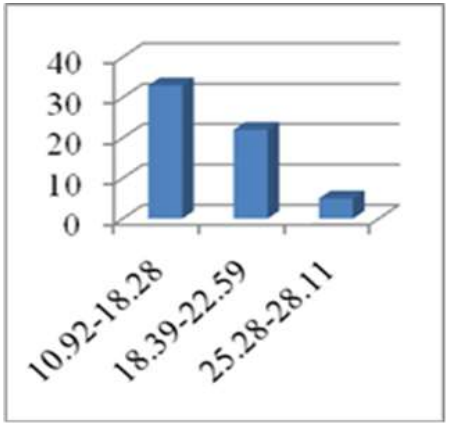
f. Total raw quality

Figure 2a-f. Number of Hararghe coffee collections with mean values lower, near to average and higher than the overall mean performance of collections for beans raw quality & its components.

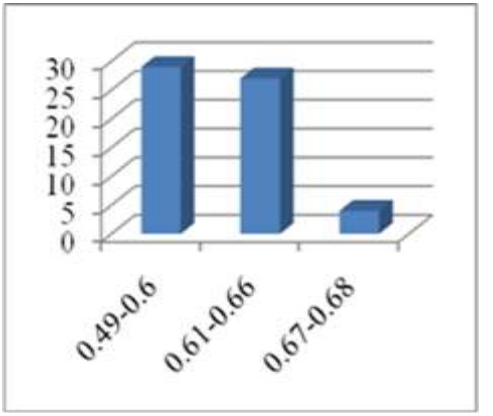
The Hararghe coffee collections were evaluated for overall coffee quality in the range between 71 and 86% with mean value of 79.68% and standard deviation of 2.9. The variations for flavor and cup quality ranged from 12.33 to 16.67 and 38 to 49%, respectively. Hararghe coffee collections had mean values of 14.67% and 44.67% with standard deviation of 0.84 and 2.26 for flavor and cup quality, respectively. The overall mean of flavor for 60 Hararghe coffee collections was 14.67% with the standard deviation of 0.84%. The collections also showed variations for body and acidity ranging from13 to 16.33 and 12.67 to 16.67%, respectively. More collections had mean values lower than the overall mean values of collections for body, acidity, cup and overall coffee quality but not for flavor (Figure 4). However, considerable number of collections (21 out of 60) had >81% overall coffee quality value and fall under grade two. None of the collections had overall coffee quality value that can be considered as grade one.



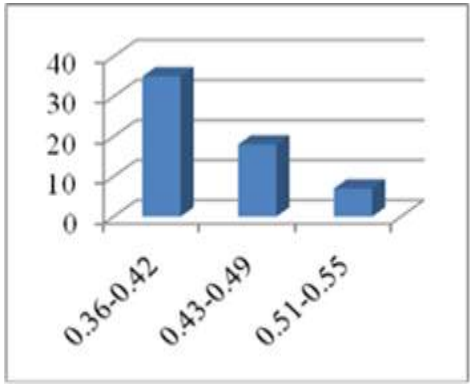
a. Weight of roast coffee



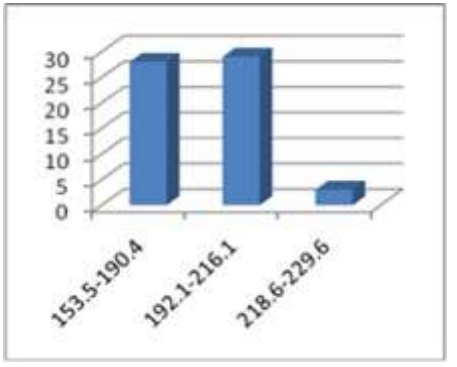
b. Roast weight loss



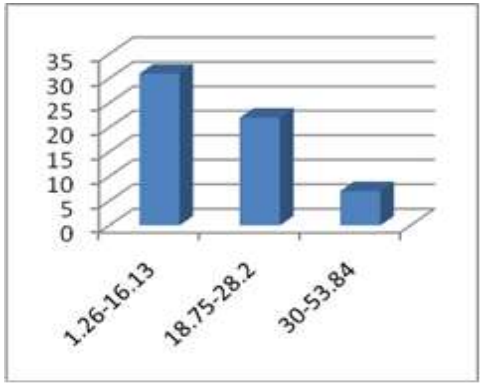
c. Bulk density of green coffee



d. Bulk density of roast coffee

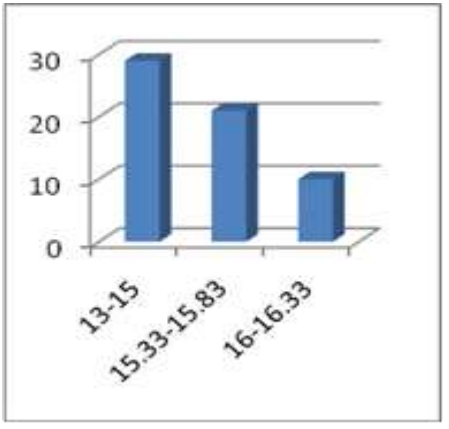


e. Volume of roast coffee

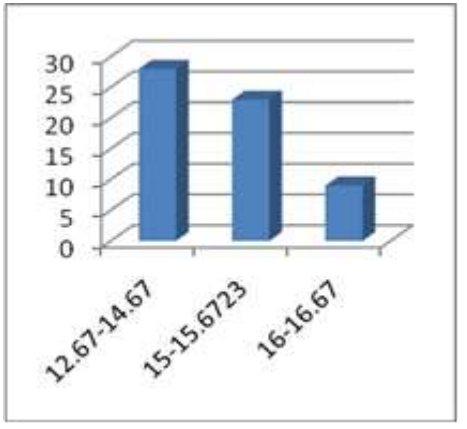


f. Roast volume change

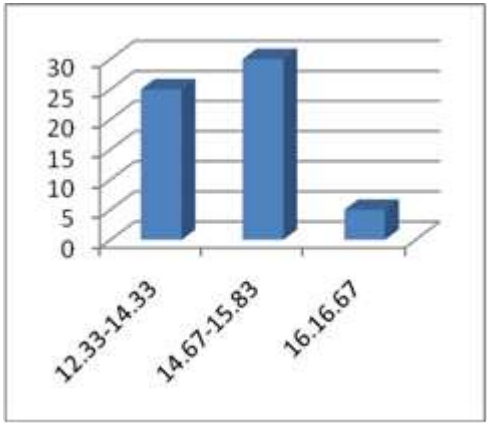
Figure 3a-f. Number of Hararghe coffee collections with mean values lower, near to average and higher than the overall mean performance of collections for characteristics of bulk density of green coffee and volume change after roasting.



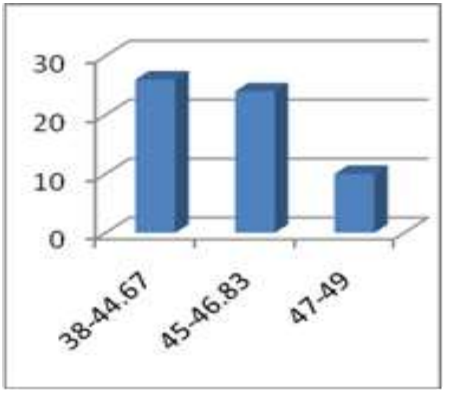
a. Body



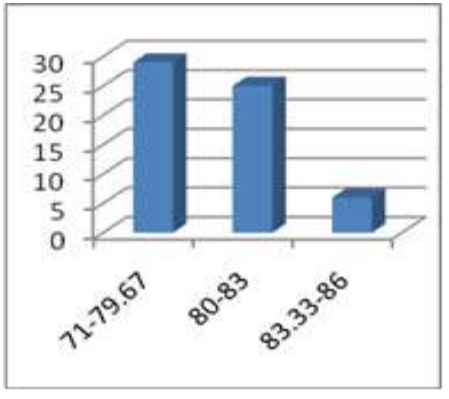
b. Acidity



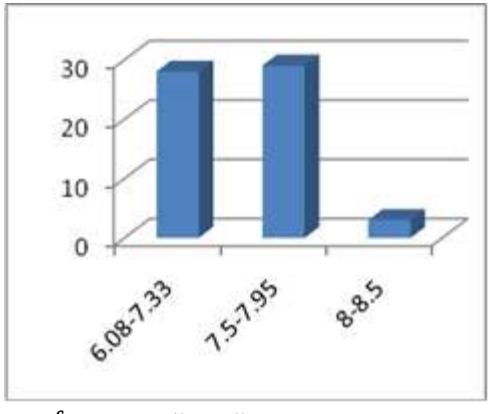
c. Flavor



d. Cup quality



e. Total quality



f. Overall quality

Figure 4a-f. Number of Hararghe coffee collections with mean values lower, near to average and higher than the overall mean performance of collections for cup and overall quality and components of these characteristics.

Estimates of Variability Components

Estimates of variability components namely, phenotypic variance, genotypic variance, phenotypic (PCV) and genotypic (GCV) coefficient of variations; heritability in broad sense and genetic advance were computed and results are presented in Table 5. The genotypic coefficient of variation (GCV) ranged from 2.46% for overall coffee quality to 41.35% for roast volume change, while phenotypic coefficient of variation (PCV) ranged from 5.25% for over screen to 41.47% for roast volume change. Generally, the values calculated for genotypic and phenotypic variances were closer each other for most of the traits.

Heritability in the broad sense (H^2) for the studied coffee quality traits ranged from 30.89% (acidity) to 99.79% (volume of green coffee). Selection for traits with higher heritability values will be helpful for the success of breeding operations. Genetic advance that could be expected from selecting the top 5% of the collections was also computed and presented (Table 5). The progress that could be expected varied from 5.07 % for overall coffee quality to 85.18% for roast volume change as percent of mean. Selection could made an increase of 38.14% for weight of lost due to roasting, 48.18% for percent pulp, 42.74% for outturn ratio, 26.03% for single berry weight and 22.23% for bulk density of roast coffee .

Table 5. Estimates of variability components for 22 organoleptic and physical raw quality traits of 60 Hararghe coffee accessions during 2014.

Traits	Mean	σ^2g	σ^2p	GCV (%)	PCV (%)	H^2 (%)	GAM (5%)
Moisture content	8.48	0.19	0.20	5.18	5.25	98.59	10.67
Over screen	92.28	24.36	27.61	5.35	5.69	93.92	11.02
Shape and make	12.47	0.40	1.40	5.09	9.48	53.72	10.50
Color	12.56	0.23	1.10	3.85	8.34	46.09	7.92
Defect	25.03	1.36	3.68	4.67	7.66	60.88	9.61
Odor	10.18	0.50	0.70	6.95	8.22	84.60	14.32
Total Raw quality	35.01	1.32	3.92	3.28	5.66	57.94	6.75
Acidity	14.91	0.18	1.93	2.88	9.31	30.89	5.92
Body	15.09	0.23	1.35	3.16	7.70	41.10	6.52
Flavor	14.67	0.22	1.67	3.18	8.82	35.99	6.54
Cup quality	44.67	1.57	12.16	2.81	7.81	35.94	5.78
Overall quality	79.68	3.85	18.77	2.46	5.44	45.30	5.07
Weight of roasted coffee	81.46	16.18	16.55	4.94	4.99	98.88	10.17
Weight of lost due to roast	18.37	11.56	12.03	18.52	18.88	98.05	38.14
Bulk density of green coffee	0.61	0.00	0.01	6.66	6.72	99.21	13.73
Bulk density of roast coffee	0.43	0.00	0.01	10.79	11.29	95.58	22.23
Bean weight	12.91	1.34	1.69	8.98	10.08	89.07	18.50
Volume of green coffee	165.76	136.86	137.44	7.06	7.07	99.79	14.54
Volume of roast coffee	191.57	250.41	412.13	8.26	10.60	77.95	17.02
Roast volume change	17.23	50.74	51.05	41.35	41.47	99.70	85.18
Single berry weight	14.16	3.20	3.24	12.63	12.72	99.32	26.03
Outturn ratio	18.22	14.28	15.91	20.75	21.90	94.75	42.74
Percent pulp	0.41	0.01	0.01	23.39	26.46	88.39	48.18

σ^2_g, σ^2_p and σ^2_e = genotypic and phenotypic variances, respectively. GCV (%) and PCV (%) = genotypic and phenotypic coefficient of variations, respectively. GA and GAM (5%) = genetic advance as ratio and percent mean at 5% selection intensity, respectively, and H^2_B = heritability in broad sense in percent.

Association among Coffee Beans Quality Traits

Phenotypic and genotypic correlation coefficients

The associations of 22 coffee beans quality traits were computed at phenotypic as well as at genotypic level. The results of phenotypic and genotypic correlations are presented in Table 6**.** The phenotypic correlation coefficient among physical quality and organoleptic quality traits in 60 Hararghe coffee collections ranged from r = -0.01 to 0.96. Significant and positive phenotypic association was observed among over screen, shape and make, color, acidity, body, flavor, bean weight, single berry weight and overall quality. Flavor had negative association with odor and percent pulp. Body had positive and significant association with over screen, shape and make, color, acidity, body, flavor, bean weight, single berry weight and overall quality at phenotypic level.

The genotypic correlation coefficients ranged from r= -0.01 to 0.99 for physical and organoleptic quality attributes of beans in 60 Hararghe coffee collections. Overall coffee quality had positive and significant genotypic correlations with over screen, shape and make, color, raw bean quality, body, flavor, cup quality, bean weight and single berry weight while roast weight loss had negative and significant genotypic associations with overall quality. Odor, outturn ratio and percent pulp were negatively and non-significantly associated with cup quality attributes.

Path coefficient analysis

The phenotypic path coefficient analysis results are presented in Table 7. Shape and make, color, raw total of coffee quality, acidity, body, flavor, total cup quality, roast weight loss, bulk density of green and roast coffee, bean weight, outturn ratio and percent of pulp had positive direct effect on total coffee quality at phenotypic levels. On the other hand, highly negative direct effect was recorded for defect count (-1.191). Bean size exerted positive indirect effects on overall coffee quality through shape and make, color, defect, odor, total raw quality, flavor, body, cup quality, weight of roast coffee, bulk density of green coffee, bulk density of roast coffee, bean weight, volume of green coffee, roast volume change, single berry weight, outturn ratio and percent pulp (Table 7).

Table 6. Phenotypic above diagonal and genotypic below diagonal correlation coefficient among coffee quality attributes.

Traits	MC	OVS	SM	CO	DE	OD	TRQ	BO	FL	Cup	TO
MC		0.25*	0.28**	0.27**	0.32**	-0.12ns	0.32**	0.15*	0.11ns	0.14ns	0.25**
OVS	0.28*		0.33**	0.21**	0.32**	0.00ns	0.32**	0.07ns	0.06ns	0.06ns	0.20*
SM	0.38**	0.48**		0.48**	0.87**	-0.03ns	0.86**	0.04ns	0.22**	0.20*	0.55**
CO	0.40**	0.38**	0.71**		0.85**	0.11ns	0.84**	0.10ns	0.09ns	0.08ns	0.45**
DE	0.42**	0.47**	0.94**	0.91**		0.04ns	0.99**	0.08ns	0.18*	0.17*	0.58**
OD	-0.14ns	0.00**	-0.02ns	0.05ns	0.01ns		0.10ns	0.13ns	0.09ns	0.08ns	0.11ns
TRQ	0.42**	0.48**	0.93**	0.90**	0.99**	0.06ns		0.09ns	0.18*	0.16*	0.58**
BO	0.22ns	0.02ns	0.03ns	0.19ns	0.11ns	0.18ns	0.11ns		0.72**	0.86**	0.75**
FL	0.17ns	0.02ns	0.15ns	0.29*	0.23ns	0.22ns	0.23ns	0.68**		0.94**	0.86**
Cup	0.21ns	0.01ns	0.16ns	0.29*	0.23ns	0.18ns	0.23ns	0.83**	0.95**		0.90**
TO	0.37**	0.25*	0.59**	0.67**	0.67**	0.17ns	0.67**	0.69**	0.83**	0.87**	
WRC	0.14ns	0.28*	0.41**	0.37**	0.43**	0.09ns	0.45**	0.27*	0.28*	0.31*	0.46**
WLDR	-0.18ns	-0.25ns	-0.38**	-0.37**	-0.41**	-0.09ns	-0.43**	-0.26*	-0.25ns	-0.28*	-0.43**
BDGC	0.23ns	0.79**	0.30*	0.28*	0.31*	0.16ns	0.35*	0.01ns	-0.01ns	-0.03ns	0.15ns
BDRC	0.08ns	0.30*	0.24ns	0.26*	0.27*	-0.06ns	0.25*	-0.19ns	0.08ns	0.01ns	0.14ns
BW	0.60**	0.54**	0.50**	0.40**	0.50**	0.08ns	0.51**	0.11ns	0.12ns	0.12ns	0.35*
VGC	-0.23ns	-0.80**	-0.31*	-0.27*	-0.32*	-0.15ns	-0.35*	0.00ns	0.03ns	0.05ns	-0.14ns
VRC	0.06ns	-0.13ns	0.04ns	-0.06ns	-0.01ns	0.03ns	0.03ns	0.24ns	-0.03ns	0.06ns	0.06ns
RVC	0.18ns	0.36*	0.16ns	0.11ns	0.15ns	0.23ns	0.21ns	0.29*	0.05ns	0.10ns	0.18ns
SBW	0.35*	0.32*	0.39**	0.19ns	0.33*	0.03ns	0.33*	0.14ns	0.24ns	0.22ns	0.34*
OTR	0.03ns	-0.11ns	-0.14ns	-0.16ns	-0.16ns	-0.08ns	-0.18ns	-0.11ns	-0.15ns	-0.13ns	-0.18ns
PP	-0.07ns	-0.18ns	-0.11ns	-0.15ns	-0.14ns	0.07ns	-0.14ns	0.22ns	0.14ns	0.20ns	0.08ns

**, ** and ns, significant at 5%, 1% probability level and non-significant, respectively. MC=moisture content, OVS= overall screen, SM= shape & make, CO= color, DE= defect, OD= odor, TRQ= raw total, AC= acidity, BO=body, FL= flavor, CUP=cup total, TO= total quality WRC= weight of roast coffee, WLDR= weight of roast due to roast, BDGC= bulk density of green coffee, BW= bean weight, VGC= volume of green coffee, VRC= volume of roast coffee, RVC= roast volume change, SBWI= single berry weight, OTR= outturn ratio, PP= percent pulp and OAQ= overall quality.*

Table 6. Continued

Traits	WRC	WLDR	BDGC	BDRC	BW	VGC	VRC	RVC	SBW	OTR	PP
MC	0.14ns	-0.18ns	0.22**	0.09ns	0.54**	-0.23**	0.05ns	0.18*	0.32**	0.00ns	-0.07ns
OVS	0.26**	-0.24**	0.74**	0.29**	0.47**	-0.75**	-0.09ns	0.34**	0.31**	-0.11ns	-0.16ns
SM	0.28**	-0.26**	0.22**	0.20**	0.33**	-0.23**	-0.05ns	0.11ns	0.24**	-0.11ns	-0.08ns
CO	0.25**	-0.22**	0.18*	0.21*	0.24**	-0.18*	-0.03ns	0.07ns	0.12ns	-0.10ns	-0.10ns
DE	0.31**	-0.28**	0.24**	0.24**	0.33**	-0.24**	-0.05ns	0.11ns	0.21**	-0.12ns	-0.10ns
OD	0.06ns	-0.07ns	0.15*	-0.06ns	0.06ns	-0.14ns	0.02ns	0.20*	0.00ns	-0.06ns	0.06ns
TRQ	0.31**	-0.29**	0.26**	0.22**	0.33**	-0.26**	-0.03ns	0.15*	0.21**	-0.14ns	-0.10ns
BO	0.24**	-0.23**	0.00ns	-0.09ns	0.09ns	0.05ns	0.18*	0.19*	0.22**	-0.10ns	0.07ns
FL	0.22**	-0.19*	-0.02ns	0.10ns	0.07ns	0.05ns	-0.01ns	0.03ns	0.22**	-0.11ns	0.02ns
Cup	0.26**	-0.22**	-0.04ns	0.05ns	0.08ns	0.07ns	0.06ns	0.07ns	0.25**	-0.10ns	0.06ns
TO	0.35**	-0.32**	0.09ns	0.14ns	0.22**	-0.06ns	0.03ns	0.12ns	0.30**	-0.15*	0.00ns
WRC		-0.96**	0.17*	0.34**	0.23**	-0.14ns	0.23**	0.24**	0.27**	-0.20*	-0.13ns
WLDR	-0.98**		-0.18*	-0.30**	-0.25**	0.15*	-0.24**	-0.28**	-0.24**	0.19*	0.11ns
BDGC	0.20ns	-0.20ns		0.37**	0.43**	-0.99**	-0.22**	0.42**	0.23**	0.00ns	-0.14ns
BW	0.35*	-0.31*	0.38**		0.19**	-0.35**	-0.60**	-0.53**	0.10ns	0.05ns	-0.29**
VGC	0.26*	-0.28*	0.47**	0.21ns		-0.45**	-0.05ns	0.23**	0.32**	-0.25**	-0.01ns
VRC	-0.19ns	0.19ns	-1.00**	-0.37**	-0.48**		0.22**	-0.42**	-0.21**	-0.01ns	0.13ns
RVC	0.23ns	-0.25*	-0.24ns	-0.73**	-0.05ns	0.24ns		0.59**	0.11ns	-0.16*	0.18*
SBW	0.24ns	-0.28*	0.43**	-0.54**	0.24ns	-0.43**	0.69**		0.25**	-0.10ns	0.12ns
OTR	-0.20ns	0.19ns	0.00ns	0.07ns	-0.28*	0.00ns	-0.18ns	-0.10ns	0.08ns		-0.24**
PP	-0.12ns	0.11ns	-0.15ns	-0.32*	-0.03ns	0.15ns	0.23ns	0.13ns	0.06ns	-0.24ns	

**, ** and ns, significant at 5%, 1% probability level and non-significant, respectively. MC=moisture content, OVS= overall screen, SM= shape & make, CO= color, DE= defect, OD= odor, TRQ= raw total, AC= acidity, BO=body, FL= flavor, CUP=cup total, TO= total quality WRC= weight of roast coffee, WLDR= weight of roast due to roast, BDGC= bulk density of green coffee, BW= bean weight, VGC= volume of green coffee, VRC= volume of roast coffee, RVC= roast volume change, SBWI= single berry weight, OTR= outturn ratio, PP= percent pulp and OAQ= overall quality.*

Results for genotypic path coefficients are presented in Table 8 and showed shape and make, color, cup quality, total quality, weight of roast coffee, weight lost due to roast, volume of roast coffee, out return ratio and percent pulp exerts positive genotypic direct effects on overall coffee quality. The genotypic direct effects of these traits range between 0.03 for percent pulp and 3.13 for total quality.

Traits with negative direct effects were overall screen (-0.06), defect count (-0.92), odor (-0.01), raw total (-1.12), acidity (-0.84), body (-0.72), flavor (-0.49), bulk density of green coffee (-0.01), bean weight (-0.01), volume of green coffee (-0.82), roast volume change (-0.12) and single berry weight (-0.04). Acidity had maximum negative direct effect (P = -0.84) followed by body (-0.72). Hence, the strong association it had with overall quality was largely due to the indirect effect. The negative genotypic indirect effect contributed traits to overall coffee quality were over screen, defect, odor, total raw quality, acidity, body, flavor, bulk density of green coffee, bulk density of roast coffee, bean weight, volume of green coffee, roast volume change and single berry weight.

Table 7. Estimates of direct (bold and diagonal) and indirect effects (off diagonal) at phenotypic level of quality attributes on overall quality in 60 Coffee collections tested at Mechara (2014/15).

Traits	MC	OVS	SM	CO	DE	OD	TRQ	BO	FL	CUP
MC	**0.03**	-0.01	0.34	0.29	-0.62	0.00	0.03	0.01	0.05	0.08
OVS	0.01	**-0.04**	0.40	0.23	-0.61	0.00	0.03	0.01	0.03	0.04
SM	0.01	-0.01	**1.21**	0.51	-1.66	0.00	0.07	0.00	0.09	0.11
CO	0.01	-0.01	0.58	**1.07**	-1.61	0.00	0.07	0.01	0.04	0.05
DE	0.01	-0.01	1.05	0.90	**-1.91**	0.00	0.08	0.01	0.07	0.09
OD	0.00	0.00	-0.04	0.11	-0.07	**-0.01**	0.01	0.01	0.04	0.04
TRQ	0.01	-0.01	1.04	0.90	-1.88	0.00	**0.08**	0.01	0.07	0.09
BO	0.00	0.00	0.05	0.11	-0.16	0.00	0.01	**0.10**	0.30	0.49
FL	0.00	0.00	0.26	0.09	-0.35	0.00	0.01	0.07	**0.41**	0.53
CUP	0.00	0.00	0.24	0.09	-0.32	0.00	0.01	0.08	0.39	**0.56**
TO	0.01	-0.01	0.66	0.48	-1.11	0.00	0.05	0.07	0.35	0.51
WRC	0.00	-0.01	0.34	0.26	-0.58	0.00	0.03	0.02	0.09	0.14
WLDR	-0.01	0.01	-0.32	-0.24	0.54	0.00	-0.02	-0.02	-0.08	-0.13
BDGC	0.01	-0.03	0.27	0.20	-0.45	0.00	0.02	0.00	-0.01	-0.02
BDRC	0.00	-0.01	0.25	0.22	-0.46	0.00	0.02	-0.01	0.04	0.03
BW	0.02	-0.02	0.39	0.26	-0.63	0.00	0.03	0.01	0.03	0.05
VGC	-0.01	0.03	-0.28	-0.19	0.45	0.00	-0.02	0.00	0.02	0.04
VRC	0.00	0.00	-0.07	-0.04	0.10	0.00	0.00	0.02	0.00	0.03
RVC	0.01	-0.01	0.14	0.08	-0.21	0.00	0.01	0.02	0.01	0.04
SBW	0.01	-0.01	0.29	0.13	-0.40	0.00	0.02	0.02	0.09	0.14
OTR	0.00	0.00	-0.13	-0.11	0.24	0.00	-0.01	-0.01	-0.04	-0.06
PP	0.00	0.01	-0.09	-0.11	0.20	0.00	-0.01	0.01	0.01	0.03

MC=moisture content, OVS= over screen, SM= shape and make, CO= color, DE= defect count, OD= odor, TRQ= raw total, AC= acidity, BO= body, FL= flavor, CUP= cup quality, TO= total quality, WRC= weight of roast coffee, WLDR= weight of lost due to roast, BDGC= bulk density of green coffee, BW= bean weight, VGC= volume of green coffee, VRC= volume of roast coffee, RVC=roast volume change SBW= single berry weight, OTR= outturn ratio and PP= percent pulp.

Table 7. Continued

Traits	WRC	WLDR	BDGC	BDRC	BW	VGC	VRC	RVC	SBW	OTR	PP	r_p
MC	0.00	-0.01	0.01	0.01	0.02	-0.02	0.00	0.00	0.00	0.00	0.00	0.16*
OVS	0.00	-0.01	0.04	0.02	0.01	-0.05	0.00	0.01	0.00	0.00	0.00	0.05ns
SM	0.00	-0.01	0.01	0.01	0.01	-0.02	0.00	0.00	0.00	0.00	0.00	0.23**
CO	0.00	-0.01	0.01	0.01	0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.10ns
DE	0.00	-0.01	0.01	0.01	0.01	-0.02	0.00	0.00	0.00	0.00	0.00	0.19*
OD	0.00	0.00	0.01	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.06ns
TRQ	0.00	-0.01	0.01	0.01	0.01	-0.02	0.00	0.00	0.00	0.00	0.00	0.19*
BO	0.00	-0.01	0.00	-0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.79**
FL	0.00	-0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.93**
CUP	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95**
WRC	**0.01**	-0.03	0.01	0.02	0.01	-0.01	0.01	0.01	0.00	-0.01	0.00	0.24**
WLDR	-0.01	**0.03**	-0.01	-0.01	-0.02	0.00	-0.01	0.00	-0.01	0.00	0.00	-0.21**
BDGC	0.00	-0.01	**0.05**	0.02	0.01	-0.07	-0.01	0.01	0.00	0.00	0.00	-0.03ns
BDRC	0.00	-0.01	0.02	**0.06**	0.01	-0.02	-0.02	-0.01	0.00	0.00	0.00	0.08ns
BW	0.00	-0.01	0.02	0.01	**0.03**	-0.03	0.00	0.01	0.00	-0.01	0.00	0.10ns
VGC	0.00	0.01	-0.05	-0.02	0.03	**0.07**	0.01	-0.01	0.00	0.00	0.00	0.06ns
VRC	0.00	-0.01	-0.01	-0.04	0.00	0.02	**0.03**	0.01	0.00	0.00	0.00	0.03ns
RVC	0.00	-0.01	0.02	-0.03	0.01	-0.03	0.02	**0.02**	0.00	0.00	0.00	0.04ns
SBW	0.00	-0.01	0.01	0.01	0.01	-0.01	0.00	0.01	**-0.02**	0.00	0.00	0.24**
OTR	0.00	0.01	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	**0.03**	0.00	-0.08ns
PP	0.00	0.00	-0.01	-0.02	0.00	0.01	0.00	0.00	0.00	-0.01	**0.01**	0.04ns

Residual = 0.388

r_p=Phenotypic correlation coefficients, MC=moisture content, OVS= over screen, SM= shape and make, CO= color, DE= defect count, OD= odor, TRQ= raw total, AC= acidity, BO= body, FL= flavor, CUP= cup quality, TO= total quality, WRC= weight of roast coffee, WLDR= weight of lost due to roast, BDGC= bulk density of green coffee, BW= bean weight, VGC= volume of green coffeet, VRC= volume of roast coffee, RVC=roast volume change SBW= single berry weight, OTR= outturn ratio and PP= percent pulp

Table 8. Estimates of direct (bold and diagonal) and indirect effects (off diagonal) at genotypic level of quality attributes on overall quality in 60 coffee collections tested at Mechara (2014/15).

Traits	MC	OVS	SM	CO	DE	OD	TRQ	BO	FL	CUP
MC	**0.07**	-0.02	0.11	0.13	-0.39	0.00	-0.47	-0.16	-0.08	0.09
OVS	0.02	**-0.06**	0.14	0.12	-0.43	0.00	-0.54	-0.02	-0.01	0.01
SM	0.03	-0.03	**0.29**	0.22	-0.86	0.00	-1.05	-0.02	-0.07	0.07
CO	0.03	-0.02	0.21	**0.31**	-0.84	0.00	-1.01	-0.14	-0.14	0.13
DE	0.03	-0.03	0.27	0.29	**-0.92**	0.00	-1.11	-0.08	-0.11	0.10
OD	-0.01	0.00	-0.01	0.02	-0.01	**-0.01**	-0.06	-0.13	-0.11	0.08
TRQ	0.03	-0.03	0.27	0.28	-0.91	0.00	**-1.12**	-0.08	-0.11	0.10
BO	0.02	0.00	0.01	0.06	-0.10	0.00	-0.13	**-0.72**	-0.33	0.37
FL	0.01	0.00	0.04	0.09	-0.21	0.00	-0.25	-0.49	**-0.49**	0.42
CUP	0.01	0.00	0.05	0.09	-0.22	0.00	-0.26	-0.60	-0.47	**0.44**
WRC	0.01	-0.02	0.12	0.12	-0.39	0.00	-0.50	-0.19	-0.14	0.14
WLDR	-0.01	0.01	-0.11	-0.12	0.37	0.00	0.48	0.19	0.12	-0.12
BDGC	0.02	-0.05	0.09	0.09	-0.29	0.00	-0.39	-0.01	0.00	-0.01
BDRC	0.01	-0.02	0.07	0.08	-0.25	0.00	-0.28	0.14	-0.04	0.00
BW	0.04	-0.03	0.15	0.13	-0.45	0.00	-0.58	-0.08	-0.06	0.05
VGC	-0.02	0.05	-0.09	-0.08	0.29	0.00	0.39	0.00	-0.01	0.02
VRC	0.00	0.01	0.01	-0.02	0.01	0.00	-0.03	-0.17	0.01	0.03
RVC	0.01	-0.02	0.05	0.03	-0.14	0.00	-0.23	-0.21	-0.02	0.04
SBW	0.02	-0.02	0.11	0.06	-0.30	0.00	-0.38	-0.10	-0.12	0.10
OTR	0.00	0.01	-0.04	-0.05	0.15	0.00	0.20	0.08	0.07	-0.06
PP	-0.01	0.01	-0.03	-0.05	0.13	0.00	0.16	-0.16	-0.07	0.09

MC=moisture content, OVS= over screen, SM= shape and make, CO= color, DE= defect count, OD= odor, TRQ= raw total, AC= acidity, BO= body, FL= flavor, CUP= cup quality, TO= total quality, WRC= weight of roast coffee, WLDR= weight of lost due to roast, BDGC= bulk density of green coffee, BW= bean weight, VGC= volume of green coffee, VRC= volume of roast coffee, RVC=roast volume change SBW= single berry weight, OTR= outturn ratio and PP= percent pulp.

Table 8. Continued.

Traits	WRC	WLDR	BDGC	BDRC	BW	VGC	VRC	RVC	SBW	OTR	PP	r_g
MC	0.01	-0.01	-0.17	0.00	0.00	0.19	0.00	-0.02	-0.01	0.00	0.00	0.26*
OVS	0.02	-0.02	-0.58	0.00	0.00	0.66	-0.01	-0.04	-0.01	-0.01	-0.01	0.02ns
SM	0.03	-0.02	-0.22	0.00	0.00	0.26	0.00	-0.02	-0.02	-0.01	0.00	0.20ns
CO	0.02	-0.02	-0.21	0.00	0.00	0.22	0.00	-0.01	-0.01	-0.01	-0.01	0.34*
DE	0.03	-0.03	-0.23	0.00	0.00	0.26	0.00	-0.02	-0.01	-0.01	0.00	0.29*
OD	0.01	-0.01	-0.12	0.00	0.00	0.12	0.00	-0.03	0.00	0.00	0.00	0.17ns
TRQ	0.03	-0.03	-0.26	0.00	0.00	0.29	0.00	-0.02	-0.01	-0.01	0.00	0.28*
BO	0.02	-0.02	-0.01	0.00	0.00	0.00	0.02	-0.03	-0.01	-0.01	0.01	0.77**
FL	0.02	-0.02	0.01	0.00	0.00	-0.02	0.00	-0.01	-0.01	-0.01	0.00	0.94**
CUP	0.02	-0.02	0.02	0.00	0.00	-0.04	0.00	-0.01	-0.01	-0.01	0.01	0.97**
WRC	**0.06**	-0.06	-0.15	0.00	0.00	0.15	0.01	-0.03	-0.01	-0.01	0.00	0.30*
WLDR	-0.06	**0.06**	0.00	0.00	0.23	0.01	0.03	0.01	-0.01	0.01	0.00	-0.27*
BDGC	0.01	-0.01	**-0.74**	0.00	0.00	0.82	-0.02	-0.05	-0.01	0.00	0.00	-0.02ns
BDRC	0.02	-0.02	-0.28	**-0.01**	0.00	0.30	-0.05	0.06	0.00	0.00	-0.01	0.06ns
BW	0.02	-0.02	-0.35	0.00	**-0.01**	0.40	0.00	-0.03	-0.01	-0.01	0.00	0.15ns
VGC	-0.01	0.01	0.74	0.00	0.00	**-0.82**	0.02	0.05	0.01	0.00	0.01	0.04ns
VRC	0.01	-0.02	0.18	0.00	0.00	-0.20	**0.07**	-0.08	0.00	-0.01	0.01	0.02ns
RVC	0.02	-0.02	-0.32	0.00	0.00	0.36	0.05	**-0.12**	-0.01	-0.01	0.00	0.06ns
SBW	0.01	-0.01	-0.21	0.00	0.00	0.24	0.00	-0.03	**-0.04**	0.00	0.00	0.23ns
OTR	-0.01	0.01	0.00	0.00	0.00	0.00	-0.01	0.01	0.00	**0.05**	-0.01	-0.09ns
PP	-0.01	0.01	0.11	0.00	0.00	-0.13	0.02	-0.02	0.00	-0.01	**0.03**	0.17ns

Residual = 0.270 r_g=Genotypic correlation coefficients, MC=moisture content, OVS= over screen, SM= shape and make, CO= color, DE= defect count, OD= odor, TRQ= raw total, AC= acidity, BO= body, FL= flavor, CUP= cup quality, TO= total quality, WRC= weight of roast coffee, WLDR= weight of lost due to roast, BDGC= bulk density of green coffee, BW= bean weight, VGC= volume of green coffee, VRC= volume of roast coffee, RVC=roast volume change SBW= single berry weight, OTR= outturn ratio and PP= percent pulp.

Genetic divergence analysis

Significant differences among cultivars for almost all coffee quality traits except acidity justify further calculation of Euclidean distance (ED) using these traits to estimate the genetic distance among collections. Estimates of Euclidean distance varied from 2.5 to 13.8 with a mean and a standard deviation of 6.64 and 1.9, respectively. The highest distance was computed for H-203/02 and H-387/02 (13.8) followed by H-387/02 andH-623/02 (13.6). The lowest distance was calculated for H-10/02 and H-761/02 (2.5), followed by H-10/02 and H-231/02 (2.6) and H-10/02 and H-625/02 (2.72). The mean Euclidean distance result showed that the most distant collection to others was H-203/02 and H-623/02 (9.1) followed by H-247/02 (9.0). The closest collections to others was H-10/02 (5.2) followed by H-231/02 (5.25) and H-761/02 (5.3) (Table 4). The four released Hararghe coffee varieties had a mean distance of 7.7 (Mocha), 7.3 (Hrusa), 8.2 (Bultum) and 6.14 (Mechara-1) (Table 9).

The dendrograms constructed by Unweighted Pair-group Method with Arithmetic means (UPGMA) from distance matrix from coffee bean quality traits are presented in Figure 5. Clustering resulted in the formation of eight groups, of which Cluster II consisted of 29 collections (48.33%) which was further subdivided in two distinct subgroups. The subgroup I and II consisted of 16 and 13 out of 60 collections, respectively. This was the biggest cluster that consisted both East and West Hararghe coffee collections as well as Mechara-1 released variety. The other three clusters namely, Cluster VII, I and III also consisted 9, 7 and 5 out of 60 collections, respectively. The rest of the cluster consisted of two and three collections. The four released varieties were distributed in II, IV and VII clusters. Most of the clusters consisted of both East and West Hararghe coffee collections as well as collections obtained at different altitudes. However, Cluster I, IV, V, VI and VIII only consisted the East Hararghe coffee collections while Cluster II, III and VII consisted only the West Hararghe coffee collections.

Table 94. Euclidean distance of 60 Hararghe coffee collections measured from 22 coffee quality traits and mean Euclidean distance obtained by averaging each collection distance to other 59 collections.

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Mean
1	5.50	7.07	6.9	7.9	6.31	5.7	8.9	7.5	5.50	7.53	6.58	4.2	8.11	6.9	5.5	4.79	8.5	5.99	7.15	7.24
2		5.22	3.6	3.7	3.96	4.8	7.9	5.4	3.37	4.12	3.98	4.6	5.51	4.5	5.6	4.43	5.4	4.29	2.72	5.20
3			6.1	6.5	6.50	4.8	7.9	6.2	5.49	6.27	3.70	5.8	4.80	7.1	6.9	5.70	6.3	3.87	6.20	6.15
4				5.4	5.89	4.5	9.5	5.7	6.06	5.80	5.16	5.9	6.26	4.1	6.9	6.70	7.0	5.31	5.11	6.54
5					3.94	7.3	9.3	5.8	5.60	3.88	6.34	6.4	5.91	5.6	7.2	6.07	6.0	5.27	3.25	6.20
6						6.4	8.2	7.4	5.15	4.66	6.67	4.3	5.22	5.3	7.0	3.50	7.2	4.12	4.78	5.93
7							8.0	7.3	5.33	6.93	3.85	5.0	5.86	5.3	6.1	5.17	8.1	3.95	6.89	6.71
8								11.1	7.49	9.11	7.28	8.4	7.25	10.7	7.6	7.77	10.6	7.40	8.18	8.13
9									6.94	5.98	6.50	8.1	8.28	7.0	6.8	7.85	5.1	6.70	6.19	7.65
10										4.19	3.81	5.0	5.96	6.0	5.6	4.20	7.1	4.55	4.24	5.47
11											6.10	6.2	5.61	5.1	6.9	5.64	7.0	5.08	3.99	6.05
12												6.0	5.49	6.5	6.0	5.84	7.0	4.63	5.22	5.79
13													5.63	5.1	6.8	3.00	7.8	4.38	5.79	6.20
14														6.0	7.7	5.78	8.7	4.72	5.79	6.23
15															7.6	5.80	8.2	5.80	5.76	6.90
16																6.25	7.8	5.57	6.41	7.00
17																	7.2	3.72	5.86	5.90
18																		6.88	5.73	7.80
19																			5.53	5.39

Table 9. Continued.

	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Mean
1	8.04	6.48	6.9	8.87	8.1	7.2	8.8	6.19	5.88	8.0	4.4	8.4	8.31	11.9	6.6	6.9	11.4	10.0	7.81	5.7	7.24
2	5.90	3.30	5.4	6.35	7.0	7.0	7.0	3.06	2.60	6.5	4.8	6.4	4.82	9.3	4.7	3.1	9.5	7.1	3.91	3.0	5.20
3	6.62	5.02	6.7	8.74	9.4	6.4	9.9	5.42	4.56	4.6	6.4	7.0	5.61	9.3	5.2	6.4	7.0	7.1	4.45	5.5	6.15
4	8.42	5.66	4.3	8.67	8.4	7.9	9.6	4.30	3.95	7.0	6.3	7.5	6.80	11.5	4.2	3.7	10.9	9.4	5.52	5.0	6.54
5	6.58	4.68	7.1	6.22	6.9	8.2	7.4	5.26	4.19	8.0	6.8	5.9	5.03	8.3	6.2	4.0	10.2	6.6	4.15	4.4	6.20
6	6.06	4.41	6.3	6.39	6.4	8.1	7.6	5.37	4.28	7.0	5.2	5.4	6.10	9.0	6.2	4.8	10.0	7.1	5.34	3.9	5.93
7	7.85	5.47	4.4	8.44	9.3	7.1	9.7	5.08	4.53	5.5	4.8	7.2	6.80	11.6	4.8	5.0	9.2	9.1	6.06	5.4	6.71
8	5.11	7.47	9.4	7.60	10.6	7.5	8.7	8.39	7.75	5.5	9.0	10.2	8.38	8.6	9.9	9.1	6.2	8.7	6.59	8.6	8.13
9	9.08	5.99	6.9	9.47	10.0	7.3	10.4	6.79	6.21	9.3	8.0	8.6	7.32	11.3	4.7	5.6	11.2	8.9	6.30	6.8	7.65
10	4.83	3.14	6.9	5.00	7.6	7.2	5.6	4.46	3.97	6.6	4.5	6.1	4.50	8.4	6.6	4.8	8.5	5.9	4.71	4.3	5.47
11	6.22	3.62	7.2	5.57	7.2	8.0	6.7	5.29	4.53	7.9	5.8	5.0	4.80	7.7	6.6	4.2	9.6	5.5	4.77	4.9	6.05
12	6.09	4.55	6.4	7.12	9.0	6.3	8.1	4.28	3.81	5.0	6.0	7.1	4.60	9.3	5.8	5.1	7.3	6.9	4.07	5.3	5.79
13	7.14	5.51	6.6	8.24	6.8	7.9	8.4	4.44	4.16	6.4	2.9	6.3	6.74	10.6	6.5	6.1	10.5	8.6	6.48	3.4	6.20
14	6.24	5.77	7.8	7.68	8.4	6.6	8.7	4.79	4.08	3.9	6.7	4.9	4.90	7.6	7.6	6.2	7.4	6.1	4.64	5.3	6.23
15	9.18	6.21	6.3	8.48	8.0	8.9	9.0	4.04	4.06	8.2	4.7	5.3	6.40	11.3	6.1	3.8	12.1	8.8	6.99	4.3	6.90
16	6.45	5.30	6.8	7.15	9.3	4.5	8.5	6.74	6.29	7.6	6.5	8.8	7.30	10.8	7.1	6.3	9.7	8.9	6.10	6.0	7.00
17	6.12	4.10	6.4	6.82	7.4	7.6	7.8	5.34	4.73	6.6	3.1	6.1	6.31	9.9	6.2	5.5	9.4	7.5	6.03	3.7	5.90
18	8.24	5.45	7.6	9.61	10.0	8.8	10.7	7.00	6.89	9.3	8.2	9.9	7.68	11.5	5.5	6.7	10.8	9.3	6.15	5.8	7.80
19	5.69	3.52	4.9	6.72	7.9	6.7	8.6	5.52	4.15	5.3	4.8	5.8	5.72	9.5	4.9	4.8	8.0	7.1	4.23	4.4	5.39
20	5.60	4.08	7.6	5.98	6.9	7.4	6.1	3.68	3.54	7.4	6.3	6.7	4.05	7.9	6.8	4.4	9.6	6.1	3.38	3.8	5.80
21		4.64	8.7	5.09	8.6	7.3	6.6	7.16	6.35	6.1	7.8	8.2	6.14	6.7	8.7	7.6	6.3	5.9	4.65	6.4	6.53
22			5.8	5.25	7.6	6.9	7.3	5.36	4.67	6.6	5.3	6.6	5.14	8.6	5.4	4.3	8.0	6.1	3.75	4.2	5.36
23				9.11	9.9	8.5	11.2	7.19	6.30	7.4	6.8	9.0	9.07	13.1	3.4	5.4	10.9	10.9	7.06	6.3	7.30
24					8.6	8.8	4.4	7.73	6.82	8.7	7.5	7.2	5.88	7.0	9.6	6.2	8.9	5.8	5.86	7.1	7.19
25						10.6	8.4	7.58	7.47	9.8	7.3	7.6	8.30	10.2	9.4	8.2	12.4	9.2	8.13	7.2	8.50
26							10.0	7.18	6.81	6.2	8.4	9.1	7.38	9.9	8.3	7.9	8.2	8.5	6.20	7.4	7.70

Table 9. Continued.

	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60(**6.14**)	Mean
1	6.39	4.9	6.4	5.1	7.1	12.3	10.4	7.79	5.2	7.37	5.91	6.14	4.4	8.98	7.0	7.5	9.8	6.5	8.1	7.47	7.24
2	5.05	6.5	3.8	2.5	6.1	8.7	7.6	4.72	5.6	5.76	3.35	4.50	3.7	5.10	5.6	5.6	7.0	4.4	6.8	5.13	5.20
3	4.07	6.9	5.6	5.0	5.5	9.8	9.2	5.58	6.9	3.84	3.91	5.76	4.5	7.76	7.4	4.2	6.9	3.4	7.9	5.14	6.15
4	7.15	7.2	3.5	4.3	8.7	10.6	10.2	5.74	5.1	7.17	4.35	6.74	4.3	6.39	6.1	6.9	9.6	5.1	8.3	7.64	6.54
5	6.32	9.1	5.9	4.6	7.5	7.2	7.2	4.54	7.9	7.31	5.17	5.81	6.0	4.52	6.0	6.6	6.5	5.8	7.4	6.51	6.20
6	5.45	7.2	5.2	3.8	7.1	8.5	7.3	4.09	6.7	6.58	4.33	6.36	4.8	5.50	3.9	6.2	7.2	5.2	7.1	5.79	5.93
7	5.29	4.1	4.1	4.4	7.1	11.4	10.1	6.16	4.2	5.09	4.29	6.46	3.4	7.30	6.8	5.8	9.3	3.5	8.3	6.56	6.71
8	5.89	8.9	7.3	8.0	6.1	11.1	7.1	6.32	9.7	6.03	6.92	8.29	7.1	7.92	9.9	6.3	7.5	6.9	10.0	6.41	8.13
9	7.75	8.9	6.6	5.4	8.8	10.3	11.0	7.55	7.9	8.11	6.77	5.91	6.6	7.90	8.7	7.8	9.0	6.8	9.5	8.21	7.65
10	3.72	6.2	5.7	3.5	5.2	8.3	6.5	5.65	6.8	4.65	4.10	3.62	4.6	5.60	6.3	6.1	5.8	5.0	6.7	4.58	5.47
11	5.58	8.6	6.4	4.3	7.8	6.7	6.8	5.08	8.1	6.44	5.15	5.31	6.3	4.52	5.6	7.3	6.1	6.1	7.1	6.35	6.05
12	4.21	6.4	4.8	4.6	5.0	9.3	8.3	5.62	6.5	3.77	3.83	4.81	4.0	6.50	7.6	5.1	6.7	3.7	7.4	4.92	5.79
13	5.38	5.5	5.8	4.5	6.8	10.6	8.9	6.23	5.0	6.50	4.09	6.38	4.1	7.71	4.7	6.3	8.7	5.2	6.8	6.06	6.20
14	5.27	8.6	5.9	6.0	7.2	7.8	7.2	3.58	8.2	5.17	3.86	7.46	5.5	6.05	5.6	5.8	6.5	4.8	7.4	5.67	6.23
15	7.64	7.7	6.0	5.0	9.6	9.7	9.9	6.64	6.1	8.13	5.48	7.39	5.8	6.59	4.9	8.5	9.7	6.4	7.7	8.15	6.90
16	5.58	6.8	6.3	5.3	7.4	10.8	8.7	7.10	6.7	6.80	5.89	4.82	5.4	6.88	8.9	6.2	8.5	5.6	9.2	6.22	7.00
17	4.20	5.0	5.8	3.7	6.0	9.7	7.8	5.80	5.6	5.67	4.52	5.69	4.5	6.75	5.5	5.8	7.4	4.7	7.2	4.75	5.90
18	7.32	9.0	7.1	5.8	7.9	10.5	10.1	8.24	7.8	8.40	6.82	6.18	7.3	8.24	9.5	6.5	8.6	6.7	9.9	6.33	7.80
19	3.19	5.3	4.5	3.1	6.0	9.5	8.1	4.30	5.4	4.02	3.12	4.99	3.4	5.96	5.6	3.9	7.1	2.3	7.6	4.95	5.39
20	5.79	8.7	5.8	4.4	6.6	7.1	6.3	5.15	7.8	6.57	4.43	4.50	5.6	4.98	6.6	6.3	5.9	5.8	6.6	5.33	5.80
21	3.82	8.4	6.8	5.9	4.7	8.3	4.5	5.14	9.1	5.08	5.21	5.70	6.3	5.94	8.0	5.0	4.5	5.8	8.5	4.01	6.53
22	3.39	6.4	4.9	2.9	5.9	8.2	6.6	4.99	6.5	4.79	4.05	4.00	4.9	4.69	6.6	4.8	5.9	4.1	7.5	3.67	5.36
23	6.87	5.3	3.3	4.2	8.9	12.7	11.2	6.58	3.6	7.37	5.33	7.55	4.6	7.23	7.1	6.3	10.8	4.7	10.5	7.87	7.3
24	5.75	9.2	7.9	6.4	7.2	7.1	4.3	6.15	9.8	6.90	7.09	5.93	7.7	4.04	8.5	7.8	5.4	7.2	8.5	6.46	7.19
25	8.23	9.8	9.0	8.0	9.2	10.2	9.3	8.01	9.4	9.14	7.87	8.92	8.0	8.74	6.7	9.7	9.3	8.9	4.7	8.59	8.50
26	6.41	8.9	7.0	7.3	7.8	10.5	9.1	6.84	8.8	6.85	6.27	6.78	6.2	7.87	9.8	6.3	8.1	6.2	9.8	6.53	7.70

Table 9. Continued.

	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	Mean
27	7.61	10.5	9.6	7.7	7.7	7.3	5.3	7.83	11.1	8.22	8.25	6.50	8.7	6.88	8.9	9.8	6.2	9.3	7.6	8.09	8.20
28	6.10	7.7	5.4	4.8	7.0	8.6	8.2	5.73	6.6	6.37	3.94	5.83	4.7	6.42	5.9	6.8	7.6	5.4	6.3	5.94	5.92
29	5.07	7.1	4.5	3.7	6.1	8.3	7.7	4.20	6.2	5.35	2.89	5.10	3.5	5.58	5.1	5.8	6.8	4.2	6.4	5.71	5.27
30	4.83	7.7	5.3	6.7	6.2	10.6	8.5	4.82	7.7	4.46	3.98	7.98	4.9	7.62	7.5	4.5	7.7	4.2	8.9	5.49	6.90
31	5.53	5.2	6.6	4.5	7.4	10.4	9.1	7.11	5.2	6.61	5.37	5.95	5.0	7.48	5.8	7.5	8.8	5.7	6.7	6.61	6.50
32	6.73	9.2	8.2	6.6	8.7	7.0	8.2	5.89	9.2	6.91	6.30	7.62	7.0	6.76	5.2	8.7	7.2	6.9	6.2	7.86	7.10
33	5.51	9.3	7.3	5.9	6.4	5.2	6.1	5.49	9.3	5.37	5.38	5.03	6.5	5.69	7.4	7.0	4.5	6.0	6.0	5.57	6.14
34	8.03	13.3	11.0	10.0	8.3	5.1	5.0	7.25	13.8	8.07	9.09	9.01	10.4	7.97	10.2	9.7	3.7	9.8	8.9	8.28	9.10
35	6.64	6.0	4.2	3.9	8.0	11.9	11.3	6.68	4.6	6.96	5.35	6.73	4.6	7.84	7.2	6.2	9.9	4.7	9.4	7.56	7.00
36	6.28	7.2	4.8	3.5	8.0	8.5	8.4	5.33	6.3	6.68	5.13	5.38	5.2	4.42	6.4	7.1	7.9	5.1	7.7	6.86	6.00
37	6.16	10.6	9.0	9.4	6.6	10.2	8.0	7.38	11.9	5.24	8.03	9.09	8.9	9.08	11.3	6.6	6.3	7.5	11.0	6.56	9.00
38	6.13	10.8	9.2	7.6	7.0	3.9	5.2	6.20	11.6	5.95	7.21	6.50	8.4	6.64	8.5	8.2	2.6	7.7	7.2	6.36	7.30
39	4.23	8.3	5.1	4.6	5.5	7.2	6.2	3.69	8.0	4.36	3.82	4.50	5.0	4.77	7.3	4.3	4.9	4.0	7.3	4.43	5.51
40	5.24	6.8	5.3	3.8	6.8	9.0	7.7	5.71	5.4	6.78	3.68	5.38	4.6	5.84	5.5	5.6	7.6	4.7	7.3	4.94	5.70
41		6.0	5.7	4.4	4.0	9.1	6.6	4.99	6.9	3.04	3.91	4.68	4.5	6.14	7.2	3.7	5.4	3.3	7.6	3.27	5.60
42			5.9	5.2	7.3	13.5	11.3	8.22	3.9	6.66	6.27	7.26	4.8	9.20	7.8	6.9	10.7	5.6	9.7	7.41	7.70
43				3.7	7.0	11.0	9.3	4.49	4.7	5.95	3.43	6.68	3.1	5.98	6.3	5.0	8.8	3.7	9.2	6.25	6.20
44					6.2	9.6	8.2	4.87	4.8	5.31	3.44	4.19	3.3	5.55	5.4	5.2	7.4	3.8	8.0	5.45	5.30
45						10.1	7.5	6.46	8.5	4.56	5.71	5.64	5.6	8.19	8.7	5.1	5.5	5.6	8.1	4.77	6.90
46							5.9	7.94	13.6	9.13	9.29	8.68	10.8	7.14	9.9	10.6	5.3	10.0	8.6	8.62	9.10
47								6.63	11.6	7.63	7.68	7.54	9.2	5.60	9.3	8.0	4.2	8.4	9.0	5.95	7.90
48									7.9	5.06	3.81	6.72	4.7	4.57	5.4	5.2	6.0	4.5	7.9	5.93	5.90
49										7.94	5.50	7.52	4.4	8.58	7.3	6.7	11.4	5.2	10.0	7.77	7.50

50						4.48	5.50	4.8	7.20	7.5	4.9	5.8	4.0	7.4	4.91	6.15

Table 9. Continued.

	52	53	54	55	56	57	58	59	60 (**6.14**)	Mean
51	5.30	2.6	5.84	5.1	4.0	7.0	2.8	7.5	4.61	7.24
52		5.4	6.61	8.3	6.0	6.2	5.4	7.9	5.46	6.23
53			6.94	5.6	4.8	8.2	3.1	7.6	5.82	5.60
54				7.5	6.9	6.5	6.0	9.2	6.34	6.65
55					8.2	9.1	6.8	7.3	8.16	7.10
56						7.1	3.0	9.6	4.01	6.40
57							7.4	7.9	5.39	7.20
58								8.3	4.56	5.60
59									7.95	8.00

Table 10. List of 60 Hararghe coffee collections under eight clusters.

Cluster	No	Acc. Code	Cluster	No	Acc. Code	Cluster	No	Acc. Code	Cluster	No	Acc. Code
I	1	H-626/02	II	44	H-761/02	II	51	H-643/02	VII	12	H-749/02
	31	H-22/02	Subgr-I	22	H-648/02	Subgr-II	53	H-657/02	Subgr-IV	41	H-568/02
	17	H-743/02		10	H-735/02		56	H-662/02		50	H-01/02
	6	H-627/02		28	H734/02		14	H-168/02		7	H-666/02
	55	H-636/02		29	H-231/02		48	H-641/02		19	H-544/02
	32	H567/02		40	H759/02		30	H-588/02		58	H-599/02
	2	H-10/02		5	H-55/02		23	H-402/02		34	H-203/02
III	43	H-595/02		20	H-625/02	VI	21	H-630/02		38	Hrusa
	35	H-668/02		39	H-644/02		60	H-656/02		57	H-236/02
	42	H-160/02		11	H-383/02		45	H-744/02		46	H-623/02
	49	H-387/02		33	Mechara1	VII	37	H-247/02	VIII	25	H-614/02
	16	H-716/02		52	H-382/02	Subgr-III	24	H-612/02		59	H-27/02
IV	26	Mocha		4	H-717/02		54	H-719/02			
	9	H-16/02		36	H-762/02		47	H-13/02			
V	18	H-569/02		15	H-655/02						
	8	H-645/02		3	H-05/02						

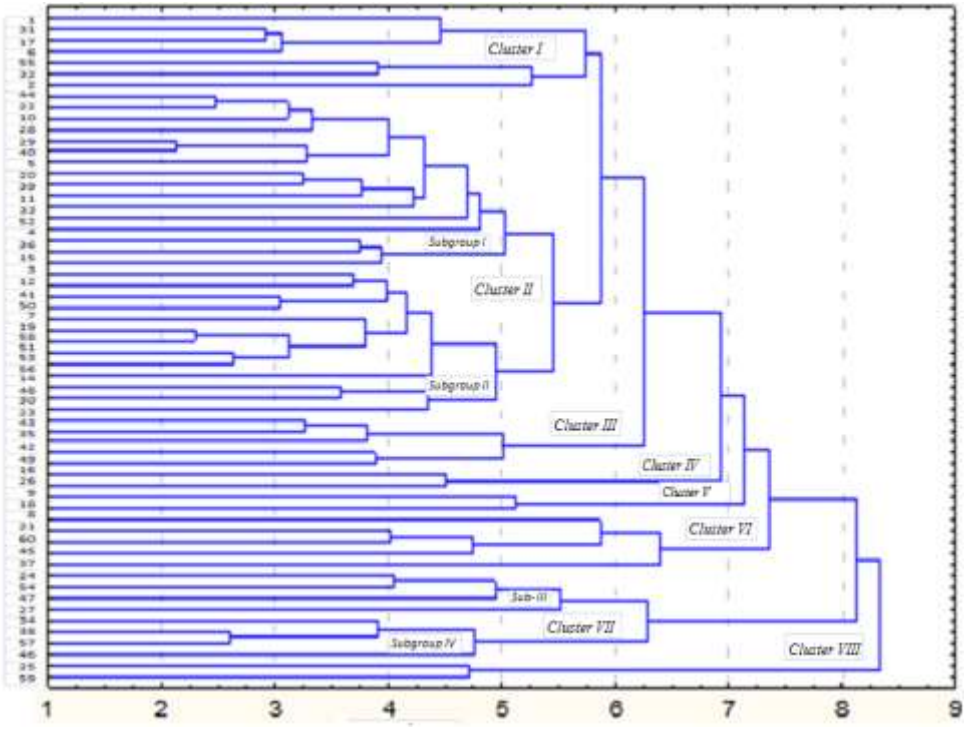


Figure 5. Dendrogram generated based on UPGMA clustering method depicting relationship among 60 Hararghe coffee collections based on beans quality attributes.

4. Discussion

The existence of variations among Hararghe coffee collections for most of the coffee quality traits suggested the higher chance of improving the crop through selection. Ethiopia is both the center of origin and diversification of *Coffea arabica* L. (Bayetta, 2001) that offers great potential for improvement of the crop (Ashenafi *et al.*, 2014). Yigzaw, (2005) and Getu, (2009) reported the existence of high genetic diversity for coffee quality among coffee types of major coffee growing areas. Significant genetic variability for bean chemical composition and organoleptic characteristics exists at both between and within species levels (Leory *et al.,* 2006). Ethiopia has coffee types with unique flavor, taste and variable specialty coffee types (Workafes and Kassu, 2000) and these specialty coffees will have good opportunity in the international market to fetch premium prices as far as their conspicuous unique aroma and flavor are maintained and/or improved (Wassu, 2011a).

A wide range of mean values for raw bean, organoleptic and overall coffee quality among Hararghe coffee collections suggested the higher chance of improving the quality of Harar coffee through selection. It was reported a wide range of performance for total raw, total cup and overall coffee quality of coffee genotypes in Ethiopia (Yigzaw, 2005; Wintegens, 2004; Anwar, 2010; Wassu, 2011a&b; Berhanu *et al.*, 2015). Moreover, none of the Hararghe collections had <70% and had not less than grade three (ECX, 2010). Generally, this research results indicated that Hararghe coffee collections had higher

total raw bean and overall coffee quality, but small bean size than the minimum mean values reported by other authors for coffee genotypes collected other than Hararghe.

According to Deshmukh *et al. (*1986), high genotypic (GCV) and phenotypic (PCV) coefficient of variations were computed for roast volume change, percent pulp and outturn ratio while both the PCV and GCV values were moderate for traits like weight of lost due to roast, bulk density of roast coffee and single berry weight. The results suggested improvement through selection is easy for traits that exhibited high PCV and GCV but repeated selection is required for those traits that exhibited moderate PCV and GCV values. Moreover, high heritability associated with relatively high genetic advance was also noticed for roast volume change, beans weight loss due to roasting, outturn ratio and percent pulp. This suggested that improving these traits could be possible via selection because of high heritability accompanied with high genetic advance. This is because of the existence of a close correspondence between genotype and phenotype variance due to a relatively smaller contribution of environment to phenotype expression (Singh and Ceccarelli, 1995). Burton (1952) suggested that genetic coefficient of variation together with heritability values would give the best estimates of the amount of the genetic advance to be expected from selection. Heritability estimates show only the effectiveness of selection of genotypes based on phenotype, their utilities can increase when used only with estimate of genetic advance (Allard and Bradshaw, 1964).

Beans physical quality such as over screen, shape and make, color bean weight and single berry weight, body and flavor from organoleptic coffee quality attribute showed significant correlation with overall quality of Hararghe coffee. Of which shape and make followed by color, and others cup quality, total quality, weight of roast coffee and roast weight loss exerted high and positive direct effect on overall coffee quality. Body, flavor bulk density of green coffee, bulk density of roast coffee, bean weight, volume of green coffee roast volume change and single berry weight had strong positive indirect effect through total raw beans quality and its components on overall quality. This suggested selection of genotypes should be made in favor high mean performances to those traits that have strong associations and exerted strong positive direct and indirect effects on overall quality. Decasy *et al.* (2006) reported the presence of highly significant and positive association of overall quality with body and flavor in Arabica coffee. Similarly, Yigzaw (2005) indicated flavor as an all-round organoleptic attributes to be considered during selection to develop superior coffee genotypes and Getachew *et al.* (2009) also suggested considering body and flavor for direct and indirect selection to improve the overall coffee quality.

Hararghe coffee collections grouped into eight major clusters and exhibited wide ranges of genetic distances suggested the possibility of obtaining heterotic hybrids through crossing distant collections from different clusters. This is because, the more the distant the parents the higher chance of obtaining heterotic hybrids (Bayetta, 2001; Senbet *et al.*, 2008). Clustering is the partitioning of a set of objects into similar groups so that objects within a group are similar and objects in different groups are dissimilar (Singh and Chaundary, 1977; Abeyot *et al.*, 2011). Coffee hybrids obtained by crossing of parental lines from the same and different regions exhibited positive standard heterosis for all Sidamo coffee quality parameters (Wassu, 2011b). The observed higher

magnitude of heterosis over the best checks in Ethiopian coffee hybrids for yield and coffee quality might be due to high genetic variability among and between coffee growing regions' coffee types as it was reported by many researchers (Carneriro, 1997; Fazuoli *et al.*, 2000).

5. Summary and Conclusion

The results of analysis of variance, genetic distances and cluster analyses showed the presence of significant difference among Hararghe coffee collections for coffee quality traits suggested the presence amble opportunity to improve Harar coffee overall coffee quality by developing varieties through selection and/or crossing of lines. Moreover, 20 collections and only one released variety had overall quality ≥81% and grade two indicating that the higher chance improving Hararghe coffee quality through selection of genotypes than the existing released coffee varieties. In addition, the collections that had grade two overall quality were originally collected from districts of East and West Hararghe known as Harar A and B types might suggested the more determinant factor was the inherent genetic constitute of genotypes for the quality attributes than the growing districts classified as producing Harar A and B coffee quality types. Physical quality attributes of berries and beans, body and flavor from organoleptic quality attributes could be used as selection criteria to obtain varieties with high overall quality of Harar coffee types due to the high heritability, genetic advance, phenotypic and genotypic coefficient of variations values and strong positive associations of these traits to overall coffee quality. The research results allow concluding the importance of evaluating more number of collections to increase the chance of obtaining coffee varieties that would attain high coffee quality grade in international market. The improved varieties in turn would change the good opportunity of obtaining premium prices to reality for growers by producing Harar coffee of distinctive mocha flavor. This also saves the genetic resource erosion due to the substitute of coffee trees with competent crop(s) that provide high price for the farmers in the region.

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6. Classification of Genetically Variable Hararghe Coffee (*Coffea arabica* L.) Beans using Imaging Techniques and Artificial Neural Network

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Abstract: Hararghe coffee has a unique quality that fetches premium prices in the world market. However, to exploit this good opportunity, the distinct unique shape, color and size of Hararghe coffee need to be maintained and improved. The first step to improve the crop is to understand the exiting variability in the genotype/accession. Therefore, this research work, a digital image analysis technique was used to classify beans of Hararghe coffee genotypes based on their morphological, color and textural features. Artificial Neural Network (ANN) was used to classify Hararghe coffee beans (HCBs) produced under different agronomical management in different districts and HCBs of coffee genotypes which were grown under the same agronomical management at same locations, to check weather correctly classifies to their origin of collection or not. Four classification set-ups, classification based on morphology features, color features, texture features and combination of color, texture and morphology features were used. For HCBs genotype all set up features of 390 images were used as inputs of the ANNs. From those data sets 70% (272 images), 15 % (59 images) and 15% (59 images) were used in the network for training, testing and validating, respectively. The accuracy of classification using (morphological feature was 93.8%, 87.7%, color features was 1.5%, 99.5%, texture features was 82.6%, 79.5% and combination of morphological, color and texture feature was 68.7%, 61.5%) for Harar A and Harar B, respectively, and the overall performance of 390 images classification account 90.8% (354 images), 50.5% (232 images), 81.0% (316 images) and 65.0% (254 images) were correctly classify into Harar A and Harar B, respectively. The classification performance of the machine was best for morphological features and HCBs of genotypes were not correctly classified to their origin of collections as HCBs collected from market.

Keywords*:* Artificial Neural Network; Classification; Feature extraction and Image analysis

1. Introduction

Coffee is the most popular soft drink in the world and its popularity and volume of consumption are growing every year, and coffee shops are the fastest growing part of the restaurant business. Over 2.25 billion cups are consumed every day (Ponte, 2002). Economically, coffee is the second most exported commodity after oil, and employs over 100 million people worldwide (Petit, 2007; Pedegrast,2010; Gray *et al.* 2013) and global coffee production area covered around 10,142,285 ha in 2013 (FAO, www.faostat3.fao.org). Though there are over 120 species of genus *Coffea,* only two species viz. *Coffea arabica* L. and *Coffea canephora* Pierre have economic importance in which the former species dominating over 70% in volume of production and over 90% of traded value globally. Ethiopia is the center of origin and diversity of *Coffea arabica* and it is the most important export commodity for the country, with a share of 20-25% of the total foreign exchange earnings. At least 15 million people also directly or indirectly rely on coffee for their livelihood (Gray *et al.*, 2013).

Quality is a determining factor in the price of coffee beans. Coffee quality may seem subjective, since it is related to how it tastes and smells, and personal preferences and sensitivities can vary widely. The quality of coffee is becoming more important for smallholder farmers at time of price fluctuation. For instance, during the period from 1994 to 2004, farmers saw the lowest price during the 20th century that a pound of green Arabica beans ranged from 0.54 to 2.22 USD (ICO, 2006). During this period farmers were forced to focus on a higher quality product to export to increase their profits. Therefore, the quality of coffee needs to determine precisely to be supplied to international market to the satisfaction consumers. Ethiopia has set its own minimum standards to evaluate export coffee and grouped all these quality controlling ingredients into two, as raw (physical) and cup taste (liquor) qualities. This is based on international consensus quality evaluation ingredients as a base line in which coffee grading is based on the number of defects and type of processing (Yared, 2010). In Ethiopia coffee quality measurement is done visually and manually by human inspectors (Endale, 2007).

In Hararghe, farmers grow coffee landraces having their own characteristic features which are produced in highly diversified garden production systems adapted to different ecological conditions (Bayeta *et al.,* 2000; Mesfin and Bayetta, 2003). Hararghe coffee bean is grown in the eastern highlands of Ethiopia. It is one of the oldest coffee beans still produced and is known for its distinctive fruity wine flavor which fetches premium price at international coffee market. The bean is medium in size, with a greenish-yellowish color. It has medium acidity and full body and a distinctive mocha flavor. It is considered as an excellent premium coffee with balanced complexity (Guzman, 2002). The factors that determine quality are numerous in a coffee bean's entire journey from the field to the final drinking-cup; notably the genotype is a key factor. Genotype determines to a great extent important characteristics such as the size and shape of the beans as well as their color, chemical composition and flavor. The shape and structure of beans (elephant, pea bean and empty beans) are the result of both genotype and environmental factors (Wintgens, 2004).

Hararghe coffee classified into Harar A and Harar B types and keeping the distinguishing characteristics of these coffees allows sustaining the high prices obtained

in international market by satisfying the consumers. The satisfaction consumers influenced by consumers' perceptions of product quality, price and the factors and personal circumstances of the consumer (Parasuraman *et al.*, 1985). The product quality is not only a matter of its inherent characteristics but the methods used to determine its quality has an impact on satisfaction of consumers. Decisions making on the beans quality of Hararghe coffee genotypes by human heavily depends on the expertise of the operators that may be affected by external factors like fatigue and bias, and it has less processing speed and accuracy (Endale, 2007). But it is possible to overcome this problem by using image processing techniques. The implementation of artificial neural network as automation decision algorithm in computer vision has evident advantage in classification process of agriculture products (Faridah et al., 2011). The development of computer vision in classification of beans of Hararghe coffee genotypes would be more accurate by reducing observer biases, faster and saves time. Therefore, this research was initiated with the general objective of modeling consistent, efficient and cost effective by image analysis method for classification beans of Hararghe coffee genotypes with specific objectives; i) to classify Hararghe coffee accessions samples that are grown under similar agronomic management using their features, and ii) to extract and classify morphological and color features of Hararghe coffee accession samples grown under different agronomical management.

2. Materials and Methods

Experimental Materials

Two major groups of sample coffee beans were used. The first group of sample was bean of 60 Hararghe coffee genotypes of which 52 and 8 (including the four released varieties) originally collected from East and West Hararghe representing Harar A and Harar B coffee classes, respectively. These genotypes were collected from nine Woredas' during the year 2002 and planted at Mechara Agriculture Research Center in Daro Labu district of West Hararghe Zone (Table 1). Six plants for each genotype were planted in single row at the spacing of 2 m both between plants and between rows. The experimental plots maintained under temporary shade tree known as *Sesbania susban.* All the field management practices such as weeding, hoeing, shading and fertilizer application were applied similarly to all plots using the national recommendation.

Selective picking method was applied to collect cherries produced in six trees per collection, i.e., only the red ripe cherries were handpicked from the trees selectively and unripe green beans were left behind to be harvested later. Accordingly, more than three harvests were carried out to collect cherries. The harvested red ripe cherries during each harvesting time were measured and dried on raised bed with mesh wire in a place where there was no any type of shade tree, building, and shade producing material around or near to raised bed. The cherries were dried until the outer shell was become dark brown and brittle in the open sun with regular stirring to promote even drying, prevent fermentation and the growth of mold. From each genotype, 200g clean coffee beans were taken for image analysis. The second group of samples were obtained from ECX in which 300g coffee beans were taken each from randomly selected 20 quintals for each

class of selected area representing Harar A and Harar B coffee classes. These samples used for comparison of the genotypes beans with Harar A and Harar B, coffee samples.

Study Design

A vision-based approach to describe genotype Hararghe coffee samples involves defining and measuring some specific visual characteristics such as color descriptor like mean, variance and range of each RGB channel, shape descriptor like area, perimeter, major and minor axis length and texture features descriptor like energy, correlation, homogeneity and contrast. In this experiment, quantitative analogues of these features were extracted from the images of Hararghe coffee (Harar A and Harar B) beans using image processing techniques. Automatic thresholding and color image processing algorithm were employed to extract a descriptor for classifying genotypes of Hararghe coffee beans.

Five images were taken for each genotype (60 Hararghe coffee genotypes) and totally 300 images were captured for this research work. Forty-five images were taken for each class and totally 90 images were captured from the samples beans were collected from ECX representing Harar A and Harar B coffee classes. The samples were used for image analysis in comparison of the genotypes beans with Harar A and Harar B coffee classes.

Table 1. List of Hararghe coffee genotypes and varieties.

No.	Acc.code	District	No.	Acc.code	District	No.	Acc.code	District
1	H-01/02	Deder	21	H-599/02	Melka Belo	41	H-716/02	Kurfa Chele
2	H-05/02	Deder	22	H-612/02	Melka Belo	42	H-717/02	Kurfa Chele
3	H-10/02	Deder	23	H-614/02	Mid altitude	43	H-719/02	Kurfa Chele
4	H-13/02	Deder	24	H-623/02	Melka Belo	44	H-734/02	Kurfa Chele
5	H-16/02	Deder	25	H-625/02	Meta	45	H-735/02	Kurfa Chele
6	H-22/02	Deder	26	H-626/02	Meta	46	H-743/02	Kurfa Chele
7	H-25/02	Deder	27	H-627/02	Meta	47	H-744/02	Kurfa Chele
8	H-27/02	Deder	28	H-630/02	Meta	48	H-749/02	Kurfa Chele
9	H-55/02	Deder	29	H-636/02	Meta	49	H-759/02	Jarso
10	H-160/02	Kombolcha	30	H-641/02	Meta	50	H-761/02	Jarso
11	H-168/02	Aramaya	31	H-643/02	Meta	51	H-762/02	Jarso
12	H-203/02	Aramaya	32	H-644/02	Meta	52	H-247/02	Doba
13	H-231/02	Aramaya	33	H-645/02	Meta	53	H-382/02	Tulo
14	H-236/02	Aramaya	34	H-648/02	Meta	54	H-383/02	Tulo
15	H-544/02	Melka Belo	35	H-655/02	Meta	55	H-387/02	Tulo
16	H-567/02	Melka Belo	36	H-656/02	Meta	56	H-402/02	Tulo
17	H-568/02	Melka Belo	37	H-657/02	Meta	57	Harusa	Mechara
18	H-569/02	Melka Belo	38	H-662/02	Meta	58	Mercha-1	Mechara
19	H-588/02	Melka Belo	39	H-666/02	Meta	59	Mocha	Mechara
20	H-595/02	Melka Belo	40	H-668/02	Meta	60	Bultum	Bultum

Note: All genotypes were collected from East Hararghe except four genotypes collected from Tulo district and four varieties originally collected from Mechara and Bultum districts are from West Hararghe.

Image Acquisition and Pre-Processing

The samples were captured using regular digital Nikon Camera with sixteen megapixels of resolution, of focal length of F 5.6 and frame size 2304×3456 for better quality. Each image was captured at the same condition i.e., at equal distance from the camera lens, in the same light luminous and the same camera adjustment. If these conditions become variable it makes the amount of light reflected from the sample and reach the camera become highly variable. The images were uploaded to a computer via a USB provided with image acquisition and processing tool-boxes of MATLAB software to visualize, acquire and process the image directly from the computer.

Image pre-processing can be defined as a technique in which various mathematical operations were applied to the digitized image. The enhanced image becomes useful and informative or pleasing to a human observer. Pre-processing uses various techniques like image resizing, filtering, morphological operations like image opening and closing etc. In image processing applications the initial captured images may be resized to a fixed resolution to utilize the storage capacity or to reduce the computational burden.

Image Segmentation

Image segmentation extracts objects/regions of interest from the background. These objects and regions are the focus for further coffee beans identification and classification (He *et al.,* 2009). The image segmentation is very important to simplify an information extraction from images, such as color, texture, shape, and structure (Barakbah and Kiyoki, 2010). It used to separate the desired objects (coffee beans) from the background.

Once the image was enhanced, the next process was to extract the required features i.e., shape, size and color of the part of the image in the region of interest. This can be achieved by image segmentation. Image segmentation refers to the process of partitioning the digital image into multiple segments to change the representation of an image into something that is more meaningful and easier to analyze i.e., to identify regions in the image that are likely to classify the variety of HCBs (Biniyam *et al.* 2013).

In this research work, automatic threshold method was used, which is automatically selected threshold value for each image by the system without human intervention. The more advanced technique of automatically segmentation is optimal thresholding. It usually seeks to select a value for the threshold that separates an object from its background. This suggests that the object (coffee bean) has a different range of intensities with respect to the background. An appropriate threshold was chosen using Otsu's method (Otsu, 1979). The Otsu method of thresholding is coded as a standard Matlab function, *graythresh (),* in the Image Processing Toolbox (IPT).

Algorithm for iterative (optimal) threshold

1. Assuming no knowledge about the exact location of objects, consider as a first approximation that the four corners of the image contain background pixels only and the reminder contains object pixels.

2. At step t, computes $\mu_B^{\,t}$ and $\mu_O^{\,t}$ as the mean background and object gray-levels respectively where segmentation into background and objects at step t is defined by the

$$\mu_B^{\,t} = \frac{\sum_{(i,j)\in background} f(i,j)}{\#background\_pixels} \qquad \mu_O^{\,t} = \frac{\sum_{(i,j)\in objects} f(i,j)}{\#object\_pixels} \tag{3.1}$$

3. Set

$$T^{(t+1)} = \frac{\mu_B^{\,t} + \mu_O^{\,t}}{2} \tag{3.2}$$

$T^{(t+1)}$ now provides an updated background – object distinction.

4. If $T^{(t+1)} = T^{(t)}$, halt; otherwise return to step 2

Feature Extraction

Image features have a major importance in image classification. There are several types of image features that have been proposed for image classification. Morphology, color and texture are some of the basic image features. This research work used texture, shape, size and color to classify Hararghe coffee genotype. An image feature is a distinguishing primitive characteristic or attribute of an image. One of the key factors of image analysis is the extraction of sufficient information that leads to a compact description of an examined image (Habtamu, 2008). Some qualitative features are extracted from the objects to be analyzed in the images. These extracted attributes are called 'patterns'. Features are used as inputs to the algorithms for classifying the objects into different categories. Pattern recognition was done by analyzing the morphology, color and texture of these features of the images.

Color Feature Extraction

One of color model that is frequently used in image processing is RGB (Red Green Blue) model. Color image that is commonly used is 24-bit color image that is known as true color. Image in this format is RGB image with specific intensity composition for each component. By combining intensity variation in each color component, various color composition could be made. The color features to be sorted in this system are the mean of the three colors component intensity of pixels in each coffee bean sample image is called by R mean, G mean, and B means (Birhanu *et al.*, 2013).

In relation with RGB colors, there are three common descriptors of a light sensation. These are HIS (Hue, Intensity and Saturation). HIS color model is a popular color model because it is based on human perception. Hue is a color attribute that describes a pure color and saturation is a measure of how much a pure color is diluted with white light. Intensity describes the brightness of color. The color features are extracted by computing the mean values of RGBs and HISs of coffee bean images (Biniyam *et al.,* 2013; Habtamu, 2008).

Color images carry more information than gray level one. The RGB color model is an especially important one in digital image processing because it is used by most digital imaging devices. In RGB model, a color is expressed in terms that define the amounts of Red, Green and Blue colors it contains. The values of RGB were expressed between 0 and 1. During image processing HSI (Hue, Saturation, Intensity) color model is used to compare two colors, or for changing a color from one to another. To use this model, first the RGB color image is converted to HSI space beginning with normalizing RGB values (Birhanu *et al*., 2013)

$$r = \frac{R}{R+B+G} \qquad g = \frac{G}{R+G+B} \qquad b = \frac{B}{R+G+B}$$

(3.3)

Where: the r, g and b are the normalized values of R, G and B

Each normalized H, S and I components are obtained by

$$h = \begin{cases} \theta & if \ \ b \le g \\ 360 - \theta & if \ \ b > g \end{cases}$$

(3.4)

$$\theta = \cos^{-1}\left\{ \frac{0.5\left[(r-g)+(r-b)\right]}{\left[(r-g)^2+(r-b)(g-b)\right]^{0.5}} \right\} \tag{3.5}$$

$$s = 1-3\left[\min(r,g,b)\right]; \qquad s \in [0,1] \tag{3.6}$$

$$i = \frac{r+g+b}{3}; i \in [0,1] \tag{3.7}$$

For convenience h, s and i values are converted in the range of [0, 360], [0, 100], [0, 255] respectively.

$$H = h\frac{180}{\pi},\ S = s*100,\ I = i*255$$

(3.8)

Equations (3.9), (3.10) and (3.11) are used to evaluate the mean (μ), variance (σ) and range of HSI image samples, respectively.

$$\mu = \sum_x x \sum_y P(x,y)$$

(3.9)

$$\sigma^2 = \sum_{x,y} (x-\mu)^2 P(x,y)$$

(3.10)

$$Range = Max(P(x, y)) - Min(P(x, y))$$

(3.11)

Where P (x, y) is grey level intensity value of an image.

Texture Feature Extraction

Texture features are extracted from the gray-level image. The texture properties of image hold useful information for discrimination purposes. Texture features were adopted in this work. The co-occurrence matrix was adopted to obtain textural features. A gray level co-occurrence matrix (GLCM) contains information about the positions of pixels having similar gray-level value (Charles, 2009)

The idea is to scan the image and keep track of how often pixels that differ by Δz in value are separated by a fixed distance, d, in position. In other words, the co-occurrence matrix method of texture description is based on the repeated occurrence of gray level configuration. This configuration varies rapidly with distance in fine textures and slowly in coarse textures. An occurrence of a gray level configuration is described by a matrix of relative frequencies Pφ, d(x, y), giving how frequently two pixels with gray levels x, y appear in the window separated by a distance d in direction φ (Charles, 2009). MatLab can be used to calculate energy, contrast, homogeneity and correlation using the function *graycoprops ()*. This function requires as input the GLCM of the grey scale image.

Size and Shape Feature Extraction

The size and shape variability of coffee beans of similar genetic sources grown under different or same agronomic management may be obtained from the analysis of binary images. So, the following geometric features was extracted from the binary image to determine the size and shape to classify Hararghe coffee samples. Geometry related features including area, perimeter, major axis length, minor axis lengths, eccentricity and surface roundness measured from the binary image (Charles, 2009).

i. **Area** – represents the object pixels in binary image.

$$A = \sum_{i} \sum_{j} O(i, j) \qquad (3.12)$$

Where A is area and O (i, j) represents the Object pixels in image

ii. **Perimeter**: - is defined as the sum of boundary object pixels. In other words perimeter of object is the count of the number of pixel sides around the boundary of the object starting at an arbitrary initial boundary pixel and returning to the initial pixel.

If $X_1, X_2, \ldots X_n$ is a boundary co – ordinate list; the object perimeter is given by:

$$P = \sum_{i=1} di = \sum |X - X_{i+1}| \qquad (3.13)$$

Where; P is the perimeter.

iii. **Major and Minor axes length**: - these image features give image's elongation or eccentricity. Maximum diameter (D_{max}) and minimum diameter (D_{min}) are the major and minor axis lengths of the object in binary image respectively. They are defined, respectively, as follows:-

$$Major-axislength = \sqrt{\left((x_2 - x_1)^2 + (y_2 - y_1)^2\right)} \quad (3.14)$$

$$Minor-axislength = \sqrt{\left((x - x_0)^2 + (y - y_0)^2\right)} \quad (3.15)$$

Where (x_1, x_2) and (y_1, y_2) are the coordinates of the two end points of the major axis and (x,x_0) , (y,y_0) are the coordinates of the two end points of minor axis. Once the end points of the major and minor axis are found, their length is given by the same equation.

iv. **Eccentricity**: - Eccentricity is the ratio between the lengths of the short axis to the length of long axis and is defined by the following relation.

$$\text{Eccentricity} = \frac{b}{a} \quad (3.16)$$

Where, a and b are short axis length and long axis length respectively.

v. **Surface roundness**: - this parameter is defined as the ratio of area of object by area of smallest circumscribed circle and it is for noncircular objects.

$$S_r = \frac{A}{\pi\{\frac{D_{\max}}{2}\}^2} \quad (3.17)$$

Where, $S_r, A \text{ and } D_{\max}$ are surface roundness, area and maximum diameter of an image respectively.

Artificial Neural Network

In this study, the Artificial Neural Networks (ANN) were used for recognizing pattern of this study and to classify color, texture and morphological features of coffee beans by using features which can be extracted from image processing techniques.

Data Analysis Procedure

In this study, images of HCB were captured for classification into two classes. Each image contains approximately twenty-five individual HCB. This is for uniformity of the image classifications for predefined classes. The image segmentation algorithm, feature

extraction, and ANN classification model of HCB were implemented by using MATLAB software.

The images of 390 coffee samples were fed into a computer and the necessary features of the images were extracted using different techniques of image processing. Features that were extracted from the images were used to develop and train the classification algorithm (i.e. ANN). The images of coffee samples with unknown genotypes were fed to the ANN to classify the coffee samples based on their genotypes and identify their origins using MATLAB software.

Steps of Image Processing

Image processing start with image capturing, converting RGB to gray scale image and, converting gray to binary (Figure 1). The final analysis depends on the output of previous processes, so it is important to study the sensitivity of a stage output with respect to the input. For example, small changes in background segmentation would ideally not affect classification accuracy. A flow diagram in Figure 3 shows the image processing stages.

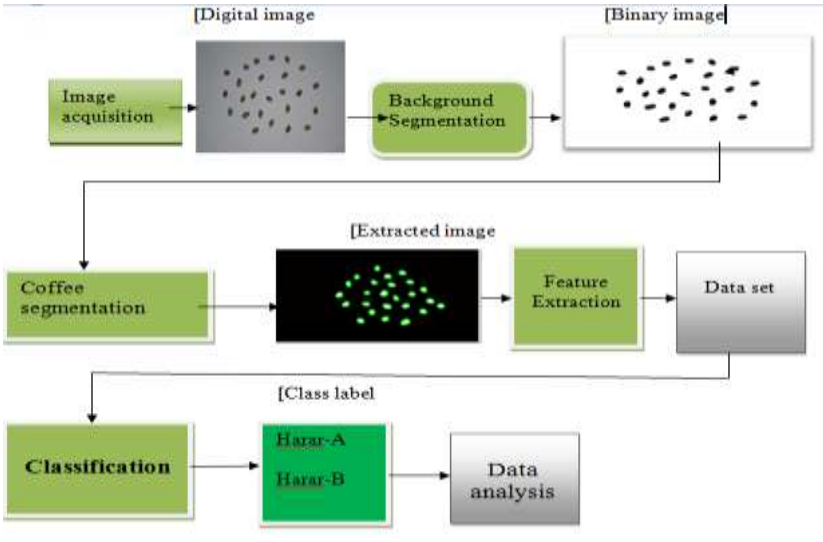

Figure 1. Steps of image processing.

3. Results and Discussion

Segmentation Result

The captured RGB images (I) were converted into gray level images (g) and then binary image (bw) to extract features. Thereafter, the images were enhanced by increasing contrast. In this work, we have used simple automatic thersholding method to segment the image from the background. Before segmentation the gray level image should be converted to binary image using *level = graythresh (g) and bw = im2bw (g, level); then L=* bwlabel (*bw, 8*); label each bolb so we can make measurements of it; Matlab toolbox functions. Fig 4 shows the result of segmented Hararghe coffee beans.

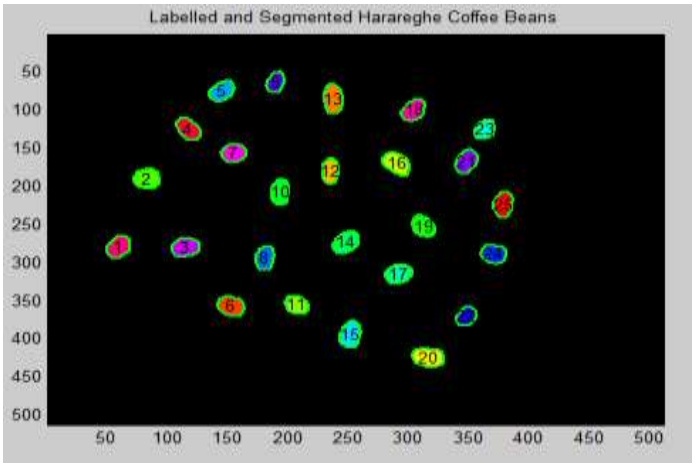

Figure 2. Segmented and labeled Hararghe coffee beans using automatic thresholding.

Result of Morphological Features

The six morphological feature samples of average values are shown in table 2. The MATLAB code used to extract these features is annexed in Appendix D.

Table 5. Samples of morphological features extracted from Hararghe coffee beans of each parameter were measured by number of pixels in the image.

	Hararghe coffee samples					
Morphological feature	Harar_A			Harar_B		
Grade	4A	5A	6A	4B	5B	6B
Area	523.721	544.923	677.081	583.842	545.401	600.401
Perimeter	87.424	90.792	100.404	94.332	89.211	93.656
Major axis. Length	33.008	35.251	37.288	36.463	33.304	35.056
Minor axis. Length	20.508	19.912	23.816	20.704	21.132	22.072
Eccentricity	0.744	0.812	0.682	0.788	0.736	0.732
Surface roundness	0.636	0.565	0.664	0.588	0.648	0.642

Result of Color Features

The strength of color features are summarized in Table 3.

Table 6. Sample colour features extracted from Hararghe coffee beans.

Color feature		Hararghe coffee samples					
		Harar_A			Harar_B		
Grade		4A	5A	6A	4B	5B	6B
	Red	159.755	169.793	166.015	152.451	148.606	152.452
Mean	Green	166.676	169.604	169.548	155.782	152.156	155.782
	Blue	170.588	181.556	171.751	158.035	154.369	158.035
	Hue	0.545	0.556	0.551	0.552	0.551	0.552
Mean	Saturation	0.012	0.011	0.013	0.013	0.011	0.013
	Intensity	0.917	0.958	0.967	0.979	0.985	0.979
	Hue	0.091	0.092	0.071	0.074	0.071	0.074
Variance	Saturation	0.005	0.004	0.008	0.009	0.008	0.009
	Intensity	0.796	0.674	0.655	0.831	0.735	0.831
	Hue	0.676	0.723	0.683	0.629	0.613	0.629
Range	Saturation	0.006	0.007	0.007	0.007	0.005	0.008
	Intensity	0.621	0.635	0.638	0.596	0.569	0.596

Result of Texture Features

The results of texture features were extracted from the gray level image and the results were calculated for each coffee bean as shown in Table 4. Four texture features were computed from GLCM by counting the number of occurrences that the pair arrangement shown in the structured matrix appear in the original matrix. In this study different direction ($\theta = 0^0, 90^0, 45^0 \; and \; 135^0$) and distance ($d$=1, unit pixel and d=2, unit pixel) have been used to calculate the GLCM, this gives different values for the features and they were combined together by taking their mean values. Those four textural features including Energy, Contrast, Homogeneity and Correlation of HCSs that were grown at different agronomical management were calculated. These features were the main textural component considered in this work to determine the coffee genotype. The results after applying texture feature extraction algorithm shown in appendix (C) all values are the average values are presented in Table 5.

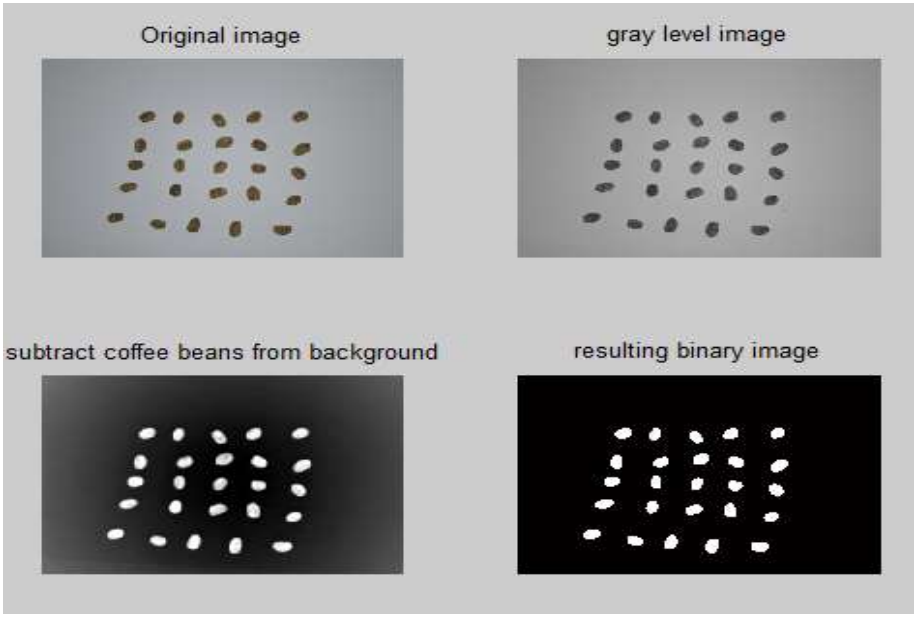

Figure 3**.** RGB to Gray and Binary color conversion is to extract texture features.

Table 4. Texture feature results for individual coffee beans.

No. of beans	Contrast	Energy	Homogeneity	Correlation
1	139.5532	0.0206	0.3764	0.6622
2	197.0937	0.0497	0.4974	0.5164
3	221.9817	0.0297	0.3821	0.5422
4	272.2003	0.0481	0.4341	0.629
5	231.2515	0.0611	0.4552	0.7426
6	244.5443	0.0597	0.5098	0.6792
7	249.7109	0.0611	0.4356	0.6994
8	110.7066	0.053	0.4935	0.6867
9	141.3801	0.0402	0.5043	0.5558
10	149.7634	0.0348	0.4131	0.7395
11	275.6252	0.0327	0.4181	0.7284
12	208.8004	0.0558	0.4443	0.611
13	236.991	0.0573	0.4875	0.7095
14	183.6457	0.0467	0.4767	0.6762
15	152.1167	0.0607	0.4889	0.6299
16	162.3409	0.043	0.4603	0.5533
17	332.3032	0.0473	0.4568	0.4755
18	137.4113	0.0419	0.4747	0.5058

Table 5. Sample texture features extracted from Hararghe coffee beans.

Texture-feature	Hararghe coffee samples					
	Harar A			Harar B		
Grade	4A	5A	6A	4B	5B	6B
Contrast	206.829	152.478	212.138	222.684	226.211	213.484
Correlation	0.617	0.492	0.602	0.453	0.641	0.437
Energy	0.045	0.046	0.045	0.043	0.048	0.044
Homogeneity	0.454	0.493	0.456	0.589	0.467	0.586

Classification Model Using ANN

Classification model result based on morphological features

In this model, six shape and size features (namely, area, perimeter, major axis length, minor axis length, and eccentricity and surface roundness) of HCSs that were grown under different agronomical management were selected for classification. Hence, the numbers of neuron in the input layer were six which corresponds to the number of input features. While the output neurons were two corresponding to the two predefined coffee growing regions (Harar A and Harar B). The numbers of neurons in the hidden layers were twenty as shown in the Figure_6 below. There is no magic formula for selecting the optimum number of hidden neurons. Therefore, some approaches to find out the number of hidden layers are trial and error methods to get optimum result.

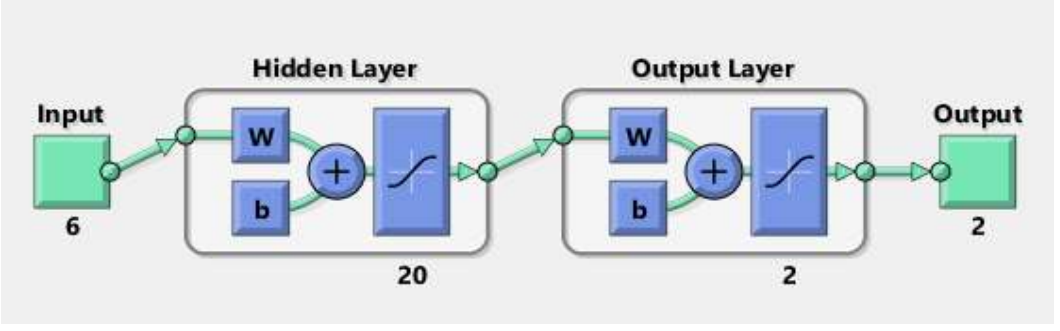

Figure 4. Training and testing model for shape and size feature.

The classification results based on morphological features are shown in Table 6 as the test of confusion matrix. The table shows that the test of confusion matrix that indicates the correct classification and misclassification of 90 images of which 75% (62 images) for training, 15% (14 images) for validation and the remaining 15% (14images) for testing.

Table 6 Test Confusion matrix of Morphological features.

	Harar A	Harar B	Total (%)
Harar A	8	0	100
Harar B	2	4	66.7
Total (%)	80	100	85.7

In Table-6, the diagonal cells show the number of classes that were correctly classified and the off diagonal cells show the misclassified cases. The cell in the bottom right shows the total percent of correctly classified cases. The summary result of artificial neural network classifier using morphological features, from the total 14 test instances 85.7% were correctly classified and 14.3% were misclassified. This means two sample of Harar A misclassified as Harar B which accounts 20% of total samples of Harar A used for testing.

The coffee samples were collected from east and west Hararghe, incase. The samples were taken from the border region must have misclassified to one or the other. The morphological feature differences of coffee beans were influenced by botanical variety and environmental growth circumstances (Sivetz and Dosrosiier, 1979; EAFCA, 2008). There is no regular pattern regarding morphological feature classification because there is slight similarity among the morphology of each coffee beans from Harar A and Harar B.

Classification Model Result Based on Color Features

The HCB samples were classified using the extracted twelve color features (Mean, Range and Variance) as inputs and two target outputs (Harar A and Harar B). Accordingly, the classification, set-up was adjusted to twelve inputs, twenty hidden layers of neuron and two output layers. The classification result based on color features are shown in Table7 as confusion matrix. The confusion matrix indicates the correct classification and misclassification of a total of 90 sample images of which 70% (62 images) used for training 15% (14 images) for validation and the remaining 15% (14 images) for testing.

Table 7. Test Confusion matrix result of colour features.

	Harar A	Harar B	Total (%)
Harar A	1	0	100
Harar B	4	9	69.2
Total (%)	20.0	100	71.4

As shown in Table 7 the summary result of neural classifier using color feature of the total 14 images, 10 images (71.4%) were correctly classified and 4 images (28.6%) were misclassified. Geographical designation of Harrar A (East Harrar) and Harrar B (West Harrar) might be the quality of coffee lots have a chance to be classified beyond the geographical locations. In blind cupping or the testing techniques of West Harrar coffees and even Bale and Arsi coffees can outscore East Harrar lots. Often West Harrar coffees have a thicker, smoother body, and a milder fruit flavor. Therefore, some growing areas that are geographically located in the West Harrar region are nevertheless classified as East Harrar coffees (Ethiopian Coffee Buying Manual, 2011). This is because the letters do not represent a quality designation, only a geographical region and excellent Harrar A coffee profile can be found in all corners of Hararghe.

Classification Model Result Based on Texture Feature

In this model, the four texture features (energy, contrast, homogeneity and correlation) of Hararghe coffee were used as input to the network. Hence, the number of neurons of the input layer was four. The two output neurons which correspond to the two predefined coffee growing regions considered in this study. To find out the number of hidden neurons in hidden layer by using try and error methods, therefore, the number of neurons in the hidden layer was twenty.

The classification result based texture features are shown in Table -8 of test confusion matrix. Table-8 shows the confusion matrix that indicates the correct classification and misclassification of 90 images of which 75% (62 images) used for training 15% (14 images) for validation and 15% (14 images) for testing.

Table 8. Test confusion matrix result using texture feature

	Harar A	Harar B	Total (%)
Harar A	7	0	100
Harar B	1	6	85.7
Total (%)	87.5	100	92.9

Table-8 shows the confusion matrix of ANN as the result of texture features were used as the input or classifier. Out of the total 14 images, 13 images (92.9%) were correctly classified and the remaining1 image (7.1%) was misclassified. The result of ANN classification using texture feature showed that the classification accuracy of Harar A and Harar B coffees were 87.5% and 100%, respectively. Harar A coffee was misclassified (12.5%) more to B. Because HararA coffee sample were possibly make them share certain textural similarity with Harar B.

Classification Model Result Based on Mixed (Color & Morphological) Features

In this model, eighteen features were selected as input to the network. These are six features of morphology and twelve colours. Hence, the neuron numbers of the input layer were eighteen. The output neurons were two which corresponds to the two predefined coffee growing regions (Harar A and Harar B) considered in this study. The total numbers of neurons in the hidden layers should be 2/3 the size of the input layer, plus the size of output layers in the hidden layers were fourteen.

Table 9 shows the test result of classification using all available features of Hararghe coffee samples collected from coffee growing regions. As indicated in Table 9, the summary result of ANN classifier test confusion matrix on mixed features shows that from the total of 14 images, 10 images (71.4%) were correctly classified and (28.6%) images were misclassified. Harar A coffee was misclassified more to Harar B. This showed that an existence of strong color and morphological relationship between Harar A with Harar B. They have similar size and color, which is smaller to medium and amber in color, respectively.

Table 9. Test confusion matrix result using mixed (colour and morphological) features.

	Harar A	Harar B	Total (%)
Harar A	1	0	100
Harar B	4	9	69.2
Total (%)	20	100	71.4

Classification Result of Morphological Features of Hararghe Coffee Genotype Samples

In this section morphological features of HCGSs that are grown at Mechara Agricultural research center using the same agronomical management were used for training and testing. Sixty Hararghe coffee genotype samples of morphological features were extracted; the mean features result was attached in appendix (E). The multilayer feed forward neural network with back propagation (BP) algorithm was employed for the classification of the coffee samples. First, random selection of data was used for the network training and the residual data was used for the testing. The classifier architecture designed in such a way that it has six inputs and two output neurons with twenty hidden layers. The classification result of Hararghe coffee genotypes samples by using ANN were shown in Table 10.

Table 10. Confusion matrix results of HCSs by morphological feature.

	Harar A	Harar B	Total (%)
Harar A	183	24	88.4
Harar B	12	171	93.4
Total (%)	93.8	87.7	90.8

As indicated in Table-10, the summary result (confusion matrix) of ANN classifiers using shape and size features, out of the total of 390 images, 354 images (90.8%) were correctly classified and the remaining 36 images (9.2%) were misclassified. Close analysis of the result of classification using shape and size features showed that the classification accuracy of Harar A and Harar B coffee genotype samples were 93.8 and 87.7 in percent, respectively. Harar A coffee genotype samples were misclassified as Harar B (12 images (6.2%)) and Harar B coffee genotype samples were also misclassified as Harar A (24 images (12.3%)).

From Table-10, one can deduce that the classification result using morphological features of the Hararghe Coffee genotype samples which are grown at the same environment and agronomical management for the last nine years were not hundred percent correctly classified into their origins of collection. Morphological feature difference of coffee beans was influenced by botanical variety and environmental growth circumstances (EAFCA, 2008).

Classification Result of Color Features of Hararghe Coffee Genotype Samples

Twelve color features were used as input while the target outputs were two. The classifier architecture was set-up so that it has 12 inputs corresponding to the 12 color features, 10 hidden layers and two output layers of neuron. Sixty Hararghe coffee genotype samples of color features were extracted; the mean features result was attached in appendix (F). The classification result based colour features are shown in Table11 of confusion matrix. The Table shows the classification result of 390 images of which 70% (272 images) used for the training, 15% (59 images) for validation and 15% (59 images) data used for testing.

Table 11. Confusion matrix of HCSs using color features.

	Harar A	Harar B	Total (%)
Harar A	3	1	75
Harar B	192	194	50.3
Total (%)	1.5	99.5	50.5

The summary result of ANN classifier indicates that out of the total of 390 images, 197 images (50.5%) were correctly classified and 193 images (49.5%) were misclassified. The accuracy of result of classification using color features shows that Harar A and Harar B genotype were 1.5% and 99.5%, respectively. This means 192 images (98.5%) of Harar A genotype coffee samples were misclassified as Harar B while only 1 image (0.5%) of Harar B coffee genotype samples were misclassified as A.

Environment has a strong influence on coffee bean colors (Decazy *et al*., 2003). Altitude, daily temperature fluctuations, amount and distribution of rainfall and the physical and chemical characteristics of the soil are very important factors. Climate, altitude, and shade play an important role through temperature, availability of light and water during the ripening period (Decazy *et al*., 2003). Rainfall and sunshine distributions have a strong influence on flowering, bean expansion, and ripening (Harding *et al*., 1987). From the result, the color features of Hararghe coffee accession samples were almost all tends to Harar B, because Hararghe coffee accession grown at the same environment, the same altitude and the same agronomic management for the last nine years.

Classification Result of Texture Features of Hararghe Coffee Genotypes Samples

Sixty Hararghe coffee genotype samples of texture features were extracted; the mean features result was attached in appendix (G). In this set up, 4 textural features were used as input to the neural network with 4 number of neuron as the input layer and 2 output neurons which corresponds to 2 predefined outputs. To determining the correct number of neurons to use in the hidden layer should be try and error method. So, the numbers of neurons in the hidden layer was twenty. Deciding the number of neurons in the hidden layers is a very important part of deciding your overall neural network architecture. Though these layers do not directly interact with the external environment, they have a tremendous influence on the final output. Both the number of hidden layers and the number of neurons in each of these hidden layers must be carefully considered. Using too few neurons in the hidden layers result in something called under fitting. Under fitting occurs when there are too few neurons in the hidden layers to adequately detect the signals in a complicated data set (Panchal *et al*., 2011). Using too many neurons in the hidden layers can result in several problems. First, too many neurons in the hidden layers may result in over fitting. Over fitting occurs when the neural network has so much information processing capacity. The limited amount of information contained in the training set is not enough to train all of the neurons in the hidden layers.

Table 12. Confusion matrix results of HCSs by texture features.

	Harar A	Harar B	Total (%)
Harar A	161	40	80.1
Harar B	34	155	82
Total (%)	82.6	79.5	81.0

As indicated in the Table12 the summary result of ANN classifier using texture features alone shows that of the total of 390 images, 316 images (81.00%) were correctly classified and 74 images (19%) were misclassified.

The classification accuracy of Harar A and Harar B coffee genotype samples were 82.6% and 79.5%, respectively. Thus 34 images (17.4%) of Harar A coffee genotypes samples were misclassified as Harar B and 40 images of Harar B coffee genotypes samples were misclassified as Harar A. From the result we could say that Hararghe coffee genotype samples that are grown at the same agronomical management share textural features, with Hararghe coffee samples that are grown at different agronomical management, which may be attributed to the proximity of the region from which the coffee samples were drawn which possibly make them share certain genotype similarities (Habtamu, 2008).

Classification Result of All Features of Hararghe Coffee Genotypes Samples

In this setup, twenty two features which correspond to six shape and size features, twelve color features and four textural features of Hararghe coffee were used as input to the neural network hence; in total there were twenty two neurons in the input layer. This set up has two output classes corresponding to the predefined coffee growing regions (Harar A and Harar B) while the number of neurons in the hidden layers were twenty obtained by trial and error method.

The classification result based on all features is shown in Table_13 as confusion matrix. Table shows the correct classification and misclassification of 390 images used for training (70% (272 images)), validation (15% (59 images) and testing (15% (59 images) data.

Table 13. Confusion matrix results of HCSs by all features.

	Harar A	Harar B	Total (%)
Harar A	134	75	64.1
Harar B	61	120	66.3
Total (%)	68.7	61.5	65

As indicated in Table 13, the summary result of ANN classifier confusion matrix on all the features showed that out of the total of 390 images, 254 images (65%) were correctly classified and 136 images (35%) were misclassified. The result of ANN classification using all feature showed that the classification accuracy of Harar A coffee genotype samples and Harar B coffee genotype samples were 68.7% and 61.5%, respectively. Thus 61 images (31.3%) Harar A coffee genotype samples were misclassified as B and 75 images (38.5%) Harar B genotypes were misclassified as Harar A.

From the result we could say that the Hararghe coffee genotype samples which are grown at the same place with the same agronomical management were not correctly classified to their origin of collection, because geographical designation of Harrar A (East Hararghe) and Harrar B (West Hararghe) might be the quality of coffee lots have a chance to be classified beyond the geographical locations (Ethiopian Coffee Buying Manual, 2011; ECX, 2009).

4. Summary and Conclusion

In this work, coffee samples from Ethiopia Commodity Exchange (ECX) and sixty Hararghe coffee genotype beans of both classes (Harar A and Harar B) from Mechara Agriculture Research Center (McARC) were objectively collected. The images of the collected samples were captured and undergone through different image processing steps and finally six shape and size, four textures and twelve color features of the image were extracted and classified into their genotype categories of HCSs. The summary result of ANN classifier confusion matrix on the morphological feature shows that from the total of 390 images of Hararghe coffee samples, 354 images (90.8%) were correctly classified and 36 images (9.2%) were misclassified. Therefore, the classification result of morphological features, show that the genotype Hararghe coffee samples which are grown at the same place with the same environment and same agronomical management for the last 9 years, were not correctly classified into their origins of collection. The summary result of ANN classifier confusion matrix on the color feature alone showed that from the total of 390 images, 197 images (50.5%) were correctly classified and 193 images (49.5%) were misclassified. The summary result of ANN classifier confusion matrix on the texture feature alone showed that from the total of 390 images of Hararghe coffee genotype samples, 316 images (81%) were correctly classified and 74 images (19%) were misclassified. The summary result of ANN classifier confusion matrix on all the features showed that from the total of 390 images, 254 images (65%) were correctly classified and 136 images (35%) were misclassified.

In general, the overall result showed that the Hararghe Coffee genotype samples which were grown at the same place with the same environment and same agronomical management for the last nine years were not correctly classified into their origins of collection. However, the experimental results showed that morphological features have more accuracy to classify genotype Hararghe coffee samples based on growing regions in artificial neural network (ANN) classification. Therefore, when used under properly controlled conditions, DIP is a good discriminating and indispensable tool for classification of coffee it may also use not only for geographical discrimination but also

in grading the coffee quality. By understanding the factors that affect the image quality and selecting features that have discriminating power, robust classification model can be built for classification purpose of coffee bean. The 60 genotypes were grown in one location and originally collected only from nine districts of the two Hararghe zones; therefore, the same work should be extended for other region genotypes.

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7. Spatio-temporal Analysis of Climate Dynamics in Eastern Ethiopia: A Road Map for Agricultural Water Management and Sustainable Rural Livelihoods

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Abstract: In a nation like Ethiopia where most of the livelihood support system depends on rain-fed agriculture, realization of sustainable rural livelihoods has made climate to remain a determining critical variable in production feedback loop. Taking shortfall of detailed research works that reveal spatio-temporal variability of climate and considering the existing information gaps, this research was initiated with the general objective of analyzing spatio-temporal climate variability in eastern Ethiopia and its implication. Data is obtained from NMSA; key informant interviews and FAO local climate database. Various climate variability descriptors and statistical tests are undertaken using SPSS with integration of ordinary kriging in ArcGIS. Results showed that, there was diverging maximum and minimum temperature trend, tendency of decreasing inter-annual rainfall especially in belg and summer seasons with statistically significant trends. Rainfall is also experiencing unpredictable nature in its onset and cessation in major agricultural season. More importantly, there is sporadic rainfall pattern manifested by high Coefficient of Variability (CV) and Precipitation Concentration Index (PCI) values. Additionally, the site is experiencing decreasing number of rainy days and frequent meteorological droughts. This variability pattern is found a challenge for sustainable agricultural production. Therefore, better coping and adaptation strategies have been recommended.

Keywords: Climate variability; eastern Ethiopia; Rural livelihoods and Water management.

1. Introduction

Currently climate variability and change is a global agenda and its developmental challenge is an established reality (Dube & Phiri, 2013). Its risk magnitude is projected to escalate in the future (IPCC, 2013). As per this, it is found burning research and

development policy area (Malone, 2009). In developing nations like Africa the risks and vulnerability magnitude is very high. One third of African population lives in drought-prone areas and 220 million are exposed to drought each year (UNFCCC, 2007). It is expected to cost US$ 20-30 billion over the next 10 to 20 years for financing adaptation activities to this perturbation (AfDB, 2011). Similar to other developing nations, eastern Africa is repeatedly shocked by climate related vagaries where livelihood support system is primarily depend on rain-fed pastoral and agro-pastoral economy (Funk *et al*., 2012). Similarly, Ethiopia has also experienced livelihood shocks emanated from climate variability manifested by recurrent drought episodes and livelihoods production failures. Until 2025, it is predicted to reduce national GDP by 3 to 10% (Evans, 2012).

In due course of observed climate variability and its related risks, adaptation is an inevitable option for sustained agricultural production and rural livelihoods. Indeed, informed adaptation and coping mechanisms reconsiders the concept of '*what adapts and adaptation to what*' (Smit *et al*., 2000). Therefore, as Ethiopia have diverse agro-ecology and farming systems, detailed regional studies are highly demanding (Adugna, 2005) to design appropriate adaptation option tailored to each variability pattern in terms of agricultural water management to sustain rural livelihoods. With this argument, there are some studies undertaken in a national level like dry spell and climate extremes in Ethiopia (Sileshi & Camberline, 2008), dry spell trend and precipitation variability (Yilma & Zanke, 2004), local climate change signals (Mengistu & Eyale, 2011) and others with specific regional focus like Central Ethiopian Rift Valley (Kassie *et al*., 2013), in northern Ethiopia (Gebre *et al*., 2013) and Amhara Region (Dereje *et al*., 2012; Mulugojam *et al*., 2013) have tried to explain the state of climate dynamics and its implied implication on agricultural livelihoods. In spite of eastern Ethiopian complex climate, agro ecology, production system and frequent climate induced livelihood shocks at most patches of eastern Ethiopia, there is found paucity of detailed studies. Therefore, this study has tried to reveal the state of climate dynamics in time and space at eastern Ethiopia by using the state-of-the-art climate variability descriptors and analytical methods.

2. Materials and Methods

The study area

The study area is located within 3°32'56" and 9°52'8" N Latitude and 39°9'43" and 48°0'0" E Logitude (Figure 2). The geographic delimitation of the study site encompasses spatial extent bounded as "Eastern Census Division of Ethiopia" in *Atlas of Ethiopian Rural Economy* (CSA, 2006). It extends from a drought prone pastoral and agro-pastoral lowlands to some afroalpine climatic situations (CSA, 2010) with varied vegatative and biophysical characteristics.

Data collection and analytical methods

Primarily the study utilized four data sources, *viz*, metreological data from National Metreological Service Agency (NMSA), key informant interviews, and Food and Agricultural Organization(FAO) database. For the study purpose, 26 metreological stations were selected based on long-term data availability, type of data recorded and

location of stations to acount phisiographic and agro-climatic situations of the study site. Key informant interview was done with Agricultural Development Agents(DAs) within representative agroecologies purposively selected based on their accessibility for the researcher to have information concerning climate variability and its implication on agricultural activity and respective livelihood production. FAO database local climate estimator (LocClim) software was also used to identify long-term growing season for areas where representative metreological stations for key interviews was undertaken.

Obtained meteorological data was checked for its consistency and completeness. Stations that had incomplet data and annual records that had less than 85% record were ignored from analysis. As per this, based on data completeness and consistency stations Imme, Errer, Filtu, and Gode were also ignored from analysis. Missing dataset was filled by long-term averages, if it have greater than 85% records within observation time span. Relative temporal variability of temperature and rainfall is analyzed by coefficient of variability(CV) (Woldamlak, 2009):

$$CV = \frac{\sigma}{\mu}100 = \frac{\sqrt{\frac{\sum_{i=1}^{n}(x_i-\mu)^2}{n-1}}}{\frac{1}{2}\sum_{i=1}^{n}x_i}100$$

where σ is standard deviation of a given dataset, μ is mean and n is number of observations while x_i is the ith observation of a given data set. Drought occurrence, frequency and duration were quantified by Standardized Precipitation Index (SPI) (Agnew & Chappel, 1999) as:

$$SPI = \frac{P_t - P_m}{\sigma}$$

where SPI is standardized rainfall anomaly, P_t annual rainfall in year *t*, P_m is long-term mean annual rainfall over a given temporal span and σ represents standard deviation of rainfall over the period of observation. Even though there are little deviations on interpretation of SPI drought severity classes, literatures such as Lloyd-Hughes & Saunders (2002) have classified SPI values into drought severity classes of 0 to -0.99 as mild drought, -1 to -1.49 moderate drought, -1.5 to -1.99 severe drought, and $\leq$-2 extreme drought of which this study has adopted for its operationalization. Rainfall seasonal concentration, distribution and erosivity power is analyzed by Olivers Precipitation Concentration Index (PCI) as given in de Luis *et al.* (2011).

$$PCI = \frac{\sum_{i=1}^{12}{P_{it}}^2}{\left(\sum_{i=1}^{12}P_{it}\right)^2} \times 100$$

where P_i is monthly precipitation of the *i*th month in year *t*. PCI values less than 10 indicate uniform distribution of rainfall, 10 to 15 moderate concentration, 15 to 20 reveals irregular distribution while greater than 20 shows strong irregularity of rainfall distribution (Oliver 1980 cited in de Luis *et al.* (2011). Computed PCI and CV values are interpolated in ArcGIS using ordinary krigging to see the spatial variability of rainfll. Presence of long-term trend is tested by Spermans *roh* test (Nicolson, 1985 cited in

Dereje *et al.*, 2011) and overall explained change is analyzed by coefficient of determination(R^2) in Statistical Package for Social Sciences (SPSS).

3. Results and Discussion

3.1. Long-Term Trends in Temperature and Rainfall

Taking its great implications on normal functioning of crop phenology and agricultural water availability, maximum and minimum temperature trends, inter-annual and seasonal rainfall has been given greater emphasis. As per this, in most parts of eastern Ethiopia there is a statistically significant increasing maximum daily temperature and decreasing minimum daily temperature. This creates an increasing monthly surface temperature ranges. The presence of maximum temperature at the day time and an extremely falling minimum temperature in seedling and flowering period can have detrimental implications for cereal producing areas.

Increasing daily temperature range reduces productivity of cereal crops (Lobell, 2007). Rasule *et al.* (2011) have reported that, escalations of daily maximum temperature can cause crop stress and have big implications on crop yield. Similarly, Jerry and Prueger (2015) have claimed that temperature scenarios warmer than long-term averages are causing reductions in maize production. This is because of maximum temperature creates abnormal water stress that detrimentally affects crop phenology. Similar to temperature patterns, except in some stations, there is no a statistically significant trend in inter-annual rainfall. Significant reductions and increments are profound in inter-seasonal spring (*Belg*) and summer (*Kiremit*) rainfall whose deviations can have an impact on agricultural production and livelihood sustainability. As reported by Sileshi and Camberline (2008) reduction and temporal variability pattern is spatially heterogeneous across study site.

Table 7. Long-term temperature and rainfall trends.

	Max T in °C		Max T in °C		Inter-annual rainfall			Long-term spring(*belg*)			Long-term summer(*kiremit*)		
Station	Trend	R^2	Trend	R^2	Trend	Constant	R^2	Trend	Constant	R^2	Trend	Constant	R^2
Abomsa	0.005	0.066*	0.001	0.004	-6.65	1007	0.112*	-1.21	248	0.017	-1.76	533	0.019*
Adele	0.011	0.124	0.007	0.03*	10.96	718.6	0.103	-10.27	334	0.288*	16.13	292	0.305
Degehabur	∞		-0.004	0.017*	-4.41	416.6	0.078	-3.38	242	0.068	-2.50	131	0.076
Alemaya	0.003	0.057*	∞		3.08	750.7	0.023	-1.55	282	0.016	4.91	357	0.155*
Delomena	0.004	0.017*	0.13	0.072*	13.92	756.6	0.150	11.01	273	0.121	7.76	125	0.131
Gelemso	-0.002	0.004	0.004	0.014	-13.51	1156	0.097	-2.43	358	0.017	-5.87	563	0.033
Ginir	0.004	0.037*	∞		25.61	652.2	0.274*	9.82	294	0.070	11.05	113	0.257*
Robe	0.003	0.045*	0.002	0.003	-1.31	964.7	0.005	-1.11	274	0.013	3.45	474	0.072
Jijiga	0.003	0.031	0.003	0.013	1.130	544.9	0.005	-0.21	226	0.000	0.47	239	0.004
Kebridhar	0.005	0.037*	-0.003	0.004	-7.32	321.2	0.142	-5.09	173	0.254*	1.77	5.01	0.014
Meiso	0.006	0.033*	0.007	0.004	12.85	619.5	0.11	3.17	180	0.068	15.53	255	0.312*
Kulumsa	0.001	0.007	-0.003	0.027*	-1.70	853.9	0.026	-1.19	274	0.016	1.36	430	0.028
Melkasa	0.002	0.008	-0.003	0.013*	7.55	693.1	0.279*	0.63	152	0.006	6.03	464	0.230*
Metehara	0.003	0.029*	0.002	0.005	-2.11	540.6	0.045	-0.62	142	0.006	-1.14	319	0.018
Moyale	-0.003	0.013	0.001	0.001	-2.61	593.1	0.010	-1.50	292	0.008	-0.46	46	0.016
Neghele	0.005	0.041*	0.01	0.0442*	-4.30	713.6	0.077	-4.94	442	0.127*	2.50	30.2	0.135*
Seru	0.10	0.151*	∞		2.47	1078	0.001	0.42	397	0.000	8.96	352	0.123
Sinana	0.004	0.054*	-0.008	0.074*	-4.05	919.9	0.075	-1.08	355	0.009	-2.73	387	0.090
Girawa	-0.003	0.011	0.003	0.027*	-4.20	1010	0.023	-6.16	455	0.149*	-0.06	445	2E-05
Hirna	0.01	0.313	-0.015	0.0159*	2.51	967.9	0.01	-7.57	397	0.140	8.66	499	0.156*

* *Statistically significant at 0.05 margin of error.*

3.2. Precipitation Variability and Meteorological Drought Incidences

Table 8: Rainfall CV and trends in number of rainy days.

Station	% Coefficient of variability			Number of rainy days			
	Annual	*Belg*	*Kiremit*	Mean	Trend	Constant	R^2
Abomsa	17	31	20	88	-0.40	93.6	0.032
Adele	19	34	31	102	1.05	92.8	0.112
Degehabur	41	62	90	30	0.22	25.71	0.076
Alemaya	21	38	24	85	-0.02	85.1	0.00
Delomena	27	54	68	79	1.12	64.0	0.158
Gelemso	31	40	46	90	0.82	79.3	0.085
Ginir	34	59	59	76	-0.71	83.1	0.089
Robe	15	28	19	116	-0.42	121.1	0.068
Jijiga	23	42	26	61	-0.22	63.6	0.037
Kebridhar	53	57	381	19	-0.51	24.3	0.163
Meiso	25	28	34	76	-0.17	101.7	0.028*
Kulumsa	12	35	17	99	1.49	62.2	0.258
Melkasa	16	47	21	73	-0.06	74.0	0.005
Metehara	17	53	24	60	-0.32	64.4	0.182*
Moyale	53	58	90	57	-0.50	64.0	0.072
Neghele	21	33	87	63	0.04	61.9	0.001
Seru	35	54	36	96	-1.97	17.6	0.218*
Sinana	16	29	24	97	-1.06	113.1	0.315*
Girawa	23	34	26	81	-0.92	2.40	0.137*
Hirna	18	47	26	90	-0.07	0.60	0.001

**, statistically significant at 0.05 margin of error.*

As presented in Table 2, eastern Ethiopia has experienced acute inter-annual and seasonal rainfall variability which is manifested by larger coefficient of variability. A rainfall coefficient of variability greater than 30% is reported as a challenging threat for

rain-fed crop production in Ethiopia (CSA, 2011). Similar to findings of this study, others like Woldeamlak (2009) and Mulugojam *et al.* (2013) have reported that in Ethiopia *Belg* and *Kiremit* coefficient of variability is greater than inter-annual variations especially in lowland agro-pastoral areas (CSA *et al.* 2010) where livelihood production is highly associated with climatic scenarios (Okoti *et al.* 2014). As *Kiremt* and *Belg* seasons were main agricultural growing seasons, it created a formidable challenge for agricultural production (Woldeamlak, 2009). More than its relative variation, inter-annual and seasonal rainfall has shown a decreasing tendency though it is not statistically significant for all stations.

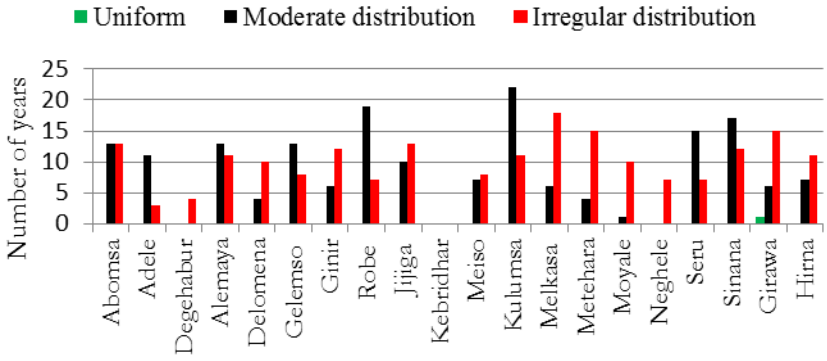

Figure 5. Seasonal rainfall distribution pattern

This variability of rainfall is also attested from rainfall distribution patterns generated from computed precipitation PCI values (Figure 1). Almost all stations did not experience uniformly distributed rainfall pattern. With past 30 years, they experienced from moderately towards irregularly distributed pattern. This indicates that much amount of annual rainfall share is precipitated within little days (Martin-vide, 2004). This kind of rainfall is highly powerful, which cause flooding and soil erosion (de Luis *et al.*, 2011) that can damage seedling crops.

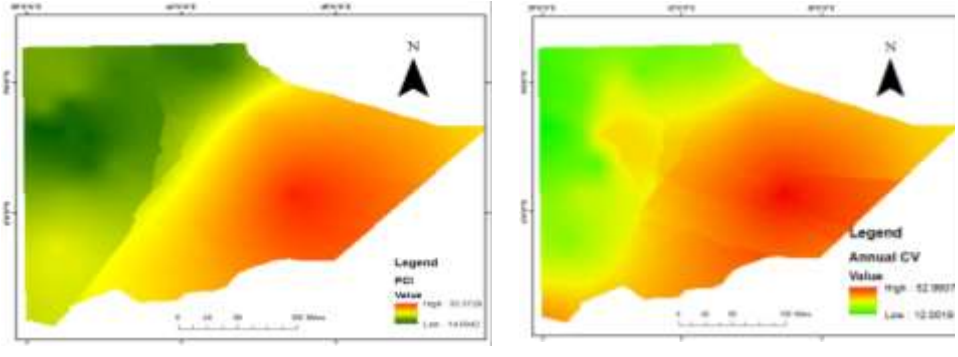

Figure 6. Spatial pattern of PCI and coefficient of variability.

Coupled with seasonal and annual rainfall variability and its irregular pattern, the area is also repeatedly affected by meteorological drought incidences, which are attested from computed SPI values. As shown on Figure 3, within 30 years period, each station has experienced much drought years than normal precipitation scenario ranges from moderate to extreme drought years. Within temporal scale of analysis, each station has experienced at least one to three severe drought episodes and one extreme drought episodes (Figure 3). Though drought episode is unpredictable, its pattern resembles a monotonicity of two to three years whatever its magnitude varies (Funk *et al*., 2012).

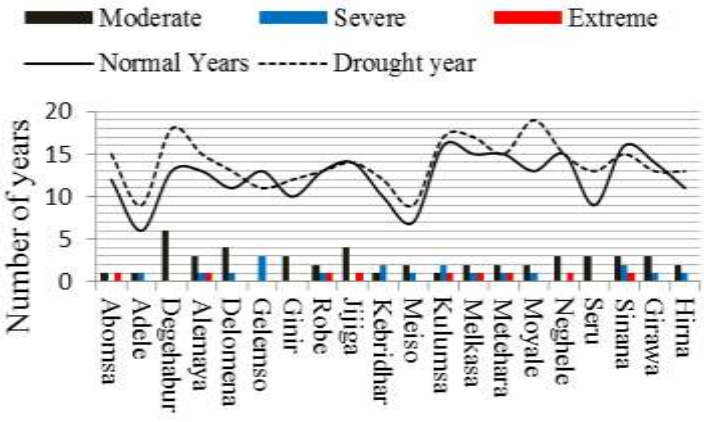

Figure 7. Meteorological drought frequency.

3.3. Changes in Growing Season, Onset and Cessation of Rainfall

Taking information generated from FAO local climate estimation database for some representative areas, *viz*, Meiso, Alemaya, Kulumsa, Abomsa and Adele. Extended interview made with DAs has showed that, cessation of rainfall before end of growing period, delay on its normal onset and onset is followed by extended dry spell and sometimes fails intensely beyond its usual scenario where in both aspects distorts agricultural activity. When these happen at the *belg* season, it creates constraint for field preparation and phonological disorders of sown crops. Due to these, length of growing season is contracted (Fink *et al.* 2012). Contrary to these, there is also reported hailstorm at crop maturity season and extension of rainfall at the harvest season where it causes damage of matured crops and initiates crop diseases like blight fungus that perishes cereals especially wheat and sorghum. In all key interview sites, unpredictable nature of rainfall is reported that livelihoods production is mainly determined by rainfall scenario at field preparation, sowing and harvesting season. These variability patterns are also reported by Woldamlak (2009) and CSA (2011).

4. Conclusions and Recommendations

Rather than climate change, eastern Ethiopia is experiencing unpredictable climate variability. In all stations, there was an observed increasing daily maximum temperature and reductions in daily minimum temperature, which increases diurnal temperature

range. Contrary to these, rainfall has shown a tendency of reductions within past 30 years but its trend is not statistically significant except at some patches. This is ascertained by highly seasonally concentrated and irregularly distributed rainfall. This cause's extreme relative variability of inter-annual rainfall but coefficient of variability is pronounced in *Belg* and *Kiremt* seasons, which have significant agricultural and livelihoods production significance. Frequent meteorological droughts were also causing precipitation deficit and livelihood shocks. Early onset and cessation of rainfall, occurrence of dry spell in sowing, field preparation season and extension of rainfall in harvesting season were challenging crop production. This variability has locational and temporal heterogeneity, which demands site specific coping and adaptation strategies. With these conclusions, the following coping and adaptation strategies were recommended to envision sustainable rural livelihoods through better agricultural water management in eastern Ethiopia.

- ✓ For frequent precipitation deficit and meteorological drought, research and extension should focus on adoption of water stress tolerant crops and adoption of moisture responsive agricultural strategies.
- ✓ As there is high rainfall seasonality and concentration of rainfall that can cause soil erosion, there should community based soil and water conservation activities that account precipitation pattern and biophysical characteristics of the area.
- ✓ As decreasing number of rainy days reduce length of growing period, extension should focus on agricultural crops that need shorter growing period.
- ✓ As most patches of eastern Ethiopia has experienced high inter-annual and seasonal coefficient of variability coupled with high temperature that works to cause temporal moisture deficit, facilitation of moisture retention activities at farm level.
- ✓ Distorted rainfall in pastoral and agro-pastoral areas can cause pasture shortage for livestock production. For resilient agro-pastoral livelihoods, there should be an introduction of modern forage system, introduction of watering points from ground water and community based water harvesting to reduce climate variability risks.
- ✓ Undertaking spatially referenced weather forecast research and organizing public domain platforms where farmers, agro-pastoralists and agricultural practitioners can access weather information.
- ✓ There should also national agricultural insurance schemes for better resiliency.

5. Acknowledgement

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8. Spatial Modeling of Soil Erosion Dynamics and its Implication for Conservation Planning: The Case of Gobele Watershed, East Hararghe Zone, Ethiopia

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Abstract: The objective of this study was to examine the magnitude of soil erosion during the period from 2000 to 2016 in the Gobele Watershed, East Hararghe Zone, Ethiopia. The Landsat satellite images data from Enhanced Thematic Mapper Plus (ETM+) 2000, Operational Land Imager (OLI) 2016, rainfall data, soil map and Digital Elevation Models (DEM) were used for the analysis. Moreover, Geographic Information System (GIS) and the Revised Universal Soil Loss Equation (RUSLE) were used to estimate the magnitude of soil loss. The result showed that the mean annual soil loss induced by water erosion was decreased from 51.04ton/ha/yr in 2000 to 34.26ton/ha/yr in 2016. The results were greater than that of the maximum tolerable soil loss estimate at the national scale and normal soil loss tolerance (SLT) values. Based on soil loss rates, erosion risk classes that range from very low to extremely high were identified. The high, very high and extremely high areas decreased by 0.23%, 0.21%, and 0.05% of the total study area, respectively. But, erosion risk areas in the class of very low increased from 77.52% in 2000 to 87.02% in 2016. The results revealed that the status of soil erosion in the Gobele Watershed was improved over the study period. Based on soil erosion rates, trends in erosion risk areas and multi criteria decision rules, soil and water conservation (SWC) priority were identified. Eight conservation priority levels were obtained for locations with a high and increasing risk of erosion at the watershed level. The top three priority levels marked for urgent soil and water conservation respectively cover about 0.04%, 0.49%, and 0.83% of the total watershed area. Much of the three priority areas are located to north, northwest of the Gobele Watershed. It is, therefore, very critical to undertake appropriate intervention measures by beginning on these priority areas for sustainable land resource management in the watershed.

Keywords: GIS; Landsat satellite images; RUSLE; Soil erosion; Soil and water conservation

1. Introduction

Soil erosion is a naturally occurring environmental process by which soil materials are displaced, transported and deposited in downstream areas by wind, water or gravitational forces (Haan *et al*., 1994; Adediji *et al*., 2010; Boardman, 2013). In the context of water induced soil erosion, removal of soil particles is the result of raindrops, while the transportation process is carried out by surface runoff (Vrieling, 2006). Though soil erosion is the result of the interplay between erodibility and erosivity factors, human activities such as cultivation on upslope areas, deforestation, extension of urban areas and roads, and uncontrolled and overgrazing aggravate the problem (Abate, 2011; Kertesz and Gergely, 2011; Meshesha *et al*., 2014). In connection to this, Knapen *et al.,* (20006) reported that irregular terrain and surface topography are the other causes of soil erosion. Several studies have shown that soil loss by water erosion is highly associated with on and off-site effects (e.g., land and water quality degradation, emission of soil organic carbon, decrease in agricultural productivity, impacts on biodiversity and ecosystem etc.) (Sutcliff, 1994; Lal, 2004; Saravanan *et al*., 2010; Arekhi *et al*., 2012; Mutowo and Chikodzi, 2013; Jiang *et.al*., 2014; Castrignano *et al*., 2008; Panagos *et al*., 2015; Bhattacharyya *et al*., 2016. It was also found that in developing countries that largely rely on efficiency and workability of their soil, loss of the most productive topsoil has caused severe economic and environmental impacts (Lal, 1998; Fazlı *et al*.,2012; Rabia, 1996; Ermias *et al*., .2006; Hudad, 2010; Kassu, 2011; Amsalu and Mengaw, 2014). In relation to this, Nill *et al.* (1996) reported that, "huge investment in a civil engineering works aiming at renovating the results of erosion is comparatively higher than investments in soil conservation."

The impacts of soil erosion risk are spatially found variable among diverse agro-ecological, biodiversity and micro environments throughout the world. In Ethiopia where agriculture is the backbone of the country's economy and sustains the livelihood of about 85% of population, loss of productive soil by erosion has massive environmental and economic impacts (Erenstein, 1999; Gizachew, 2015; Lal, 2001; CBPWM, 2005; CRGES, 2011). There are intense soil and water conservation (SWC) and management efforts in Ethiopia. Despite this, land degradation has continued to threaten livelihood, food security, and economic growth in the country (FAO, 1986; Sutcliff, 1993; Tamene and Vlek, 2005; Tamene and Vlek, 2006).

Reports from FAO (1986) estimated the annual soil loss in Ethiopia is about 1.5 billion tones. According to the study by FAO (1984), about 27 million hectares of the land, nearly half of the Ethiopian highland areas, was affected by serious erosion. Particularly, in Wollo, Tigray and Hararghe, almost half of the agricultural lands have soils with a depth of less than 10cm(FAO,1984). This problem has decreased the soils' production potentials. Moreover, the annual productivity potentials of lands in Ethiopian high land areas were estimated to decline by 2.2% per year (FAO, 1986; Gebreyesus and Lulseged, 2014).

In response to rapid population growth, accelerated threats of water induced soil erosion risk on agricultural productivity, food security and ecosystem service, and to ensure sustainable utilization of natural resource, the Ethiopian government has taken SWC measures (RDPS, 2003; GTP, 2010). Since it is difficult to address conservation problems at a time, it is important identifying areas that are vulnerable to soil erosion **(**Hurni, 1988; Tripathi *et al*.,2003). Given the shortcomings in the traditional soil erosion risk assessment methods, one needs a more systematic approach to do effective soil erosion assessment (Barakat *et al*., 2014; Ganasri and Ramesh, 2015). Substantial efforts have so far been made to local and global levels to assess the magnitude of soil erosion risk. This has certainly provided a promising ground for sustainable use planning and an appropriate SWC strategies development at the watershed or basin scales (Claessens *et al*., 2008; Tekwa *et al.* 2016).

So far, several models for predicting soil erosion have been developed and applied. The major models include Modified Universal Soil Loss Equation (MUSLE), the Universal Soil Loss Equation (USLE), Morgan-Morgan-Finney (MMF), Agricultural Non-Point Source Model (AGNPS), Erosion Productivity Impact Calculator (EPIC), Water Erosion Prediction Project (WEPP), Soil and Water Assessment Tool (SWAT) and European Soil Erosion Model (EUROSEM) (Williams, 1975; Wischmeier and Smith, 1978; Morgan *et al*., 1984; Young *et al*., 1989; Sharpley and Williams, 1990; Flangan and Nearing, 1995; Arnold *et al*., 1998; Morgan *et al*.,1998). Among these models, the RUSLE is the most widely applied empirical model for offering quantitative soil erosion estimation and conservation planning around the globe (Renard *et al*., 1997; Laflen *et al*., 2004; Adediji *et al*., 2010; Panagos *et al*., 2015; Chang *et al*., 2016).

Nowadays, the RUSLE, in combination satellite remote sensing and Geographic Information Systems (GIS) mapping techniques, was found to be a convenient tool for soil loss assessment and successful conservation planning (Gebreyesus *et al*., 2014; Mellerowicz *et al*., 1994; Millward and Mersey, 1999; Ratnam *et al*., 2005; Li, 2011). Over the past few years, the RUSLE and prediction models have been applied in different parts of Ethiopia for soil erosion risk assessment and conservation planning by integrating them with a remote sensing data and GIS technology. For instance, Ghebreyesus *et al.* (2014) examined soil erosion risk in Mai-Negus catchment, northern Ethiopia using Morgan-Morgan-Finney Model and reported the average annual soil loss rates of 26 ton/ha/yr, which is above the maximum tolerable soil loss threshold predicted at national level. On his part, abate (2011) analyzed soil loss rates using the RUSLE for soil conservation planning based on erosion risk level in the Borena Woreda of South Wollo Highlands. Likewise, Kiflu (2010) applied RUSLE and Multi-criteria Analysis (MCA) to prioritize critical soil erosion risk areas for conservation measures in Mojo river watershed. Ayele (2011) also explored soil erosion risk using similar techniques in Holeta watershed in Central Oromiya, Ethiopia.

Furthermore, Israel (2011) reported the mean annual soil loss rate of 58.3ton/ha/yr, and recommended the implementation of conservation measures to reduce the on-site and off-site effects of soil erosion in Dire Dam watershed. In a

related study conducted on Lake Haramaya catchment Senti *et.al* (2014) suggested the importance of an integrated physical soil erosion control and conservation measures to tackle the on and offsite effects of soil erosion. However, none of these addressed the change dynamics in soil erosion risk. Therefore, this study was designed to: (i) examine the magnitude of soil loss rates; (ii) assess the dynamic changes in soil erosion risk from 2000 to 2016 in the Gobele Watershed, East Hararghe Zone, Ethiopia; and (iii) identify priority areas for SWC in the study area.

2. Materials and Methods

Description of the Study Area

The Gobele Watershed is one hydrological watershed within Wabi Shebelle Basin, located in east Hararghe Zone in Oromia National Regional State, Ethiopia. The astronomic location of the watershed extends from 80 48' 30"N to 90 24' 00"N latitude and from 410 42' 30"E to 420 10' 50" E longitude, with elevation ranges between 974 and 3264meters above mean sea level (Figure1). It covers a surface area of 237,786.44 hectares. Topographically, about 77.51%, 21.58%, and 0.91% of the total study area has a slope gradient ranging from 0% to 10%, 10% to 30%, and 30% to 100%, respectively. The mean annual rainfall of the watershed is 820.01mm, with August (152.31mm) and April (1.16 mm) being the wettest and the driest months, respectively (NMA, 2015).

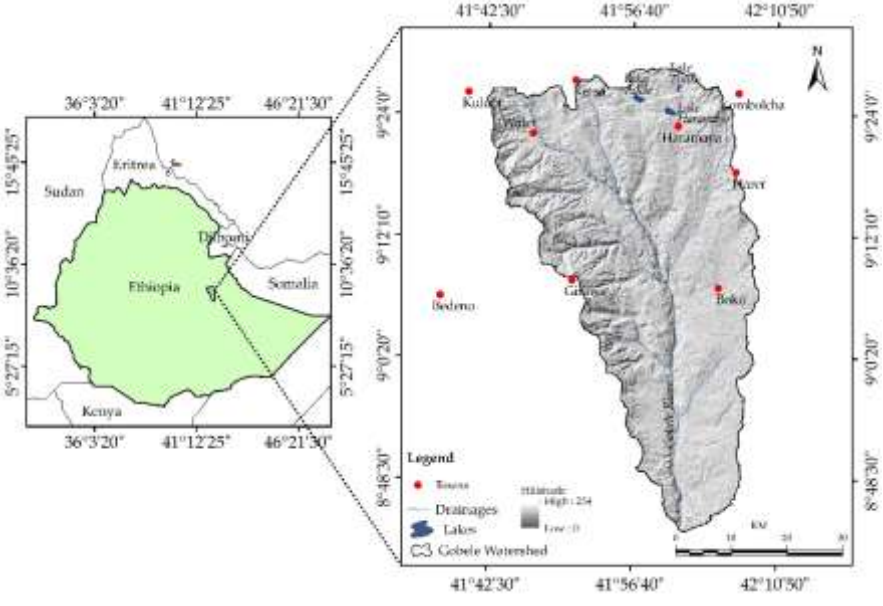


Figure1. Location of the Gobele Watershed, Eastern Ethiopia.

Geospatial Datasets

For this study, geospatial datasets were collected and processed in a raster format to suit the RUSLE model. A sixteen-year data (1999-2015) on distribution of the mean monthly rainfall data was obtained from national meteorological agency (NMA,

2015). Moreover, a multi-temporal Landsat satellite images were employed. Satellite data from Landsat7 Enhanced Thematic Mapper Plus (ETM+) acquired on March 26, 2000 and Landsat8 Operational Land Imager (OLI) acquired on March 14, 2016 (bearing Path 164 and Row53) were downloaded in a GeoTIFF file format from Landsat images archives in United States Geological Survey (USGS) website (Earth Explorer, 2016). In addition, a 30 x 30meters grid size Digital Elevation Model (DEM) was accessed from Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) online portal (NASA, 2016). The soil data covering the study area was downloaded from Food and Agriculture Organization (FAO) website in Environmental System Research Institute (ESRI) shape file format (FAO, 1995). Furthermore, field observation was made between September 2015 and November 2016 to collect a reference data representing each Land use/Land cover (LULC) class across the study area. Handheld Global Positioning System (GPS) was used to collect the required data. A total of 150 training samples were collected to support image classification processes and accuracy assessments.

Methods

Satellite images preprocessing

Before interpretation and visualization of the Landsat satellite data, one should correct distorted and degraded images to ensure results of adequate quality with a more accurate and faithful representation of the real ground scene. In the context of the current study, this involved removing or diminishing any undesirable image characteristics occurred during the acquisition process (Lillesand and Kiefer, 1999; Mather and Koch, 2011). This was done for all raw satellite image bands. However, the operation excludes a 15m panchromatic band, Band8 (0.515 μm to 0.896μm) from ETM+ and Landsat8 OLI (from0.503μm to 0.676μm), and Thermal Infrared Sensor (TIR), Band 6 from ETM+ (10.31μm-12.36μm) and the two Thermal Infrared Sensors (TIRS) bands, Band10 (TIR-1; 10.60μm to 11.19μm) and Band11 (TIR-2; 11.5μm to 12.51μm) were excluded from a (Earth Explorer, 2016).

The first step involved projection of all geographical data into World Geodetic System (WGS 84) coordinate reference system, and UTM Zone 37N. The preprocessing consists of series sequential operations. This includes atmospheric and radiometric correction to diminish the effects of clouds, and the sun elevation angle of satellite images taken during different periods and from different sensors, image rectification to accurately link to a ground reference data and other ancillary datasets, and masking operations (Song *et al*., 2001; Papadavid *et al*., 2011). The data from the Landsat satellite image were preprocessed at each band level using the Environment for Visualizing Images (ENVI) software Version5.1. Then, single-band images were combined using layer stacking tool to get multi-band composite images (Liu and Yuanzhi, 2011). Additionally, image enhancement operations including density slicing, contrast adjustment, edge enhancement and color composite were employed to enhance the interpretability of image data (Raja, 2012).

Since the entire scene of ETM+ and OLI images respectively covers 170 km by 185 km and a 190 by 180 km surface area (Earth Explorer, 2016), the area of interest (AOI) that covers the Gobele Watershed (237,786.44ha) was extracted using vector polygon layer and the subset tool available in ERDAS IMAGINE software.

Land use/Land cover (LULC) classifications and accuracy assessment

A computer aided digital image classification procedure was employed to classify satellite images and generate thematic land use/land cover (LULC) maps of the study area based on known features on the ground (Lillesand and Kiefer, 1994). For this purpose, the training signatures polygons collected from each LULC class and the supervised classification method with maximum likelihood of parametric classifier decision rule were used (Otukei and Blaschke, 2010; Mehebub and Raihan, 2016).

As shown in Table 1, a total of seven LULC classes were distinguished in the study area. This includes bare land, cultivated land, settlements, forest, grazing land, shrub and water bodies, with a share of each LULC class in 2000 contributes 28.19%, 26.98%, 0.50%, 3.25%, 0.13%, 40.72%, and 0.23% of the total watershed area, respectively (Figure 2a).

Table9. LULC classes and their corresponding area proportion.

	2000		2016		Changes (2000-2016)	
LULC Class	ha	%	ha	%	ha	%
Bare land	67,021.03	28.19	49,932.80	21.00	-17,088.23	-25.50
Cultivated land	64,159.60	26.98	135,972.81	57.18	71,813.21	111.93
Forest	7,728.48	3.25	4,794.84	2.02	-2,933.64	-37.96
Grazing land	299.16	0.13	1,863.97	0.78	1,564.81	523.07
Settlements	1,199.16	0.50	13,320.50	5.60	12,121.34	1010.82
Shrub	96,822.90	40.72	31,704.40	13.33	-65,118.50	-67.26
Water bodies	556.11	0.23	197.12	0.08	-358.99	-64.55

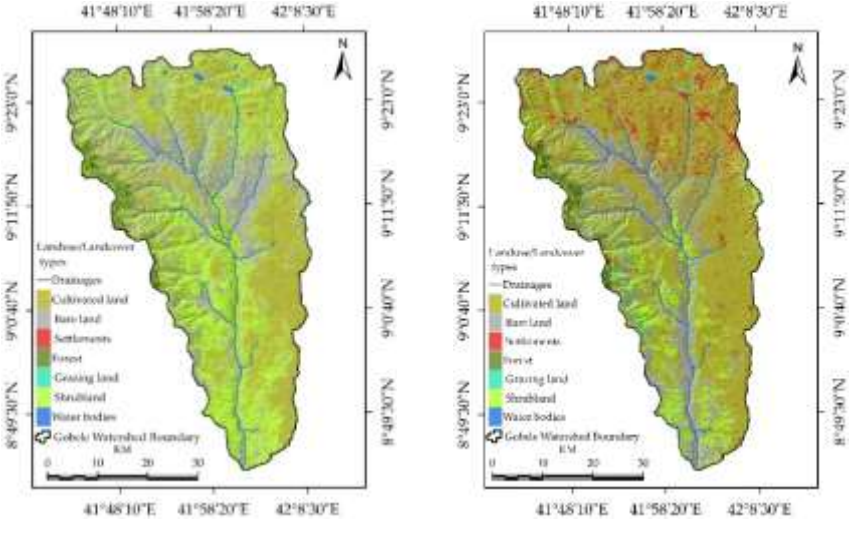
Each LULC class in 2016 accounted for 21%, 57.18%, 5.60%, 2.02%, 0.78%, 13.33%, and 0.08% of the total watershed area, respectively (Figure 2b). In the study period, shrub land decreased from 40.72 % to 13.33%, bare land was decreased from 28.19% to 21.00, forest decreased from 3.25% to 2.02%, and water bodies diminished from 0.23% to 0.08% (Table1). On the contrary, areas covered by cultivated land have increased from 26.98% to 57.18%, settlements increased from 0.50 % to 5.60%, and grazing lands increased from 0.13% to 0.78%. The thematic layers of the classified LULC images were validated using field reference data collected by a handheld GPS device. The classification accuracy was determined in terms of producers' and users' accuracy, overall accuracy, and Kappa Statistics (Congalton, 1991).

Table 2. Accuracy assessment of the classified LULC images of the Gobele Watershed, East Hararghe Zone, Ethiopia.

	2000			2016		
LULC types	Producers Accuracy %	Users Accuracy %	Kappa (K^)	Producers Accuracy %	Users Accuracy %	Kappa K^
Bare land	69.57	86.96	0.84	95.65	100.00	1.00
Cultivated land	100.00	94.12	0.93	100.00	95.24	0.94
Settlements	100.00	66.67	0.63	91.67	100.00	1.00
Forest	70.00	58.33	1.00	100.00	100.00	1.00
Grazing land	70.00	81.82	0.54	60.00	100.00	1.00
Shrub	60.00	81.82	0.79	100.00	75.00	0.71
Water bodies	93.75	100.00	1.00	100.00	100.00	1.00

	2000	2016
Overall Accuracy (%)	84.26	94.44
Overall Kappa Statistics	0.815	0.934

The results revealed that the overall classification precision obtained per LULC maps in 2000 and 2016 was 84.26% and 94.44%, respectively (Table2). Moreover, the Overall Kappa Statistics (K^) calculated for each class of LULC images in 2000 and 2016 were 0.815% and 0.934%, respectively.



(a) (b)

Figure 2. A comparative map showing LULC classifications of Gobele watershed, East Hararghe Zone, Ethiopia: (a) in 2000 and (b) in 2016.

Revised Universal Soil Loss Equation (RUSLE)

The RUSLE is a practical tool for predicting the long-term average annual soil loss attributed to raindrop splash and runoff (Renard et al., 2015). This was done based on Jiang et al. (2014) recommendation. According to Jiang et al. (2014), "to build the quantification model, as many as possible of the criteria that influence soil erosion should be taken into consideration". Similarly, the methodology presented in this study was based on the RUSLE factors generated in ArcGIS 10.3 software model builder devised to estimate soil erosion rates in the study area(Figure3). The RUSLE requires five input factors: rainfall erosivity (R-factor), soil erodibility (K-factor), slope length and steepness (LS-factor), cover management (C-factor) and conservation practice (P-factor) (Renard et al., 1997). Since input model layers were derived from different sources, and at varying scales, resampling procedures provided in digital analysis tools need to be compatible with each other (Burrough and McDonnell, 1998; Ai et al., 2013). According to Renard et al. (2014), the RUSLE Equation can be written as:

$$A = R * K * L * S * C * P, \quad (1)$$

where A is the average annual soil loss rate per unit area (ton/ha/yr), R is the rainfall erosivity factor (MJ mm ha-1 h-1 a-1), K is the soil erodibility factor (t.h.MJ-

1.mm-1), L is the slope length factor, and S is slope steepness factor (dimensionless), C is the land surface cover management factor (dimensionless) and P is the erosion control conservation practice factor (dimensionless).

Rainfall erosivity (R factor)

It is the capacity of rainfall and runoff to erode soil materials. Rainfall erosivity is largely influenced by storm energy, duration, and potential (Hurni, 1985; Owusu, 2012). In this study, the R-factor was derived from a grid rainfall data of sixteen years (from 1999 to 2014) collected from a total of twelve nearby towns across the Gobele Watershed (NMA, 2015). The rainfall (mm) and rainfall erosivity factor at each station were interpolated using spline interpolation method in ArcGIS10.3 model builder and converted into 30m x 30m spatial resolution (Table3, Figure4a and 4b). The rainfall erodibility factor was determined by Equation 2 stated in Hurni (1985) derived after spatial regression analysis by Hellden (1987) as:

$$R = -8.12 + (0.562 * P), \quad (2)$$

Where; R is the rainfall erosivity (MJ mm ha-1 h-1 y-1 mm) and P is the mean annual rainfall (mm).

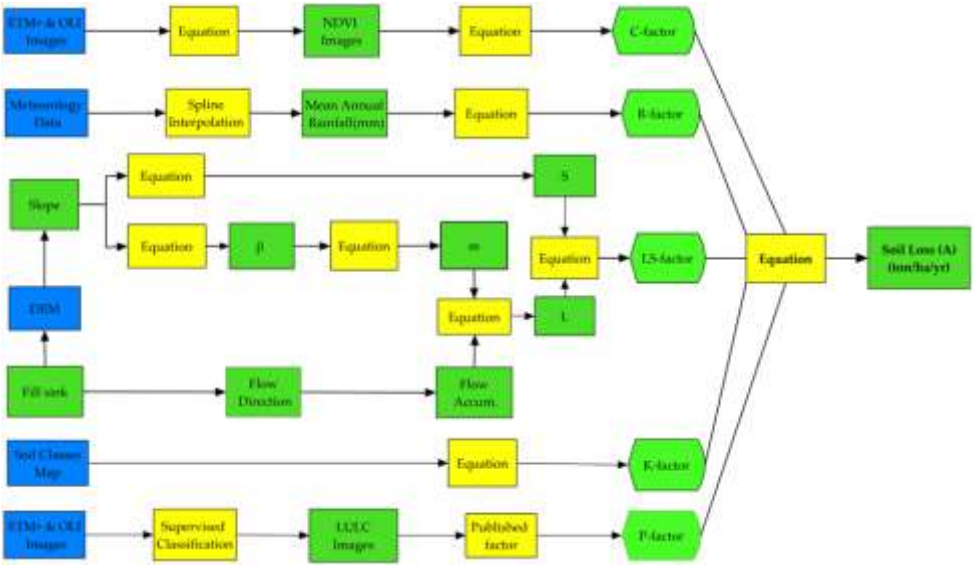


Figure 3. The schematic diagram of the RUSLE Model in ArcGIS Model builder.

Table 3. Mean Annual Rainfall (mm) and Rainfall erosivity (R-factor).

Station	Easting	Northing	Altitude (meter)	Rainfall (mm)	R Factor
Babile	206981.00	1019910.00	1678	785.61	433.25
Bedeno	789485.00	1008638.00	2232	1253.01	696.41
Boku	179517.00	1009277.00	1706	709.63	390.27
Fiq	204156.22	912963.80	1210	666.53	366.73
Girawa	812770.65	1010524.43	2404	990.01	549.82
Haramaya	172365.73	1038392.16	2046	742.85	409.30
Harer	182732.61	1030077.11	1977	694.99	382.58
Kersa	812949.02	1046429.85	2043	844.80	466.30
Kombolcha	183294.13	1045081.00	2148	744.29	409.73
Kulubi	793726.65	1044098.62	2258	955.83	528.45
Legehida	755850.50	876600.82	1367	731.24	402.84
Majo Weldiya	755850.50	964589.29	1363	1104.79	612.56

Soil Erodibility (K factor)

The K-factor is the rate of soil loss per rainfall erosion index unit measured on a standard plot determined by inherent soil properties (Parysow et al., 2003) The K-factor is largely attributed the average prolonged effects of soil profile characteristics, soil properties (e.g., soil texture, organic matter, and permeability) and human activities on soil loss (Lal,1994; Renard et al., 1997; Hoyos, 2005; Yang et al., 2005; Rabia, 2012; Chang et al., 2016).The erodibility of a soil will increase proportionally with increase in the amount of fine sand and silt content (Giordani et al., 1995). For instance, the finer and the richer the soil texture in clay ratios are, the more resistant is soil to particle detachment and the lower the soil erodibility factor is and vice versa. Moreover, the content of the organic matter is an important factor that determines erodibility. It contributes to the increment of particle aggregation (due to the presence of chelating agents) and water infiltration (Rao et al., 2014; Zakerinejad and Maerker, 2015).

When the K-factor value of a specific soil class gets higher, more erosion occurs as the soils are exposed to the erosive force of rainfall, splash, or surface flow (Hudson, 1981). According to Yahya et al. (2013) the soil erodibility value mostly ranges between 0 and 1, where 0 indicates the soil class's sensitivity to erosion while 1 represents the high susceptibility of the soil class to erosion by water. For this study, the soil map covering the study area was accessed from Food and Agriculture Organization (FAO) harmonized digital soil map (FAO, 1995). A total of six major types of soil class were identified in the study area. These were Dystric Cambisols (Bd), Eutric Cambisols (Be), Eutric Regosols (Re), Eutric Nitosols (Ne), Haplic Xerosols (Xh), and Humic Cambisols (Bh) (Figure4a). The K-factor was estimated using equation 3 (Williams, 1995; Neitsch et al., 2000; Wawer et al., 2005; Anache et al., 2015).

$$K_{USLE} = f_{csand} \cdot f_{cl-si} \cdot f_{orgC} \cdot f_{hisand}, \quad (3)$$

Where fcsand is a factor that lowers the K indicator in soils with high proportion of coarsesand content and higher for soils with little sand; fcl-si gives low soil erodibility factors for soils with a high clay-to-silt ratio; forgC reduces the K values in soils with a high organic carbon content while fhisand reduce the K value of soil classes with a high sand contents. The fcsand, fcl-si, forgC and fhisand (Table4) was determined using the following equations (Williams, 1995; Zakerinejad and Maerker, 2015).

$$f_{csand} = \left(0.2 + 0.3.Exp\left[-0.256.m_s.\left(1 + \frac{m_{silt}}{100}\right)\right]\right), \quad (4)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3}, \quad (5)$$

$$f_{orgc} = \left(1.0 - \frac{0.256 .orgC}{orgC + exp[3.72 - 2.95.orgC]}\right), \quad (6)$$

$$f_{hisand} = \left(1.0 - \frac{0.7\left(1-\frac{m_s}{100}\right)}{\left(1-\frac{m_s}{100}\right)+Exp\left[5.51+22.9\left(1-\frac{m_s}{100}\right)\right]}\right), \quad (7)$$

The highest K-factor value was found in the Eutric Nitosols (0. 421t.h.MJ1.mm-1), while the lowest was determined for Eutric Cambisols (0.332t hMJ1mm-1) in the southeastern and northwestern part of watershed (Figure4b).

Table 4. Attributes of Soil units and calculated soil erodiblity (K factor) value of the Gobele Watershed, East Hararghe Zone,Ethiopia.

Soil Units	ms(sand) Topsoil %		Silt(msilt) Topsoil %	Clay(mc) Topsoil %	OrgC Topsoil %	fcsand	fcl-si	forg	fhisand	Kusle	K
Bd	0.32	0.30	0.37	0.33	0.48	0.79	0.99	1.00	0.37	0.36	
Xh	0.55	0.21	0.24	0.04	0.46	0.80	1.00	1.00	0.37	0.36	
Be	0.36	0.37	0.26	0.01	0.47	0.85	1.00	1.00	0.40	0.33	
Ne	0.684	0.11	0.21	0.60	0.45	0.72	0.98	1.00	0.32	0.42	
Re	0.683	0.15	0.17	0.50	0.45	0.80	0.99	1.00	0.36	0.37	
Bh	0.548	0.21	0.25	0.53	0.46	0.79	0.99	1.00	0.36	0.37	

Bd= Dystric Cambisols; Xh= Haplic Xerosols; Be = Eutric Cambisols; Ne= Eutric Nitosols; Re = Eutric Regosols; Bh = Humic Cambisols

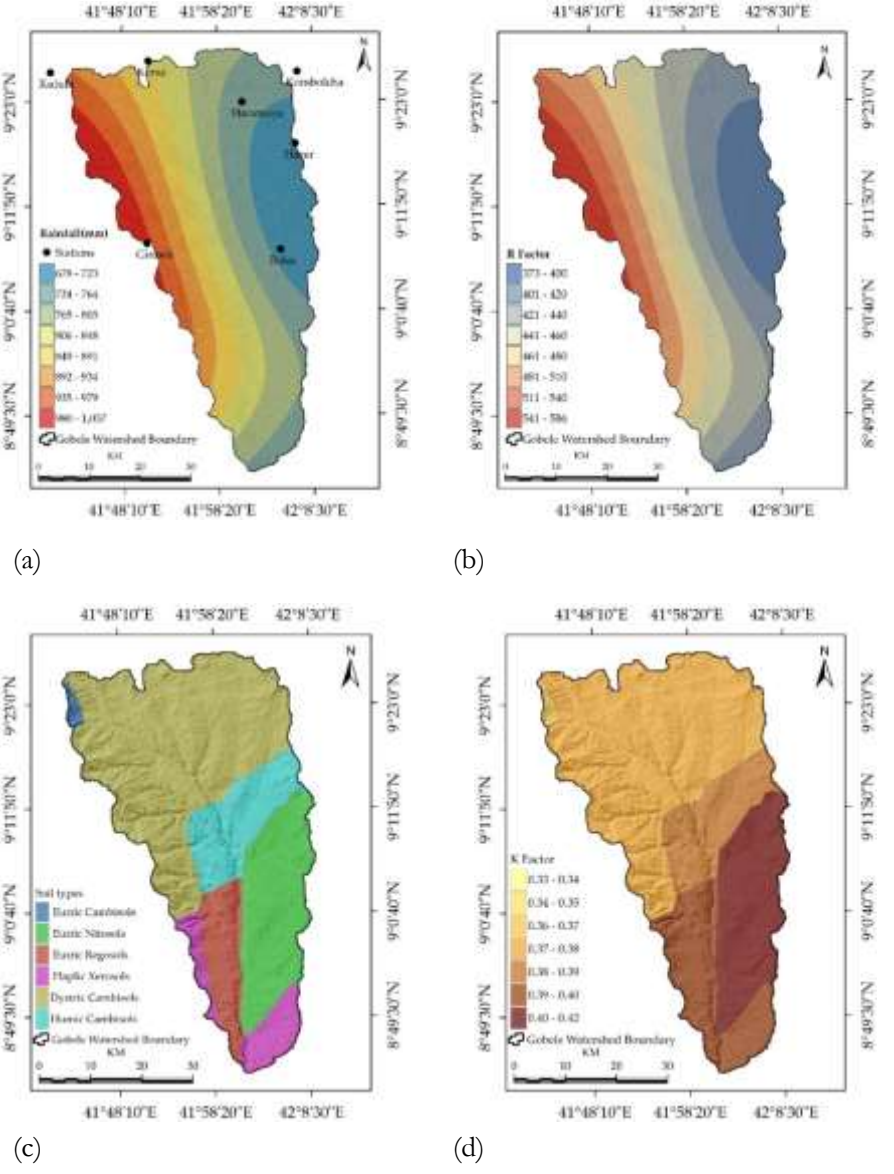


Figure 4. Mean annual Rainfall (mm) (a) and R-factor (b), Soil types (c) and K-factor (d) in the Gobele Watershed, East Hararghe Zone, Ethiopia.

Slope length (L) and Steepness (S) Factor

It represents the influences of terrain and topography on soil erosion (Chang et al., 2016). The LS factor indicates that increase in slope length (L) and slope steepness (S) can result in higher overland flow speed and higher erosion (Haan et al., 1994; Renard et al., 1997; Yahya et al., 2013). The specific effects of topography on soil erosion are estimated by the dimensionless LS factor as the product of the slope length (L) and slope steepness (S) constituents converge onto a point of interest (Nigel and Rughooputh, 2010; Abate,2011; 97). In this study, the LS factors represent a ratio of soil loss under a given conditions to a site relative to slope

length of 22.13 m and slope steepness of 9%, free of vegetation and leaved in a seedbed condition (Laflen et al., 2004; Abate, 2011). The L and S factor were determined from a 30m x 30m grid size Digital elevation model using Arc-Hydro tool in ArcGIS 10.3 Software (Williams, 1975; McCool et al., 1989; Hickey et al.; 1994).

$$LS = L * S, \quad (8)$$

$$L = \left(\frac{\lambda}{22.1}\right)^{m}, \quad (9)$$

Where L is slope length factor, S is the slope steepness factor, λ is the field slope length in meters, and m is variable slope length exponent related the value of the slope gradient. We used 0.5 for slopes steeper than 5%; 0.4 for slopes 3%–4%; 0.3 for slopes 1%–3% and 0.2 for slopes less than 1%.

The slope steepness(S) is not uniform through the study area. As suggested earlier, we used the estimation formula to sub-divide slope steepness(S) into segments the upslope drainage areas (Foster and Wischmeier, 1974; Desmet and Govers, 1996).

$$L_{i,j} = \frac{\left(A_{i,j} + D^2\right)^{m+1} - A_{i,j-in}^{m+1}}{D^{m+2} * x_{i,j}^{m} * 22.13^{m}}, \quad (10)$$

where Ai, j-in is the contributing area at the inlet of grid cell; i,j is measured in m2; D is the grid cell size; Xi,j is sin ai,j + cosi,j, ; Ai,j is the aspect direction of the grid cell (i,j). M is a variable slope length exponent related to the ratio of β of rill to interrill erosion was determined (Anache et al., 2015; McCool et al., 1989) as.

$$m = \left(\frac{\beta}{1+\beta}\right), \quad (11)$$

$$\beta = \frac{\frac{\sin\theta}{0.0896}}{3 \times (\sin\theta)^{0.8} + 0.56}, \quad (12)$$

Where β is ratio of rill to interrill erosion; θ is Slope steepness angle in degrees and m is a variable exponent calculated from β.

The S-factor was determined using equation 13(McCool et al., 1987) as:

$$S = 10.8 \sin\theta + 0.03 \qquad for\ s < 9\%, \quad (13)$$

$$S = 16.8 \sin\theta - 0.50 \qquad for\ s \geq 9\%,$$

Cover Management (C factor)

The C-factor is typically associated with effects of cropping and management practices on soil erosion (Arekhi et al., 2012; McCool et al., 1989). It is the ratio of soil loss from land with specific vegetation to the corresponding soil loss under clean tilled continuous fallow or management systems to reduce erosion (Wischmeier et al., 1978; Renard et al., 1997). The C-factor is a dimensionless factor

that ranges between Zero for a completely non-erodible condition, to values greater than one which corresponds to the greater magnitude of soil loss due to very extensive tillage, leaving a very smooth surface that produces much runoff and makes the soil susceptible to erosion (Renard et al., 1997; Rabia, 2012). Therefore, the C-factor was derived from the Normalized Difference Vegetation Index (NDVI) interpreted using Landsat (ETM+ and OLI) image data (Tucker, 1979).

$$NDVI=\frac{\text{Near Infrared(NIR)} - \text{Red(R)}}{\text{Near Infrared(NIR)} + \text{Red(R)}}, \quad (14)$$

Where NDVI is Normalized Difference Vegetation Index; NIR is near infrared bands, Band4 for ETM+ and Band 5 of OLI; while R is red band reflectance, which are Band3 from ETM+ and Band4 from OLI imagery. The C-factor was derived from NDVI image using the following equation (Fathizad et al., 2014)

$$C=((1 - NDVI)/2), \quad (15)$$

Supporting practice (P-factor)

The P-factor is associated with the effect of practices that reduce the amount and rate of water runoff (Anamika et al., 2013). Supporting practices are mechanical practices such as the effects of contouring, strip cropping, or terracing (Yahya et al., 2013; Hyeon and Pierre, 2006). In this study, the P-factor (Table5, Figure 5(e) in 2000 and Figure 5(f) in 2016) was derived from the thematic LULC maps (Wischmeier and Smith, 1978) in 2000 and 2016.

Table 5. P-factor of the Gobele Watershed, East Hararghe Zone, Ethiopia.

Land-use types	Slope (%)	P factor
Agriculture	0-5	0.11
	5-10	0.12
	10-20	0.14
	20-30	0.22
	30-50	0.31
	50-100	0.43
Other land	All	1.00

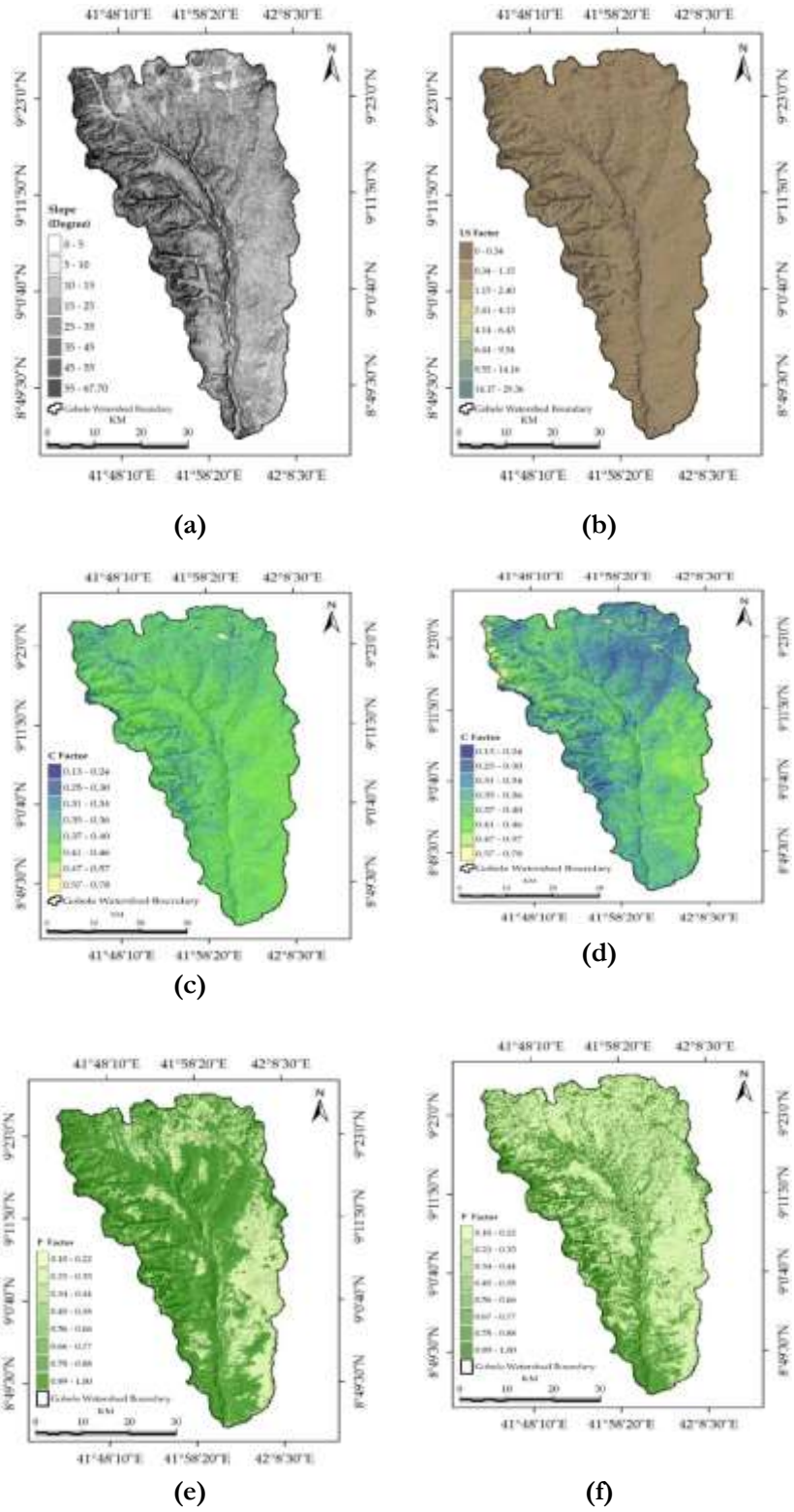


Figure 5. Slope in degree (**a**), LS-factor (**b**), C-factor in 2000(**c**),20016 (**d**) and P-factor 2000(**e**), 2016(**f**) of the Gobele Watershed, East Hararghe Zone, Ethiopia.

3. Results

Assessment of Soil Erosion Risk in Gobele Watershed

The statistical details of the soil loss rates and associated erosion risk classes are presented in Table 6 whereas the grid soil erosion estimate maps are displayed in Figure 6(a) in 2000 and 6(b) in 2016. Results showed that, the total soil loss induced by water erosion in the Gobele Watershed was 1,390,130.48tons in 2000 and 1,022,445.09tons in 2016.The result suggests a net decrease of 367,685.39tons. Moreover, the mean annual soil loss in the watershed was 51.04ton/ha/yr, 34.26ton/ha/yr in 2000 and 2016, respectively. Based on estimated mean annual soil loss, eight erosion risk classes ranging from very low (<5ton/ha/yr) to extremely high (>50ton/ha/yr) were determined.

Table 6**.** Soil loss rates, Erosion risk classes and their corresponding area in terms of hectares and percentage in the Gobele Watershed, East Hararghe Zone, Ethiopia.

Soil loss		2000		2016	
(ton/ha/yr)	Erosion risk Class	ha	%	ha	%
< 5	Very low	184,321.00	77.515	206,910.00	87.015
5 -10	Low	32,663.20	13.736	18,929.50	7.961
10 – 15	Low medium	12,935.50	5.440	6,685.71	2.812
15 – 20	Medium	4,176.67	1.756	2,986.66	1.256
20 - 25	High medium	1,986.96	0.836	1,295.24	0.545
25 - 35	High	952.93	0.401	607.86	0.256
35 - 50	Very high	608.25	0.256	244.76	0.103
> 50	Extremely high	141.93	0.060	126.67	0.053

In Table 6, soil erosion risk class within very low (<5ton/ha/yr) constitutes a larger portion of the total study area and covered 77.52% in 2000. This class continued to increase and accounts for 87.02% of the total estimated mean annual soil loss for the entire watershed area in 2016. This represents about 251ha (1.35%) increase over a 16-years period (2000-2016). However, the area coverage of erosion risk class in the high (25-35 t/ha/yr), very high (35-50ton/ha/yr), and extremely high (>50ton/ha/yr), respectively decreased by 0.23%, 0.21%, and 0.05% of the total study area during the period 2000 to 2016. In this study, soil erosion estimates that are greater than the class categorized as very low (>5ton/ha/yr) are defined as eroded areas, was decreased from 22.51% in 2000 to 12% 2016.

Erosion Risk Dynamics in the Gobele Watershed (2000-2016)

Thematic layers containing a separate soil loss values were selected to assess the spatiotemporal change dynamics in erosion risk using a transformation matrix (GIS analysis) tool in ERDAS imagine 2010 software. A significant change was observed in soil erosion risk classes during the study period. As shown in Table 7, the sum of

the diagonal values in bold represented the proportion of soil erosion risk classes that were unchanged for the total soil erosion risk areas. About 70.80% of the total soil erosion risk class covers in 2000 continued under the same soil erosion risk class in 2016. As shown in Table 7 erosion risk area categorized as the Very low was the largest unchanged class and hence, about 68.69% of the total area remains under similar class during 2000-2016. At the same period, this category raised from 77.44% to 87.16% over the study period. Erosion risk areas in Very low, Low and Low medium gained about 18.47%, 2.46% and 0.87%of the total area, respectively. Similarly, the larger net percentage change was found in the class of Very low (9.72%), Low (0.33%) and Low medium (-0.19%), respectively.

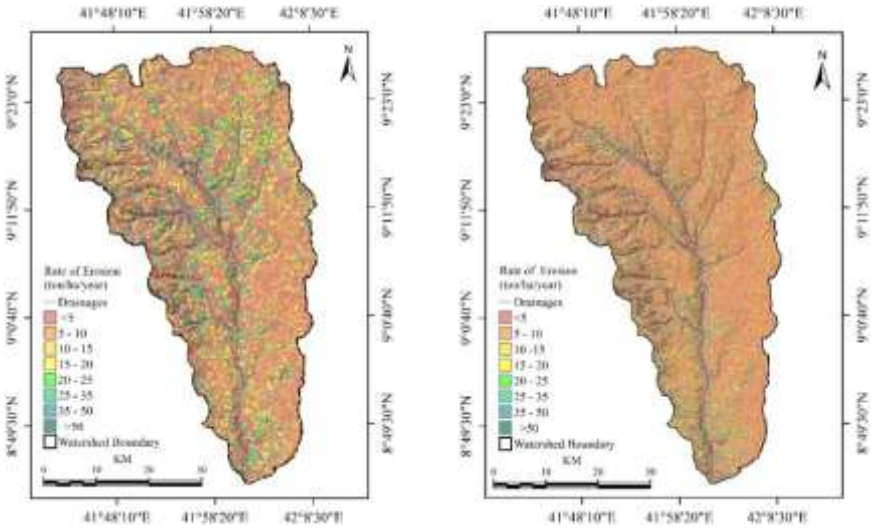


Figure 6. The spatial distribution of mean annual soil loss in the Gobele Watershed, East Hararghe Zone, Ethiopia; **(a)** in 2000 and **(b)** in 2016.

Table 7. Soil erosion risk classes change matrix (%), from 2000 to 2016 in the Gobele Watershed, East Hararghe Zone, Ethiopia

Erosion risk (ton/ha/yr)	A	B	C	D	E	F	G	H	Total 2000	Loss
A	68.69	5.51	1.94	0.79	0.36	0.13	0.03	0.01	77.44	8.75
B	11.63	1.58	0.37	0.14	0.04	0.01	0.00	0.00	13.76	2.13
C	4.38	0.58	0.34	0.09	0.04	0.01	0.01	0.00	5.44	1.06
D***-**	1.29	0.19	0.11	0.14	0.03	0.01	0.00	0.00	1.77	0.48
E	0.63	0.07	0.02	0.07	0.03	0.01	0.00	0.00	0.83	0.20
F	0.29	0.03	0.02	0.02	0.03	0.01	0.01	0.00	0.41	0.12
G	0.20	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.27	0.07
H	0.05	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.07	0.02
Unchanged										70.80
Total 2016	87.16	7.97	2.81	1.26	0.54	0.19	0.06	0.01		
Gain	18.47	2.46	0.87	0.47	0.18	0.06	0.03	0.00		
Netchange	9.72	0.33	- 0.19	- 0.01	- 0.02	- 0.06	- 0.04	- 0.02		

A = Very low; B = Low; C = Low medium; D = Medium; E = High medium; F = High; G = Very high; H = extremely high.

Identification of Priority Areas for Conservation

In this section, priority areas that are vulnerable to soil ersion risk were identified and mapped in the Gobele watershed. Proper identification of areas that are highly vulnerable to risk of ersion is critical required for designing and implementing appropriate SWC measures. In order to determine conservation priories, we considered soil erosion risk assessment results, trends and dynamics in soil erosion risk classes over the study period and multi-criteria decision rules (Zhang *et al*., 2010; Wang *et al*., 2013; Uddin *et al*., 2016). Thus, we set higher value for areas with increasing average annual soil loss. Accordingly, we classified the study area into eight conservation priority levels(Table8, Figure7).

As a result, about 104.78ha(0.04%), 1164.27ha(0.49%), 1963.74ha(0.83%) of the total study area were identified as the top three conservation priority areas. Among the top most three conservation priority levels, the majority of the first conservation levels had the slope gradient ranges from 30% to 50%, whereas the second and the third levels were found within slope gradient greater than 50%. Moreover, about 2565.27ha (79.35%) of the total study area were situated within the *Kersa, Kurfa Chele* and *Girawa* districts which are located to north, northwest,south and south west of the watershed. The remaining conservation priority areas within these levels account for 667.52ha (20.65%) and were confined within *Haramaya* and *Fedis* districts located in the eastern and south eastern part of the watershed.The three priority areas were characterized by relatively higher soil loss and dynamic changes in trends

of soil erosion.These areas require proper SWC measures. The fourth, fifth and sixth conservasion levels cover about 21,104.37ha(8.88%) of the total study area and currently needed minor SWC measures.

Table 8. Conservation priority levels of the Gobele Watershed, east Hararghe Zone, Ethiopia

Priority level	Area(ha)	Percentage of Total area
1st priority level	104.78	0.04
2nd priority level	1164.27	0.49
3rd priority level	1963.74	0.83
4th priority level	306.59	0.13
5th priority level	5611.78	2.36
6th priority level	15186.00	6.39
7th priority level	6616.90	2.78
8th priority level	206832.37	86.98

The last two conservation priority areas shown in Table 8 covered 213449.27ha (89.77% of the total watershed area. In support to the findings of this study, Abate(2011) reported that stastical soil loss estimates using erosion modelling can assist the spatia decision making to prioritize erosion risk areas for conservetion taking into consideration their severity level.

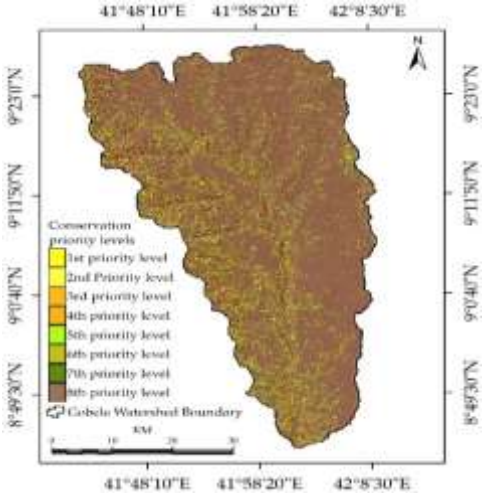


Figure 7. Conservation Priority levels of the Gobele Watershed, East Hararghe Zone, Ethiopia.

4. Discussion

In Ethiopia, land degradation is the most series problem that affects agricultural productivity (Kelbesa, 2012; Cesare and Ekbom, 2013). According to the World Bank statistical estimate, land degradation costs annual agricultural GDP ranging

from 2% to 6.75% (Yesuf *et al.*, 2007). In response to the problem, the Ethiopian government adopted intensive SWC at national level (RDPS, 2003; GTP, 2010). However, the effectiveness of the government's efforts to deal with degradation requires up-to-date quantitative information on the magnitude of soil erosion risk and its geographical distribution. This study estimated annual soil loss and dynamic changes in erosion risk areas, and identified priority areas for conservation by taking into consideration the severity levels of erosion in the Gobele Watershed, East Hararghe Zone, Ethiopia. The study employed the Revised Universal Soil Loss Equation (RUSEL) which is easily applicable at different scales with Geographic Information system (GIS) tools (Hickey *et al.*, 1994; Karamage *et al.*, 2016).

A significant variation was found in water induced soil erosion rates across the study area. The mean annual soil loss accounted for 51.04ton/ha/yr, 34.26ton/ha/yr in 2000 and 2016, respectively. The estimated mean annual loss in 2000 was higher than 47ton/ha/yr estimated in the Koga Watershed, Northwestern Ethiopia (Gelagay and Minale, 2016), 30.6ton/ha/yr estimated in Jabi Tenan Woreda in the Amhara National Regional State, Ethiopia (Amsalu and Mengaw, 2014), 42ton/ha/yr estimated for croplands in Ethiopia and 45.7ton/ha/yr estimated in the Geffersa Watershed, west Shewa Zone, Oromia Region (Hana, 2014). The mean annual soil loss declined to 34.26ton/ha/yr in 2016, which is higher than the erosion rate in the Oued El Maleh Watershed in Morocco (8.21ton/ha/yr) (Lahlaoi *et al.*, 2015), and the average annual loss rate of 24.95ton/ha/yr estimated in Zingin watershed in the highland areas of Ethiopia (Gizachew,2015). Conversely, the soil loss rates estimated in the year 2000 (51.04/ha/yr) and 2016 (34.26ton/ha/yr) are much lower than the finding of Gete (2000) who reported a mean annual soil loss rate of 243ton/ha/yr in Northwestern highlands of Ethiopia.

Based on estimated rates of mean annual soil loss, the study area was classified into eight erosion risk classes ranging from the very low (<5ton/ha/yr) to extremely high (>50ton/ha/yr). Erosion risk classified in class of high (25-35ton/ha/yr), very high (35-50ton/ha/yr), and extremely high (>50ton/ha/yr) was decreased by 0.23%, 0.21%, and 0.05% of the total area, respectively. Thus, the status of soil erosion risk across the Gobele Watershed improved during the past 16-years (2000-2016), which is reflected by declined in the mean annual soil loss rates from 51.04ton/ha/yr to 34.26ton/ha/yr and by the cumulative shrink noted in eroded classes (>5ton/ha/yr), respectively, from 22.51% to 12.99% of the total study area. Decline in soil erosion rates across the watershed area is probably due to decrease in the intensity of rainfall and some conservation measures taken by the local people and. This finding agrees with Wang *et al.* (2013) who assessed dynamics of soil erosion risk in the Danjiangkou reservoir area, China, where eroded areas declined from 32.1% in 2004 to 25.43% in 2010. The finding is also in consistent with Jiang *et al.* (2014) who reported that the eroded area decreased by 61% between 2000 and 2012 despite substantial increase in the intensity of soil erosion by 39% in some areas of Mount Elgon region, Uganda. On the contrary, the recent study by Uddin *et al.* (2016) reported that the state of soil erosion risk in the Koshi Basin has been

worsening following increase in the proportion of the eroded area by 9.0% of the total basin area between 1990 and 2010. Moreover, De Carvalho *et al.* (2014) estimated that the mean annual soil loss in Palmares‐Ribeirao do Saco watershed, Brazil ranged from 109.45Mg ha^{-1} to 300Mg ha^{-1} between 1986 and 2009. Nonetheless, the result of our study is greater than that of the maximum tolerable soil loss estimate at the national scale (18ton/ha/yr) (Hurni, 1985; Gizachew, 2015), and normal soil loss tolerance (SLT) values (5-11ton/ha/yr) (Wischmeier and Smith, 1978; Gebreyesus and Kirubel, 2009).

Therefore, since there is geospatial variation in soil erosion risk distribution across the watershed area, identification of priority area is the key factor for planning and implementing appropriate SWC (Uddin *et al.*, 2016; Carvalho *et al.*, 2014; Adugna *et al.,* 2015). Accordingly, soil erosion risk prone areas were prioritized throughout the Gobele Watershed. Prioritization was based on soil erosion rates, trends in erosion risk areas and multi criteria decision rules (Zhang *et al.*, 2010; Wang *et al.*, 2013; Uddin *et al.*, 2016). The results revealed that about 1.36% of the total watershed areas were identified as the first, second and third priority levels from the total watershed area need urgent SWC measures. In terms of the spatial distributions, the top three priority areas are found in *Kersa* and *Kurfa Chele* in Northwest, *Girawa* in southwest, *Haramaya* in North, and *Fedis* in south and southeast. Moreover, these districts are situated along the steep slope area with slope gradients bigger than 30%. In line with the finding of this study Abate (2011) reported that the steeper slopes have considerably attributed to high soil loss rate and aggravated soil erosion risk, and contributed for 39 percent of the total soil loss in Borena Wereda of south Wollo highlands, Ethiopia. According to Meshesha *et al.* (2014), vulnerability to water induced soil erosion has intensified over most highland areas in eastern Ethiopian mainly because less emphasis is given to soil and water conservation measures. For instance, a study conducted in Erer-Guda Catchment in east Hararghe Samuel (2014), suggested that poor land use practices and inappropriate land management systems are the major factors behind high soil erosion rates, loss of soil nutrient and sediment transportation problems.

5. Conclusions

This study examined the magnitude and dynamics of soil erosion risk between 2000 and 2016, and identified SWC conservation priority areas in the Gobele Watershed, East Hararghe Zone, Ethiopia. We used the RUSEL by integrating it with the Geographic Information System (GIS) tools. The finding of the study revealed that the status of soil erosion in the study area was improved over the study period (2000-2016). This is partly due to decrease in the intensity of rainfall and some conservation measures taken by the local people. Yet, the magnitude of soil loss is greater than that of the maximum tolerable soil loss estimate at the national scale (Hurni, 1985; Gizachew, 2015) and to the normal soil loss tolerance (SLT) value (Wischmeier and Smith, 1978; Gebreyesus and Kirubel 2009). Consequently, areas

with a high and increasing soil erosion risk were identified and mapped as conservation priority areas using multi-criteria decision rules.

The findings also support the effort to minimize the environmental and economic impacts of soil erosion and offer insights on policy implications on what should be done to establish sustainable watershed management practices in the Gobele Watershed. The issue has been emphasized in Ethiopia's Climate-Resilient Green Economy Strategy (CRGES) as a priority option to increase the resilience of the country's rain-fed agriculture (CRGES, 2011). In connection to this, conservation of agriculture, implementation of integrated SWC and control activities involving proactive and organized community participation and proper utilization of soil resource ahould be emphasized to safeguard sustainable agriculture growth and to ensure national food security (RDPS, 2003; GTP, 2010; CRGES, 2011). Therefore, the findings of this study can assist decision makers and conservation planners to develop appropriate SWC measures for the prioritized areas.

6. Acknowledgments

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9. Bovine Tuberculosis and Assessment of Cattle Owners Awareness on its Public Health Implication in Selected Areas of Eastern Ethiopia

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Abstract: Bovine tuberculosis is among the primary zoonotic disease caused by Mycobacterium bovis which has significant impact on the health of livestock and human. It also has been significantly a cause for great economic loss in animal production. A cross-sectional study was conducted from December 2014 to June 2016 on 315 cattle in selected areas of eastern Ethiopia, aiming to estimate the occurrence of bovine tuberculosis using comparative intradermal tuberculin skin test and assess cattle owners' awareness on its public health implication. Random sampling method was applied in order to select animals from farm/household and associated risk factors were recorded before purified protein derivative (PPD) injection. Forty three farm/household owners of tuberculin tested animals were interviewed using pre-tested structured questionnaire. The overall prevalence of bovine tuberculosis was 20.2% (n = 64) in dairy cattle farms/households at recommended cut off >4mm. From a total of 43 farms/households tested, 22 were positive; each farm exhibited at least one tuberculin positive reactor animal with a total herd level prevalence of 51.2%. The prevalence of bovine tuberculosis in individual animal level was significantly different ($\chi 2$ = 45.2; P-value = 0.000) in different sites with a higher prevalence (50%) in Dire Dawa. Farming system, herd size and other risk factors were significantly ($p<0.05$) associated with bovine tuberculosis occurrence. Of the total interviewed farm owners, only 33% had the knowledge of or had heard about bovine tuberculosis and 23% respondents were aware of the zoonotic importance of the disease. More than 50% of the interviewees had shown their preference of raw milk consumption. Out of the total interviewed households, 3 (7%) farm workers had TB cases that had direct contact with the animals. The study showed bovine tuberculosis is found prevalent in the area. Associated risk factors contributed to the prevalence of the disease in cattle and its transmission. Moreover, the majority of cattle owners lack awareness about the disease and its public health significance. Awareness rising about the disease, its transmission and zoonotic implication is of great importance for reduction and control

measures. Evidence of tuberculosis patient farm attendants calls also for further detail investigation.

Keywords: CIDT test; public health,; risk factors

1. Introduction

A close interaction between humans and animals mainly contributes to the ongoing transmission of shared infectious zoonotic diseases between cattle and humans (Mbugi *et al.,* 2012). Bovine tuberculosis is among the primary zoonotic diseases caused by *Mycobacterium bovis*, member of the Mycobacterium tuberculosis complex, which affects many vertebrate animals and humans, and characterized by progressive development of granulomas in tissues and organs (Amanfu, 2006; OIE, 2010). Tuberculosis (TB) caused by bovine origin has emerged as a significant disease with the tendency for inter-species spread. Bovine tuberculosis has been significantly distributed throughout the world and has been a cause for great economic loss in animal production (Ayele*,* 2004; Zinsstag *et al.,* 2006; Rodriguez *et al.,* 2014) and the most frequent cause of zoonotic TB in man (Tenguria *et al*., 2011).

In developed countries, dramatic decline in the incidence of human TB due to *M. bovis* has been registered with mandatory pasteurization of milk together with tuberculin skin testing and culling/slaughtering infected cattle (Palmer *et al*., 2012). In developing countries particularly in Africa; however, BTB represents a potential health hazard to both animals and humans, as nearly 85% of cattle and 82% of the human population live in areas where the disease is prevalent or only partially controlled (Thoen, 2006). In these countries where BTB is still common and pasteurization of milk is not practiced, an estimated 10 to 15% of human TB cases are caused by *M. bovis* (Perez-Lago *et al.,* 2013; Malama *et al.,* 2013). In Africa though this disease represents a potential health hazard to both animal and human populations as in most developing countries, *M. bovis* infection remains largely uninvestigated. Its epidemiology and public health significance remains largely unknown due to several factors including the high cost of testing programme, due to social unrest, political instability, wars resulting in displacement of large numbers of people and animals, and a lack of veterinary expertise and communication networks (Cosivi *et al*., 1998; Firdessa *et al.,* 2012).

In Ethiopia, BTB is considered to be a highly prevalent disease in cattle populations. Tuberculin skin test survey indicates that the prevalence ranges from 0.8% in extensive rural farming systems that keep Zebu cattle to 78% in intensive husbandry systems that keep exotic and cross breed cattle (Ameni *et al.,* 2007; Ameni *et al.,* 2008; Firdessa *et al*., 2012). Few studies have also indicated as the disease is zoonotic it transmitted from animal to humans and vice versa (Ameni and Erkihun, 2007; Regassa *et al*., 2008). Many other studies have shown that there are many risk factors such as demography, eating habits, education background, living and socio-economic status of families, culture, the existence of HIV/AIDS, and close proximity with animals that are conducive to the spreading and persistence of BTB in developing countries (Ayele *et al*., 2004; Regassa *et al*., 2008; Girmay *et al.,* 2012). Ethiopian milk consumers generally prefer raw milk (as

compared to treated milk) because of its taste, availability and lower price. The zoonotic risk of BTB is often associated with consumption of dairy products based on unpasteurized milk infected with *M. bovis*. Also, aerosol transmission from cattle-to-human should also be considered as a potential risk factor (SNV, 2008; Zeru *et al*., 2014).

In Ethiopia, the distribution of BTB is not well established in livestock, and most studies have been focused mainly around the central part of the country mainly in and around Addis Ababa. In order to go aboard the national BTB control program in the future, the updated status of the disease has to be assessed widely in the regions of the country where such study has not yet been conducted. The objectives of this study were to estimate the prevalence of bovine tuberculosis in selected areas of eastern Ethiopia namely Harar, Dire Dawa, Jigjiga using comparative intradermal tuberculin test (CIDT) and to assess cattle owners awareness on its public health importance in the areas.

2. Materials and Methods

Study Area Description

The study was conducted in selected areas of eastern Ethiopia viz; Harar, Dire Dawa and Jigjiga, Ethiopia. Harar is located 526 km far from Addis Ababa in East direction at a latitude of 8°500'-9°15'N and longitude of 9°36'N 41°52' East and situated at an altitude of 1850 meters above sea level (m.a.s.l) (Fig 1). The annual rainfall of the area is between 834 and 1300 mm. This area experiences a binominal rainfall pattern with a long rainy season from June to September and short rainy season from March to April while the annual temperature ranges from 21-26 °C (CSA, 2012).

Dire Dawa is located at about 515 km to the east of Addis Ababa. The area is located between 9°27' and 9°49' N latitude and 41°38' and 42°19' E longitude (Fig 1). The total area of the administration is 128,802 ha and it shares common boundaries with Somali Regional State to the west, north, and east and with the Oromia Regional State to the southern part. Administratively, it is divided into 9 urban kebeles (lower administrative unit) and 32 peasant associations. The rural area occupies 98.7% of the total area. The altitude of Dire Dawa Administration (DDA) ranges from 960 m.a.s.l in the northeast to 2450 m.a.s.l. in the southwest. The mean annual rainfall of the area varies from 550 mm in the lowland northern part to 850 mm in the southern mountain with average 640 mm. The monthly mean minimum and maximum temperature ranges from 14.5 °C to 34.6 °C, respectively. Out of the rural population about 4% are pure pastoralists and they are engaged in livestock production. The total livestock population in DDA is estimated to be 219,323. Goats comprise the highest proportion (54.2%) followed by sheep (21.1%) and cattle (18.4%) (CSA, 2007).

Jigjiga is located 615 km far from Addis Ababa in East direction at an altitude of 1803 m.a.s.l. It lies at 8° 44'N longitude and 40° 22'E latitude with mean minimum and maximum temperatures of around 20 and 35 °C, respectively (Fig 1). According to National Meteorological Service Agency reports, the mean annual rain fall is 660 mm and bimodal. The livestock population of the district is estimated to be 62,156 cattle, 100,516 sheep, 142,048 goats and 12,825 camels. The majority (78.33%) of the farmers raises both

crops and livestock, while 19.88% only grow crops and 1.79% raises only livestock (CSA, 2007).

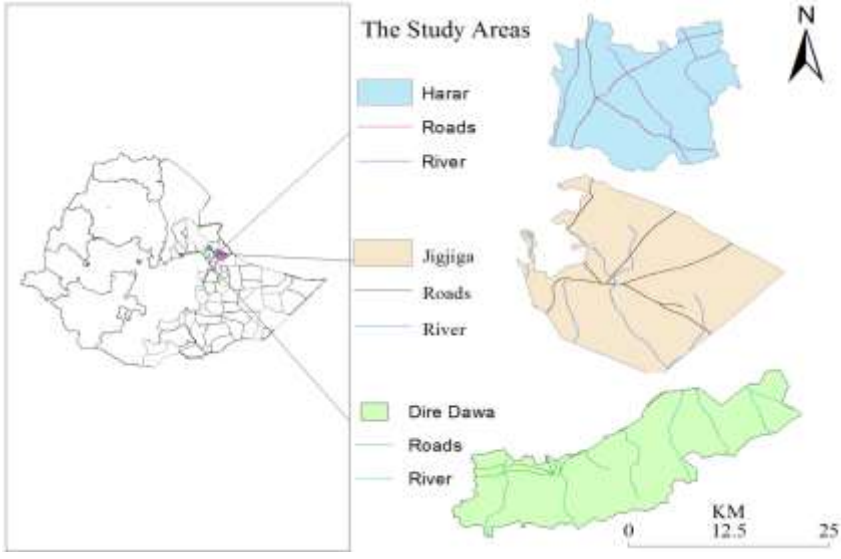

Figure 1. Illustrative representation of study areas (Harar, Jigjiga, and Dire Dawa).

Study Animals and Sample Size Determination

Cattle belonging to the study areas were considered as the study animals. Extensive, semi-intensive and intensive types of cattle production systems were practiced in the areas. Cattle production using improved breeds is a common practice in urban and peri-urban areas. In rural areas, mainly local breeds are found keeping grazing on communal land under traditional animal husbandry system. The sample size for tuberculin testing was calculated using the sampling formula described by Thrusfield (2008) with the expected prevalence of 46.8% (Ameni *et al.,* 2003a) and absolute precision value of 5%.

$$n = \frac{1.96^2 \, Pexp \, (1 - exp)}{d^2}$$

n Required sample size

Pexp Expected prevalence

d Desired absolute precision, accordingly, the total sample size calculated was n = 400. However, 315 cattle were addressed for tuberculin skin testing.

Study Design and Sampling Method

A cross-sectional study was conducted from December 2014 to June 2016 on 315 cattle in eastern Ethiopia to estimate the occurrence of bovine tuberculosis and assess cattle owners' awareness on its public health implication. A list of farms owning dairy cattle were obtained from Agricultural Offices and these households/farms were used as

sampling frames. Using a two-stage cluster sampling method households/farms and individual animals were considered as primary and secondary units, respectively. Four to eight animals above 6 months of age were randomly selected per household/farm. One month pre and post-partum cattle were excluded during the study.

Associated risk factors considered for data collection at animal and herd levels were recorded before purified protein derivatives (PPD) injection. Impermanent unique identification numbers were given for each tested animal. Body condition score (BCS) of the animals was determined according to Nicholson and Butterworth (1986) as poor, medium or good. Extremely lean cattle, having prominent dorsal spines pointed to the touch and individual visible transverse processes into which a finger could be easily pushed were considered as poor body condition score. A medium body condition score cattle was expressed as having usually visible ribs with little fat cover and barely visible dorsal spines. A good body condition score was given for the animals when fat cover easily was seen in critical areas and felt and the transverse processes were not seen or felt. The management of the farm was categorized as described by Ameni *et al.* (2003a) on the basis of housing condition (neatness, waste disposal, nature of the floor, presence of confinement), feeding (concentrate and hay), possession of an exercise yard, and contact with other herds and provision with clean water.

Study Methodology

The CIDT test was performed using both bovine and avian mycobacterium PPD. Two injection sites were chosen in the middle third of the side of the neck, one above the other, separated at least 12 cm. The hair was shaved around the sites to a radius of about 2 cm. Skin folds at both sites was measured with a caliper and the measurements were recorded. An aliquot of tuberculin containing 2,500 IU/0.1 ml bovine PPD was injected into the skin intradermally at the lower injection site and similarly, tuberculin containing 2,500 IU/0.1 ml avian PPD was injected at the upper site. After 72 h, the thickness of the same skin fold at both sites was measured and recorded. Bovine and avian positive reactors were obtained using the formula: [(Bov72−Bov0) − (Av72−Av0)] and [Av72−Av0) − (Bov72−Bov0)], respectively. Bov0 and Av0 indicate skin thickness before injecting bovine and avian tuberculin, and Av72 and Bov72 are the corresponding skin fold thickness 72 h post-injection. The tuberculin test results were interpreted based on OIE (2010) recommended cut off > 4mm. Increase in skin fold thickness of > 4 mm was regarded as positive reactor and negative if the increase in skin thickness at the bovine site of injection was less than the increase in the skin fold thickness at the avian site of injection. Increase in skin fold thickness of > 1 mm with visible reaction at avian site than at the bovine site was considered as positive for *M. avium* spp.

Questionnaire Survey

A total of 43 farm/herd owners of tuberculin tested animals were interviewed using pre-tested structured questionnaire to assess the knowledge and awareness of the communities of the study area regarding BTB and its transmission associated with dairy

product feeding habits and other factors such as the same house sharing and raw milk consumption habit of the owners or herders. In addition, information on TB status of the herders and farm members was gathered using a designed questionnaire format during the period.

Data analysis

The data obtained from tuberculin skin testing were recorded in the format developed for this purpose and were entered in to Microsoft Excel spread sheet. STATA version 11.0 was used for analysis of the data. Individual animal prevalence was defined as the number of positive reactors per 100 animals tested. The farm level prevalence was calculated as the number of herds with at least one-reactor animal per 43 herds tested. The effects of different potential risk factors were computed using binary logistic analysis. A statistically significant association between the result and the risk factors was said to exist if the calculated P value < 0.05 and the 95% confidence interval (CI) for odds ratio (OR) does not include 1.

3. Results

Individual Animal and Herd Level BTB Prevalence

The overall prevalence of BTB with comparative intra-dermal tuberculin test was 20.2% (n = 64) in dairy cattle farms/households in the areas. From a total of 43 farms/households tested, 22 were positive; each farm exhibited at least one tuberculin positive reactor animal with a total herd level prevalence of 51.2% (Table 1).

Table 10. Prevalence of bovine tuberculosis in animal and herd level.

	Animal level prevalence					Herd level prevalence				
Study site	No. Tested	Positive	Prevalence (%)	χ2	P-value	No. Tested	Positive	Prevalence (%)	χ2	P-value
Harar	224	25	11.2	45.2	0.000	35	16	45.7	2.36	0.306
Dire Dawa	58	29	50.0			5	4	80.0		
Jigjiga	33	10	30.3			3	2	66.7		
Total	315	64	20.2			43	22	51.2		

Herd Level Risk Factors associated with Bovine Tuberculosis Prevalence

The results of logistic analysis of the associated risk factors (farming system, herd size, management conditions, and presence of wild animal nearby the farm etc) on the herd prevalence are presented in Table 2.

Table 11. Evaluation of the association of risk factors to herd tuberculin test results.

Risk factor	Categories	No of herd		OR (95% CI)	P-value
		Tested	Positive (%)		
Type of farming	Extensive	15	7(46.7)	Ref.	
	Semi-intensive	6	1(16.7)	0.37(0.40-10.01)	0.22
	Intensive	22	14(63.6)	2.50(0.016-0.39)	0.031
Herd size	>10 cattle	13	6(46.0)	Ref.	
	6-10 cattle	20	13(65.0)	4.33(0.84-22.2)	0.80
	1-5 cattle	10	3(30.0)	2.17(0.52-9.01)	0.28
Management	Good	8	2(25.0)	Ref.	
	Medium	26	15(57.7)	2.24(0.04-0.202)	0.000
	Poor	9	5(55.5)	4.026(0.003-0.19)	0.000
Presence of wild animal	Present	12	6(50.0)	Ref.	
	Absent	31	16(51.6)	7.09(1.67-3.01)	0.00

Animal Level Risk Factors Associated with Bovine Tuberculosis Prevalence

The prevalence of bovine tuberculin positivity at individual animal level was 20.2% (n=64) at cut-off >4mm. Different potential animal level risk factors for the occurrence and transmission of BTB were indicated. Age, lactation, pregnancy, site of the study, farming type, farming system, herd size and management condition were significantly ($p<0.05$) associated with BTB prevalence in the areas (Table 3).

Table 12. Evaluation of the association of animal level risk factors with prevalence of bovine tuberculin positivity.

Risk factor	Categories	No. of animals		OR(95% CI)	P-value
		Examined	Positive (%)		
Site	Harar	224	25(11.2)	Ref.	
	Dire Dawa	58	29(50.0)	7.96(4.107-15.427)	0.000
	Jigjiga	33	10(30.3)	3.46(1.477-8.104)	0.004
Age	1-5 years	85	17(20.0)	Ref.	
	6-9 years	172	42(24.4)	1.29(0.685-2.439)	0.429
	>9 years	58	5(8.6)	0.37(0.130-1.089)	0.072
BCS	Poor	67	15(22.4)	Ref.	
	Medium	147	29(19.7)	0.85(0.421-1.721)	0.655
	Good	101	20(19.8)	0.85(0.402-1.820)	0.686
Lactation	Non lactating	115	11(9.5)	Ref.	
	Lactating	200	53(26.5)	0.29(0.146-0.588)	0.001
Pregnancy	Non pregnant	276	51(18.5)	Ref.	
	Pregnant	39	13(33.3)	1.10(0.218-0.942)	0.034
Breed	Local	63	11(17.5)	Ref.	
	Cross breed	15	1(6.7)	0.34(0.411-2.842)	0.318
	Exotic	237	52(21.9)	1.32(0.647-2.728)	0.439
Herd size	1-5	46	5(10.9)	Ref.	

	6-10	48	4(8.3)	0.74(0.187-2.968)	0.677
	>10	221	55(24.9)	2.71(1.022-7.218)	0.045
Farming system	Extensive	51	7(13.7)	Ref.	
	Intensive	229	50(21.8)	3.69(0.820-16.625)	0.089
	Semi intensive	35	7(20.0)	1.84(0.418-8.120)	0.419
Mgt condition	Good	83	1(1.2)	Ref.	
	Poor	63	14(22.2)	3.66(1.31-1.83)	0.000
	Medium	169	49(29.0)	1.51(0.51-1.51)	

Assessment of Cattle Owners' Awareness on the Public Health Importance of BTB

Of the total 43 farm/household owners and/or members of these households/farms interviewed for assessment of awareness on the zoonotic effect of the disease, 14 (32.55%) reported that they had the knowledge of or had heard about BTB and 10 (23.25%) respondents were aware of the zoonotic importance of BTB. Out of the total interviewed households, 3 (6.97%) farm workers/attendants had TB cases that had direct contact with the animals and within two of the three households, there had been both PPD-positive reactor cattle and human tuberculosis cases. Moreover, cattle owners were also interviewed regarding their raw milk drinking and raw meat eating and house sharing habits with their animals (Table 4).

Table 13. Summary of cattle owners' knowledge about BTB and its transmission to humans.

Question item	Number of respondents'	Number responded (%)
Know BTB can affect animal	43	14(32.55)
Know BTB is zoonotic	43	10(23.25)
Know raw milk is vehicle for TB	43	9(20.93)
Consume raw milk	43	23(53.48)
Know meat is vehicle for BTB	43	8(18.60)

Consume raw meat	43	14(32.55)
Share the same house with cattle	43	16(37.20)
Know close contact with cattle can facilitate BTB transmission	43	5(11.62)
Sick with TB	43	3(6.97)

4. Discussion

In the current study, the overall prevalence of bovine tuberculin positivity at individual animal and herd levels was 20.2% and 51.2%, respectively. The herd level prevalence was found to be higher than the prevalence of individual animals in the study, that could most probably be due the herd size that can favour the transmission of BTB in exhaustive dairy farms in particular (Ameni *et al*., 2003b; Shitaye *et al*., 2006). The finding is relatively in line with Firdessa *et al.* (2012) who found more than 30% and 58% individual animal and herd level BTB prevalence, respectively which was conducted in dairy cattle at central Ethiopia. Relative findings were reported by Ameni *et al.* (2003b) with individual animal prevalence of 24.3%, 27.3% and 27.8% at Holleta, Ziway and Ambo dairy farms respectively. Shitaye *et al.* (2006) found 18.7% animal level BTB prevalence that was conducted at Addis Ababa with a total of 2,098 examined animals. A higher animal level prevalence than the current study was reported by Ameni *et al.* (2003b) with BTB prevalence of 65.8% and 73.6% at Debre Zeit and Dessie, respectively. Comparative BTB prevalence was reported by Elias *et al.* (2008) with 23.7% animal level and 43.4% herd level prevalence. Tsegaye *et al.* (2010) found 34.1% and 53.6% individual animal and herd level BTB prevalence respectively. Higher overall individual animal prevalence of 46.8% and a herd prevalence of 91.7% were recorded in 12 dairy farms by the CIDT test (Ameni *et al.,* 2003b).

Our finding was in contrary with the findings of Ameni and Erkihun (2007) who reported 11% and 15% prevalence of BTB at animal and herd level, respectively in Adama town (Oromia state). Gebremedhin *et al.* (2013) (northern Ethiopia), Tschopp *et al.* (2011) (central Ethiopia) and Mohammed *et al.* (2012) (northwest Ethiopia) reported 6.6, 6.8 and 7.1% overall animal level prevalence respectively. Low BTB prevalence was reported by different researchers conducted in different areas of the country. Gumi *et al.* (2012) found the individual animal prevalence of 2.0% in cattle. Tschopp *et al.* (2013) reported very low BTB prevalence with an individual animal level prevalence of 0.3%.

Analysis for the effect of risk factors revealed that the animal prevalence of BTB increased with age of cattle increased. The current finding is in agreement with other previous reports (O'Reilly and Daborn, 1995; Cook *et al*., 1996; Ameni *et al.,* 2007; Regassa *et al*., 2007, 2008; Inangolet *et al*., 2008; Gumi *et al.,* 2011; Mohammed *et al*., 2012; Mamo *et al.,* 2013; Katale *et al.,* 2013) who reported that tuberculin test reaction in cattle increases uniformly with advanced age groups. As explained by other reports (Barwinek and Taylor, 1996), this could be because as the age increases the probability of acquiring the causative agent also increases. On the other hand, the decrease in

prevalence is associated with immune status of the animal. This means, the level of reaction is directly related to the maturation and wasting of organs of immune system that is, immature and very old animals rarely react to tuberculin injection regardless of the status of infection (Buddle *et al*., 2003). Furthermore, Tizard (1996) stated that lowered response to intradermal tuberculin test in older animals is due to the immune depression resulting from old age.

In the present study, the herd at medium (6-10 animals) and large (>10 animals) size showed higher BTB prevalence than small (1-5 animals) herd size. Studies had indicated as herd size increases, the risk of cattle within the herd showing a positive reaction also increases (O'Reilly and Daborn, 1995; Barwinek and Taylor, 1996; Cook *et al.,* 1996; Asseged *et al.,* 2000; Fikre *et al.,* 2014, Sisay *et al.,* 2014). Ameni *et al.* (2003a) and Cleaveland *et al.* (2007) found that herd size was positively correlated with the probability of BTB infection in the herd. In accordance with other studies finding, Ameni *et al.* (2003a) indicated as herd size increased, there was a corresponding increase in the prevalence of bovine TB; 4.6%, 6.4% and 10.5% for small, medium and large herd size, respectively. The spread of the pathogen within the herd can be promoted by increased herd size with leading to higher encounter rates of susceptible and infectious hosts.

In the study, herd tuberculin positivity result revealed a statistically significant association with herd management conditions notifying that poor managerial inputs increase the risk of BTB. Poor farm management risked 3.66 times for BTB prevalence than farm management having good status. Previous studies (Nicholson and Butterworth, 1986; Barwinek and Taylor, 1996; Radostits *et al*., 2006) had reported higher BTB infection in farms under poor management conditions. It can, therefore, be generalized that the status of BTB could be improved by adopting sanitary measures that improve hygiene conditions on farms.

In our study even though no significant variation was seen, animals with poor body condition scored slightly high infection compared to the medium and good body condition animals. Mohammed *et al.* (2012), Fikre *et al.* (2014) and Akililu *et al.* (2014) reported that poor body condition animals were highly susceptible than medium and good body condition animals. We noted that animals with good body condition showed comparable BTB infection without manifesting any clinical signs. In some farms, animals with good and very good body condition were found strongly positive. In contrast, poor body conditioned animals showed weak or negative reaction for PPD in the same farm. Based on this result, it may be difficult to say animals in poor conditions were more susceptible than those in good body condition. A study also indicated that tuberculin reactivity was significantly affected by the body condition of the animal cattle (Kazwala *et al.,* 2001). This could be because the tuberculin reaction is dependent on immune competence, which in turn may be associated with the physical condition of the animal such that animals with better physical condition are immune competent and thus give a better reaction to tuberculin. Whereas animal with poor body condition could be immune compromised and hence may not react to tuberculin although they might have been infected by *Mycobacterium* (Cook *et al.,* 1996). Other previous studies also reported

higher prevalence in animals with poor body condition as compared to those with good body condition scores (Cook *et al.,* 1996, Kazwala *et al.,* 2001) and (Asseged *et al.,* 2004).

With regard to the herd level of BTB in different farming system, cattle kept under intensive production system were at high risk with the prevalence of 63.6% than under semi-intensive and extensive farming conditions. Intensification, stress, and overcrowding are some explanations for such prevalence difference. Overcrowded herds considerably exacerbate BTB transmission through aerosol route as gross lesions usually involve the lungs and thoracic lymph nodes (Radostits *et al.,* 2006). The present finding agrees with Ayele *et al.* (2004) and Elias *et al.* (2008). This could be due to the fact that intensive farming system promotes close contact between animals, thereby favoring the spread of the disease from one animal into another animal. The possible reason for higher skin-test prevalence in semi-intensive than in extensive farming system in our case is probably due to farm owners' awareness about health and production effect of the disease as we observed during assessment (but data not shown). Sanitation and hygienic condition of the farms in each farming system can also matter this record.

The present finding revealed higher prevalence of BTB in exotic breeds compared to the local breeds and cross breed cattle with no significant difference. This might be due to less resistant of exotic breeds to BTB compared to indigenous breeds of cattle (Munyeme *et al.,* 2009). In agreement with our result, Sisay *et al.* (2013) recorded 11.55% prevalence of BTB in exotic breed with 5.3% prevalence in local breeds. Whereas Mohammed *et al.* (2012) and Gebremedhin *et al.* (2013) reported lower prevalence in exotic breeds. This probably may be due to the differences in the proportion of number of the study animals sampled.

Level of awareness of cattle owners about BTB showed 32.55% of the respondents know cattle can be infected by tuberculosis, and 23.25% recognized that BTB is zoonotic. High number of respondents had therefore, no detailed and accurate knowledge about tuberculosis and its zoonotic importance. Ameni *et al.* (2008) and Radostits *et al.* (2006) indicated that lack of understanding regarding the zoonotic effect of BTB, food consumption behavior and poor sanitary measures are among the potential risk factors of BTB to public health. Similarly, around 53.48% of the respondents were consuming raw milk indicating most of milk consumers can prefer raw milk than treated milk due to the taste, availability and lower price of raw milk (SNV, 2008). Only twenty one percent (20.93%) and (18.60%) of the interviewed farm owners and or attendants know milk and meat are vehicle for BTB, respectively. The survey indicated 37.20% of the respondents shared the same house with their cattle. The disease transmission may be cyclical: cow-to-man-to-cow (Cosivi *et al.*, 1998), underlying the existence of risk of dissemination of mycobacteria among the cattle and human populations. Humans acquire the infection primarily by ingesting the agent in raw milk and milk products, and by inhaling it when there is close physical contact between the owner and his/her cattle, especially at night since in some cases they share shelters with their animals (Anderson, 1997). Our assessment of the knowledge of the society on BTB is in line with the findings of Mohammed *et al.* (2012), Sisay *et al.* (2013), Akililu *et al.* (2014) and Fikre *et al.* (2014).

At the same time, in relation with TB patient record in the survey, 6.97% (3 out of 43) were sick with TB who had been working in dairy farms. One of the farm attendant who had TB positive and cured with long time medication after several clinical examinations explained that he had close and unreserved contact with dairy cattle in different farms for around 5 years. The patient farm attendant expressed he had night sweating and several superficial wounds mainly around neck and back. He added, he suffered for months with misdiagnosing the disease he acquired having wrongly prescribed drugs (treatment). PPD positive reactor cattle were recorded in two of the farms addressed where the mentioned patient attendant had been served. This calls for further detail investigation to study the source and see cattle to man or vice versa transmission of the disease. Close physical contact between owners and cattle can facilitate the transmission of BTB among them (Cosivi *et al.,* 1998).

Introduction of an infected animal into a BTB free herd or area is one of the major risk factors for introducing the disease (Johnston *et al.,* 2005; Gopal *et al.,* 2006). In the current survey assessment, the farm owners had purchased exotic (Holestein Friesian) breed dairy cattle from different cattle sources including from central Ethiopia where BTB prevalence is very high to replace their stock and or increase the number of cattle in the farms. They purchased cattle without any BTB pre-test that could be a potential source for the transmission of the disease in the areas.

5. Conclusion

The present study showed BTB is found prevalent both in households and intensive dairy farms with individual animal prevalence of 20.2%. Herd level prevalence was 51.2%. This study identified BTB prevalence increased with increasing herd size of the farms and with decreasing management condition of the addressed farms. The questionnaire result of this study revealed that the majority of cattle owners' in the area lack awareness about BTB and its public health significance. As a result, large portion of the community had habit of drinking raw milk and sharing the same shelter with close contact implying the possible potential of acquiring BTB from positive animals. So far, awareness rising of cattle owners and the communities about BTB and its transmission, and the zoonotic implication of the disease is of great importance for effective implementation of TB control measures. Evidence of tuberculosis patient farm attendants showed in this study that there could be either animal to human or vice versa transmission of the disease which calls for further detail investigation in order to point out and address the possible source and way of transmission of the disease.

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10. Genotypic Classification of Hararghe Coffee Beans using Imaging Techniques

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Abstract: This research was conducted to classify Hararghe coffee beans (HCBs) of six Weredas (Kombolcha, Meta, Deder, Tulo, Bultum and Mechara) based on their color, morphological and textural features using digital image analysis technique. From each Wereda, 20 images and 36 images were captured from samples collected from Mechara Agriculture Research Center. Support vector machine was used to classify HCBs and to cheek weather the genotype HCBs correctly classified to their origin of collection or not. For the analysis, 18, 8 and 6 color, morphological and textural features, respectively, and a total of 32 features were extracted from images of coffee beans. Four experimental classification setups were applied. Setups 1, 2 and 3 were classification designs by using morphology, color and texture, respectively, while setup 4 was a combination of morphology and color features. For all setups, 156 images were used as inputs of the machine. From these datasets 84 images were used for training the machine while the remaining 36 images were used for testing. The accuracy of classification using morphological features was 100% for both Harar A and Harar B, while accuracy of classification using color, texture and combination of morphological and color features were 94.4, 94.45 and 88.9% for Harar A, respectively. The accuracy of classification using combination of morphological and color features was 100% for Harar B, while it was 83.3 and 88.9% using color and texture features, respectively. The genotypes HCBs were not correctly classified into their origin of collection as Harar A and Harar B as compared to HCBs collected from markets of six districts.

Keywords: Classification; Genotype HCBs; Training and Testing

1. Introduction

Coffee is a tropical plant which requires for its growth, temperature of less than 30^0C, annual rainfall of greater than 1500 mm and a deep slightly acidic and well-drained loam soil. It is highly traded commodity next to petroleum and one of the most popular drinks with enormous commercial and social importance (ICO, 2003).

Arabica coffee is more preferred than Robusta because of its superior quality (Van der Vossen, 1985) where quality is the most important factor dictating world market. The quality of coffee in the accepted sense of the term includes the physical, chemical and organoleptic properties mainly sought after by the consumer. These properties manifest themselves in flavor, aroma, odor, strength, acidity, homogeneity, appearance, and bean shape and size (EEA, 2010).

Ethiopia has a suitable environment to grow all Arabica coffee varieties. Currently, only Coffee Arabica is grown in Ethiopia. Other coffee species are not cultivated yet. Ethiopia being the home of Arabica coffee, the first coffee was discovered from south-western massive highlands of Ethiopia called Kaffa, more specifically from a district called Buno. In Ethiopia, coffee production is concentrated in the Oromia and Southern regions of the country, though the majority of Ethiopian regions are still suitable for coffee growth (ITC, 2002).

In many coffee growing countries, the first priority in research is on coffee quality. Hence, paying much attention to quality improvement and maintenance in the country is of vital importance. This is because the market share for specialty coffees is increasing at a steady rate. The basis for coffee quality identification is often subjective using attributes of color, size, shape and flavor frequently examined by experienced human inspectors (Kotecha and Gray, 2000; Endale, 2007). However, human perception could easily be biased and hence prone to error. As a result, objective discrimination of coffee types and quality determination which is consistent, non-destructive and cost effective for commercial purposes is necessary. Image analysis and classification algorithms can provide a means to quantify objects and patterns in the image data and grade agricultural products. This offers two advantages over traditional or manual methods of analysis; i) human vision is biased due to many factors but automated image analysis provides an unbiased approach and ii) once an image-analysis routine is developed, it can be applied to a large number of sample images, facilitating the collection of large amounts of data for statistical analysis (Kueh *et al.,* 2008*).*

2. Materials and Methods

Source of Samples

An export standard known class Hararghe coffee (Harar A and Harar B) beans were purchased from coffee traders for developing the computer vision algorithm and to evaluate the accuracy of the algorithm. The genotype coffee beans from Mechara Agriculture Research Center were used to classify the genotypic coffee beans in the specified quality categories based on origin of collection.

Experimental design and data generation method

As seen from Figure 1, machine vision approach was used to describe HCBs employing and measuring color descriptors such as mean and standard deviation of each of the RGB, HSV and YIQ channels, area, perimeter, center of mass, major axis, minor axis, ferret diameter, extent, eccentricity and convex area of the shape descriptors and energy, entropy, correlation, contrast, dissimilarity and homogeneity of texture descriptors. In the experiment, quantitative analogues of the features were extracted from the images of HCBs using image processing techniques. Binary, gray and color image processing algorithm were used to extract descriptors.

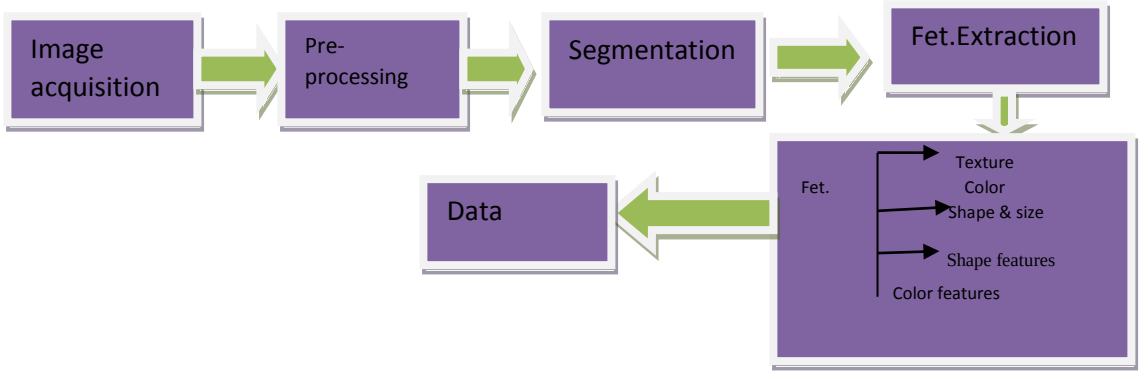


Figure 1. Block diagram for experimental design and data generation method.

Image acquisition: This is the first step of image processing. The images of sample coffee beans were captured using regular digital Nikon Camera which has sixteen megapixels resolution. The images were acquired by mounting the camera vertically on a stand so that it allows vertical movement and stable support. The camera was fixed at an appropriate focus distance from the sample table in-order to capture better images of coffee beans. A white background was used in order to get images of high contrast between the objects and the background. The images were saved in the JPG (Joint Photographic Expert Group) format. All the images were represented in Red, Green and Blue (RGB) color space for color feature extraction, gray level images for texture feature extraction and binary images for shape and size feature extraction.

Image pre-processing: This was the first step to be taken before the major image processing task was taken. In this step, basic tasks were performed in order to render the resulting image more suitable for the job to follow it. In this research, enhancing the contrast of the image and removing noise from the image were performed.

Image segmentation: Image segmentation is very essential for image analysis and pattern recognition. It is a process of dividing an image into different regions. In this work global theresholding was used to segment the image. Segmentation was used to extract the required features i.e., shape and size, texture and color from part of the image in the region of interest. All features were extracted and recorded in manageable form.

Feature extraction and data generation: This is extracting information from the raw data which is most relevant for classification purposes. For an image, a feature can be defined as the "interest" part in an image. The name feature is often used in the pattern recognition literature to denote a descriptor. Features play a fundamental role in classification.

Morphological feature: shape and size, color and texture descriptors were extracted as follows.

Shape and size features: shape and size can be understood as connected sets of points and classified into two main categories: thin and thick. Informally speaking, thin shapes and sizes are composed of contours or curves, while thick shapes and sizes involve filled portions (such as a region). There are so many shape and size descriptors. Some of them which were extracted in this research were:

Area (A): The number of pixels inside the region covered by a coffee bean, including the boundary region. The simplest approach to estimate the area of an object is to count the number of pixels representing that shape. It is measured by square pixels.

Perimeter (P): The length of the outside boundary of the region covered by a coffee bean.

Major axis length (Major): is the distance between the end points of the longest line that could be drawn through the coffee bean. The major axis end points are found by computing the pixel distance between every combination of border pixels in the coffee bean boundary and finding the pair with the maximum length.

Minor axis length (Minor): is the distance between the end points of the longest line that could be drawn through the coffee bean while maintaining perpendicularity with the major axis.

Diameter (D): is the diameter of a circle having the same area as the area of coffee bean and computed as: $D = \frac{\sqrt{4A}}{\pi}$, where A is the area of a coffee bean region in the image.

Centroid (Centre of Mass): is the distance from each boundary points of the binary image to the centre of the image. The easiest way to estimate the shape centroid is as the average values of the shape point coordinates.

Extent: it is the space or degree to which an image is extended.

Eccentricity: the eccentricity of an object is defined as the ratio of the major and minor axes of the object.

Color feature: The colour features of an image is one of the most widely used visual feature in image processing application. Typically the colour of an image is represented through some colour models. The colour model is a specification of 3-D coordinate system and a sub-system within that system where each colour is represented by a single point. The colour models most often used for image processing are the RGB (red, green and blue), the YIQ (luminance and chrominance), and the HSV (hue, saturation and value) models.

In the RGB model each colour appears in its primary spectral components of red, green and blue and they are additive, i.e., by varying their combination other colours can be obtained. The YIQ model in image processing is that the luminance (Y) and colour information (I&Q) are decoupled. The important of this decoupling is that the luminance of an image can be processed without affecting its colour content. In the HSV model the hue is the colour attribute that describes a pure colour (pure yellow, orange, or red), whereas saturation gives a measure of the degree to which a pure colour is diluted by white light.

There is a conversion relation between the colour models, especially from primary colour (RGB) to the others.

$$H = \cos^{-1}\left\{\frac{(R-G)+(R-B)}{2\sqrt{(R-G)^2+(R-B)(G-B)}}\right\}$$

(1)

$$S = 1 - \frac{3[\min(R,G,B)]}{(R+G+B)}$$

(2)

$$V = \frac{1}{3}(R+G+B)$$

(3)

$$Y = 0.3\times R + 0.5\times G + 0.11\times B$$

(4)

$$I = 0.6\times R - 0.28\times G - 0.32\times B$$

(5)

$$Q = 0.21\times R - 0.52\times G + 0.31\times B \qquad (6)$$

Where Y is luminance, I&Q jointly describe the hue and saturation of the image.

The values of each color feature can be calculated as follows.

$$mean = \sum_{b=0}^{L-1} bP(b)$$

(7)

$$Std = [\sum_{b=0}^{L-1} (b-mean)]^{1/2}$$

(8)

Where P(b) is the probability distribution of the amplitude of quantized image given by $P(b) = \frac{N(b)}{M}$

Where M is the total number of pixels in a neighborhood window centered about (j, k) and N (b) is the number of pixels in the same window where b is the number between 0 and L-1. Therefore, a total of thirty-two, (eight shape and size, six, texture and eighteen color) features and their corresponding numerical values for all of the sampled images were calculated and organized by using the developed Matlab code.

Texture features: The coffee bean may become similar in color and shape and size but may exhibit different textures. This led us to adopt texture features in this work. Texture is a very nebulous concept (description), often attributed to human perception, as either the feel or the appearance of (woven) fabric. Everyone has their own interpretation as to the nature of texture. Therefore, for the term texture, there is no permanent definition, but in our case it is an intrinsic characteristic of the image that has correlation to its roughness, and regularity or variability of pixel structure. Like shape and color features, texture features give useful information about the given image through gray level co-occurrence matrix of the pixels. Texture descriptors included in this work were:

Contrast: is the measure of difference in the strength between intensity of pixels in an image. It is calculated by $\sum_{i=0}^{G-1}\sum_{j=0}^{G-1}(i-j)^2\ P(i,j)$, where p (i,j) is (i,j)th entry in a normalized gray-tone spatial dependence matrix.

Correlation: is the measure of statistical relation between the intensity of the pixels of the image and is given by $\sum_{i=0}^{G-1}\sum_{j=0}^{G-1}\frac{p(i,j)\times(i\times j)-(\mu_x\times\mu_y)}{\sigma_x\ \sigma_y}$, where μ_x, μ_y, $\delta x, \delta y$ means and standard deviations of the marginal distributions associated with P(i,j).

Energy: is a measure of the concentration of intensity in a co-occurrence matrix of the pixel. Energy is given as $\sum_{i=0}^{G-1}\sum_{j=0}^{G-1}p(i,j)^2$

Entropy: is a feature used to calculate the degree of randomness of intensity distribution in the pixels of the image. This is equal to $\sum_{i=0}^{G-1}\sum_{j=0}^{G-1}p(i,j)\log(p(i,j))$

Dissimilarity: the quality measure of the intensity of pixels in an image is being dissimilar. So it is given by $\sum_{i=0}^{G-1}\sum_{j=0}^{G-1}|i-j|\ p(i,j)$

Homogeneity: is an inverse of contrast, which measures capital of the homogeny feature of the intensity variation within the image. Homogeneity is equal to $\sum_{i=0}^{G-1}\sum_{j=0}^{G-1}\frac{p_{ij}}{1+|i-j|}$

Support vector machine

Support Vector Machine (SVM) is a supervised classifier based on statistical learning theory and has the aim of determining the location of decision boundaries that produce the optimal separation of classes (Vapnik, 1995).

In the case of a two-class pattern recognition problem in which the classes are linearly separable SVM selects from among the infinite number of linear decision boundaries the one that minimizes the generalization error. Thus, the selected decision boundary leaves the greatest margin between the two classes, where margin is defined as the sum of the distances to the hyper plane from the closest points of the two classes (Vapnik, 1995).

The performance and accuracy of the SVM classifier depend upon some tuning parameters, which are selected during training time. SVM takes large training time in order to obtain the best tuning parameters for the optimal classifier, which increases the performance and efficacy. In order to overcome this drawback many versions of SVM was developed with comparable classification quality.

Binary class support vector machine is a binary classifier that is able to learn the boundary between classes that belong to two different classes. A binary class supervised classification problem is usually formulated in the following way: given n training sample $(\langle x_i \rangle, y_i)$ where $\langle x_i \rangle = (x_{i1}, x_{i2}, ..., x_{im})$ is an input feature vector and $y_i \in \{-1,1\}$ is the target label. The task of the discriminant function or a classifier is to learn the patterns in the training samples in such a way that at a later stage it can predict reliably a y_i for an unknown xi. SVM is fundamentally developed for such binary classification case and is extendable for multi-class classification. Like other linear classifiers, it attempts to evaluate a linear decision boundary.

Linearly separable case: A set of points $(x_i, y_i),\ i = 1,2,...L$, where $y_i = [-1, 1]$ are class labels, is called linearly separable if a linear classifier can be found so that $y_i \times f(x_i) > 0$, i = 1,…, L. As shown in figure 2, a classifier can frequently be represented as a function f(x) in a two-class case. A point is assigned to the positive class if f(x) >0, and to the negative class otherwise. The function f(x) is linear if it can be expressed as

$$f(x) = w.x_i + b \quad (2.1)$$

The decision boundary equation is $f(x)\{w.x_i + b\} = 0$. Anything above the decision boundary should have label 1. That means x_i, for $w.x_i + b > 0$ have a corresponding

value $y_i = 1$. Similarly, anything below the decision boundary should have label -1. i.e., x_i for $w.x_i + b < 0$ will have the corresponding value yi = -1.

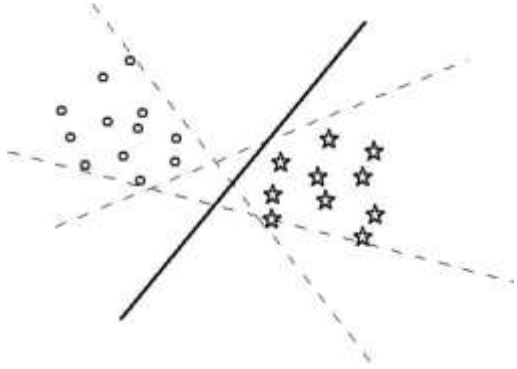


Figure 8. Linearly separable data for binary classification.

Classification method

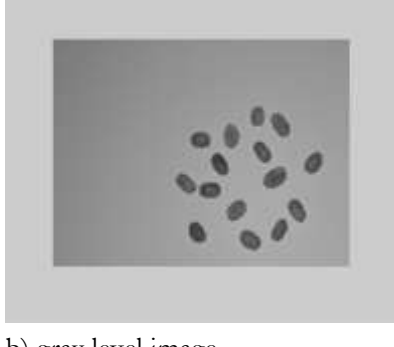
The classification was done by using support vector machine classification technique, i.e., the mean and standard deviation of each feature were used as an input of the machine and the machine was trained until a good result of training was obtained and then the machine was tested by using unseen features of coffee beans collected from the six areas. After the completion of algorithm development using features of coffee beans types A and B collected from the selected areas, then the features of the genotype coffee beans of both types A and B, which were grown in the same environment were taken and the features were used as an input to the developed classification algorithm and the genotypes were used to verify, whether they were grouped in each coffee type according to the origin from where they were collected.

3. Results and Discussion

Image Pre- Processing

The RGB images were converted into gray level and then to binary image for morphological feature extraction. After this; the images were enhanced using contrast adjustment techniques by applying *imadjust* Matlab toolbox functions. Figure 3 shows the original RGB image and its gray level image.

Figure 3. a) RGB image



b) gray level image

Segmentation

For segmentation simple global thersholding method was used to segment the image from the background. Before segmentation, the gray level image was converted to binary image using *level = graythresh(I) and bw = im2bw(I3,level);* Matlab toolbox functions. Figure 4 shows the result of segmented Hararghe coffee beans.

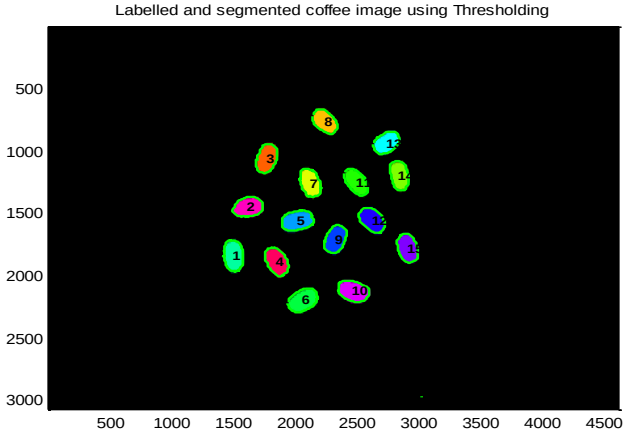


Figure 4. Segmented and labeled HCBs.

Shape and size feature extraction

The segmentation has taken place by using global thresholding method. In binary image, pixels above a specified value which was obtained from histogram of an image are set to white (bright) and pixels below the specified value are set to black (dark). Bright has pixel value 1 and black has pixel value 0. Then morphological features were extracted from binary images. For example, area of an image is equal to number of pixels with pixel value 1. Pixel value 1 represents foreground (object) and pixel value 0 represents background. The values in Table 1 show morphological features (area, perimeter, major axis length, minor axis length, equivalent diameter, centroid, extent, and eccentricity) for sample images of HCBs from each selected coffee growing weredas.

Table 14. Sample shape and size features, average bean values of one image extracted from Hararghe coffee beans collected from six selected weredas.

Features	HararA			HararB		
	Kombolcha	Meta	Deder	Tullo		Bultum
Mechara						
Area(p^2)	241994	242039	242398	241853	241832	241759
Perimeter(m)	1987.8	1993.7	1993.7	1993.7	1991.9	1993.7
Major axis(m)	585.5	586.4	586.5	582.5	584.7	584.9
Minor axis(m)	582.5	584.7	585.9	580.3	583.4	580.6
Diameter(m)	554.8	554.4	553.9	553.9	554	552
Centroid	251.6	250.8	251.3	250.1	249.9	250.3
Extent	1.4	1.03	1.91	1.85	1.69	1 .59
Eccentricity	0.12	0.19	0.16	0.15	0.13	0.17

Color feature extraction

The mean value and standard deviation of color components were extracted from each RGB, SHV and YIQ images. Eighteen color components were extracted. These are mean value and standard deviation of R, G, B, S, H, V, Y, I and Q components. Table 2 shows sample color features of HCBs collected from different weredas.

Table 15. Sample color features extracted from Hararghe coffee beans

Features	MeanR	MeanG	MeanB	Mean H	MeanS	MeanV	MeanY	MeanI
Coffee1	145.09	148.23	156.69	0.551	0.0562	-0.0165	0.603	-0.013
Coffee2	144.66	149.58	156.75	0.563	0.0551	-0.0114	0.606	-0.011
Coffee3	151.6	150.2	166.7	0.56	0.045	0.007	0.643	-0.007
Coffee4	150.9	164.5	158.2	0.561	0.049	-0.009	0.61	-0.009
Coffee 5	152.7	149.4	151.6	0.555	0.052	-0.009	0.587	-0.009
Coffee 6	161.7	153.3	166.7	0.545	0.047	-0.007	0.64	-0.007
Coffee 7	153	148.1	151	0.549	0.063	-0.015	0.583	-0.015
Coffee 8	147.6	153.6	155.3	0.551	0.051	-0.009	0.598	-0.009
Coffee 9	159.1	172.1	149.6	0.562	0.057	-0.011	0.579	-0.011
Coffee 10	146.2	156.5	155.7	0.55	0.045	-0.006	0.599	-0.006
Coffee 11	149.3	157.6	175.8	0.542	0.059	-0.012	0.667	-0.012
Coffee 12	146.06	157.83	158.4	0.554	0.0823	-0.0243	0.611	-0.024
Coffee 13	149.3	152.9	160.3	0.54	0.05	-0.009	0.611	-0.009
Coffee14	163.7	166.1	159.6	0.564	0.075	-0.019	0.617	-0.019
Coffee15	153.3	162.2	154.5	0.545	0.045	-0.008	0.596	-0.008

Texture feature extraction

In this step texture features were extracted from each segmented image using GLCM. Since a single direction might not give enough and reliable texture information, four directions and two displacements were used to extract the texture information for each segmented mass. The matrices were constructed at a distance of d = 1 and d=2 and directions 0^0,45^0, 90^0, 135^0. That means, for a given single image eight different values were used and the mean of eight values was calculated. Energy, entropy, correlation, contrast, dissimilarity and homogeneity of the image were extracted in order to classify genotypic HCBs. Table 3 shows sample texture features of HCBs collected from six different coffee growing weredas.

Table 16. Sample texture features extracted from Hararghe coffee beans

	Contrast	Correlation	Dissimilarity	Energy	Entropy	Homogeneity
Coffe1	1.025	0.7221	0.4196	0.3719	1.3266	0.8703
Coffe2	0.7817	0.7211	0.3481	0.4507	1.1747	0.8882
Coffe 3	0.883	0.73	0.394	0.383	1.329	0.873
Coffe 4	0.879	0.74	0.389	0.388	1.337	0.875
Coffe 5	0.885	0.729	0.397	0.379	1.336	0.872
Coffe 6	0.338	0.819	0.217	0.386	1.363	0.903
Coffe 7	0.273	0.822	0.159	0.536	1.026	0.929
Coffe 8	0.347	0.815	0.223	0.376	1.387	0.93
Coffe 9	0.328	0.819	0.212	0.397	1.335	0.904
Coffe 10	0.893	0.715	0.399	0.379	1.323	0.872
Coffe 11	0.992	0.735	0.408	0.38	1.312	0.874
Coffe 12	0.822	0.724	0.344	0.465	1.128	0.892
Coffe 13	0.812	0.719	0.363	0.43	1.219	0.883
Coffe 14	0.573	0.92	0.482	0.061	3.045	0.774
Coffe 15	0.59	0.916	0.496	0.06	3.061	0.769

Experimental classification results using SVM

All the dominant features of Hararghe coffee types A and B were used to develop the algorithm i.e., to train and test the machine. Features of genotype coffee beans of types A and B were the inputs of the machine to categorize them to their origin of collection.

Experiment 1: classification using shape and size features

Ten shape descriptors were used as an input of the support vector machine and the most dominant descriptors were selected for classification of genotypic coffee beans depending on the training result of the machine. The machine was trained and tested by these selected features.

The classification result of Hararghe coffee genotype by using SVM is shown in Figure 5.

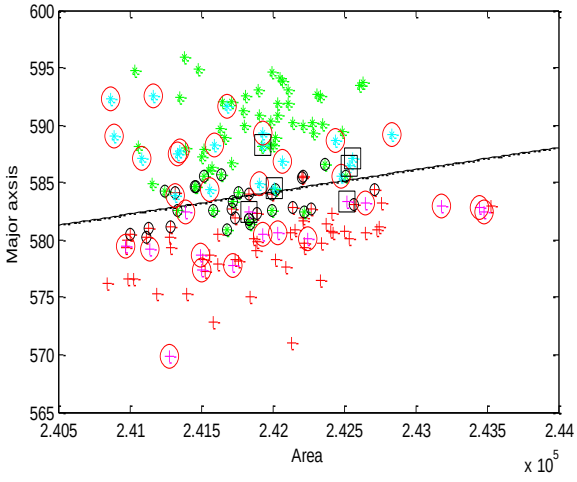


Figure 5. Output of genotypic classification of HCBs by shape and size descriptors.

In Figure 5, the classification result of Support Vector Machine (SVM) using shape and size features shows that the genotypic Hararghe coffee beans which are grown at the same place under the same environment and the same agronomical management for the last nine (9) years were not correctly classified into their origins of collection. From the figure the stars (*) and the signs were genotypic HCB images which were not correctly classified to their origin of collection and the plus and stars were genotypic HCB images that were correctly grouped into their origin of collection. The result shows that 22.2%, (four images of Harar B) genotypes classified to Harar A CB type and 11.1%, (two images, of Harar A) genotypes classified to Harar B CB types. Generally, from the classification result 33.3%, six images, of Hararghe genotypic coffee beans were not classified to their origin of collection.

Experiment 2: classification using color features

In this model, eighteen colour descriptors of coffee bean type A and type B collected from six selected areas were used to train and test the machine and the dominant descriptors, that increase the performance of SVM, were selected. The classification result of Hararghe genotypic coffee beans using the developed SVM with colour features was shown in Figure 6.

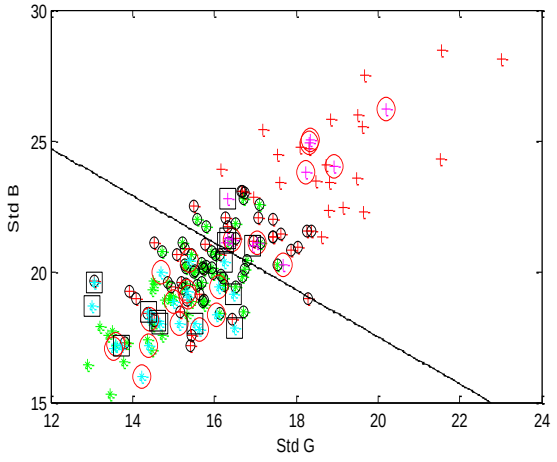


Figure 6. Output of genotypic classification of HCBs using colour features.

The above classification result of Support Vector Machine (SVM) using colour features show that the genotypic Hararghe Coffee beans which are grown at the same place with the same environment and same agronomical management for the last nine (9) years were not correctly classified to their origins of collection. The result tells that 22.2% (four images i.e. the * sing in the circle) of Harar A CB genotypes were classified to Harar B CB type and 55.5% (ten images i.e., the plus sing in a square) of Harar B genotypes CBs were classified to Harar A CB type. Generally, the result of colour feature classification of genotypic HCBs shows that (fourteen images) of genotype HCBs were not classified to their origin of collection.

Experiment 3: classification using texture features

The setup contains, six texture descriptors, which were used to train and test the machine and the dominant descriptors were selected. The classification result of Hararghe genotypic coffee beans using the developed SVM with textural features is shown in Figure 7.

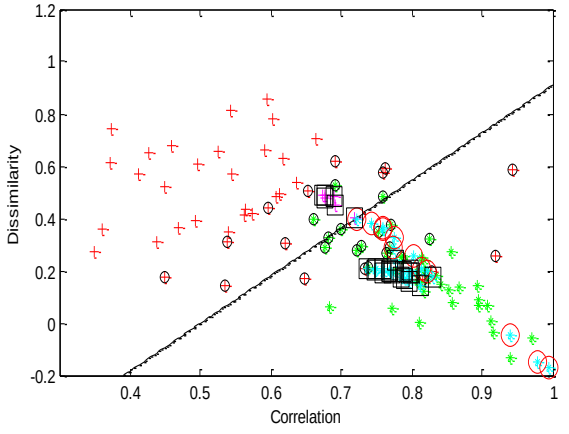


Figure 7. Output of genotypic classification of HCBs using texture features.

From Figure 7, the classification result of Support Vector Machine (SVM) using textural features showed that the features of genotypic Hararghe coffee beans were not perfectly classified to their origins of collection. The result indicated that all images of Harar B and thirteen images of Harar A coffee genotypes were classified to Harar A coffee type and five images of Harar A and no image of Harar B were classified to Harar B coffee type.

Experiment 4: classification using mixed (morphological and color) features

In this case, twenty six descriptors were used to train and test the machine and the descriptors with high training and testing accuracy were selected for genotypic classification of HCBs. The classification result of Hararghe genotypic coffee beans using the developed SVM with mixed features is shown in Figure 8.

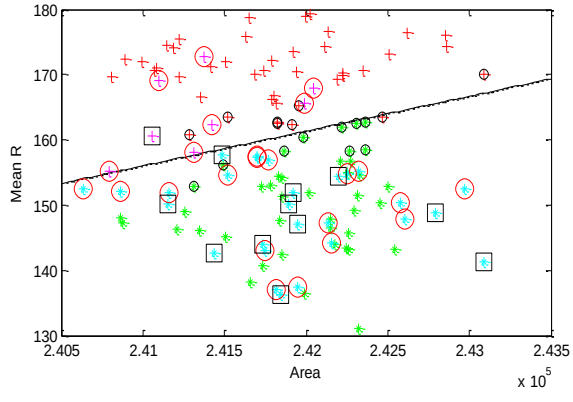


Figure 8. Output of genotypic classification of HCBs using mixed features.

The classification result of SVM using mixed features showed that the images of genotypic Hararghe coffee beans which are grown at the same place were not exactly classified to their origins of collection. From the result we saw that 11.1% or one image

(represented by plus sign in a square) of Harar A coffee genotypes was categorized into coffee type Harar B and 61.1%, or eleven images (images represented by stares in a square) of Harar B CB genotypes were grouped into coffee type Harar A. Generally, the result tells that twelve images of genotype coffee beans were not classified to their origin of collection.

4. Conclusion

In this paper, we saw the comparative results using different features of the coffee beans. It has been tried to show the comparative classification results of Hararghe genotypic coffee bean data samples using different features of the coffee beans such as shape and size, color, texture and mixed features. From the results, the similarity of the genotype coffee beans was based on the features of the coffee beans. Overall, the SVM classification approach was found very promising for image based classification of Hararghe genotypic coffee beans. It was shown that it can produce comparable or even better results than the other supervised classification methods.

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11. Management of an Emerging Pest, *Tetranychus urticae* Koch (Arachnida: Acari: Tetranychidae), with Pesticides

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Abstract: After the outbreak of red spider mite, *Tetranychus urticae* Koch, on potato in different parts of eastern Ethiopia in 2014, pesticides that could effectively help manage the mite pest and be included as part of the bigger IPM practice were sought. An experiment was conducted in green house and laboratory at Haramaya University, Ethiopia. In the greenhouse trial single potato plants infested with mites were used for testing the efficacy of two miticides (Amitraz and Profenofos), six insecticides (Chlorantroniliprole, Chlorantrniliprole + Lambdacyhalothrin, Spinosad, Flubendiamide, Profenofos "Q" 720g/l, and Paraffin oil) and Liquid soap along with untreated control. Treatments were replicated three times in a completely randomized experiment and infested potato plants were sprayed three times at weekly intervals. Numbers of mites per leaf were counted before and after each spray. Selected pesticides were further screened under laboratory in petridishes on a leaf disc spray and dip methods. Mortality was recorded 24 and 48 hours after treatment applications. In the greenhouse trial, Chlorantrniliprole + Lambdacyhalothrin, Amitraz, Profenofos, Profenofos "Q" 720g/l, and Paraffin oil showed superior efficacy (>95%) against eggs, immatures and adults. In the laboratory; however, Paraffin oil gave significantly lowest mortality (16%) compared to Chlorantrniliprole + Lambdacyhalothrin, Profenofos and Profenofos "Q"720g/l in the leaf disc spray method. Higher mortality recorded for paraffin oil with the leaf disc dip method might be related to its mode of action that requires complete wetting of the target pest. Satisfactory efficacy of paraffin oil in the greenhouse might indicate that it's a slow acting and might need a minimum of a week to reveal its effect on red spider mite population. Chlorantrniliprole + lambdacyhalothrin, Profenofos and profenofos "Q" are commonly available pesticides in the market though were not registered for red spider mite control on potato while Paraffin oil can be found in pharmacies for other uses. So, Chlorantrniliprole + lambdacyhalothrin, Profenofos, Profenofos "Q" and Paraffin oil must be tried in an on-farm verification with farmers before recommending for large scale use as part and parcel of an integrated pest management program against red spider mite.

Keywords: Insecticides; Miticides;, Outbreak; Potato and Red spider mite

1. Introduction

Potato (*Solanum tuberosum* L.) is an important crop in Ethiopia and currently planted in around 179,159.27 ha with an average yield of 8.9 tons per hectares. In Eastern Hararghe alone, potato covers 2,207.12 hectares with an average yield of 19.3 tons per hectares that was higher than the national average yield (CSA, 2014). Potato production is; however, constrained by unfavorable climatic and edaphic conditions in addition to a range of biotic factors that limit the yield of the crop. Poor quality seed tuber (Labarto, 2013; Bezabih and Mengistu, 2011), low yielding potato varieties, and insect pests and diseases (Ferdu *et al*., 2009) are among the biotic factors. Accordingly, to improve the genetic potential of potato, germplasms are often imported from external sources and presently 25 to 40 potato materials are imported every year. Recent pest risk analysis study reported by the same authors identified 61 arthropods, 48 nematodes, 41 fungi, 14 bacteria, 24 viruses and 59 weeds as quarantine pest species for Ethiopia when importing potato germplasm from the Netherlands, Peru, Uganda and Kenya (Dereje and Gebremedhin, 2013). Other means of pest introduction outside of germplasm might be possible with neighboring countries like Kenya. This makes the threat of introduced pests and diseases certain, if precautions are not taken and a robust surveillance system is not in place.

Tetranychus urticae, is a serious insect pest on roses (Belder *et al*., 2009), tomato (Gashawbeza *et al*., 2009), and was earlier reported on pigeon pea in 1986 from central Ethiopia (Tsedeke, 1987). Red spider mite is also known as two-spotted spider mite (TSSM). Outbreaks of TSSM infestation on potato occurred in the main season of 2014 on farmers' fields in limited localities of eastern Ethiopia. However, in 2015 the pest expanded its geographic distribution and covered the main potato growing districts of eastern Ethiopia and caused significant yield losses in farmers' fields, experimental plots and seed multiplication sites. Infestation was also evident on wild host plants *viz.,* wild Solanaceous plants like *Datura stramonium* L. and *Solanum elaeagnifolium* Cav. and trees like *Melia azadirach* L. and *Khata edulis* L. (Goftishu *et al*., 2016). The list of attacked plant species may increase as TSSM is known for being polyphagous and feeds on over 1,100 different plant species belonging to more than 140 different plant families (Grbic *et al.,* 2011). Two spotted spider mite problems became serious in the 2015 *meher* season when there was shortage of rain. Many researchers believe that detrimental effects of spider mites in agriculture increases with intensifying global warming (Migeon *et al.,* 2009).

Pesticide use has become the first line of defense against insect and mite pests in different parts of Ethiopia. Yet vegetable growers in the central rift valley of Ethiopia observed a decline in efficacy of pesticides used against red spider mite on tomato (Belete and Getahun, 2015). Following the first outbreak of TSSM in the major potato belt of eastern Ethiopia, potato producing farmers used the conventional insecticides available in the market for managing other insect pests, but without success. This led to

a complete failure of the crop in the area in 2014 and 2015 (Goftishu *et al*., 2016). In Ethiopia, most of the insecticides available in the local market for managing vegetable insect pests are old and broad-spectrum such as organochlorines, organophosphates and pyrethroids. The population of TSSM which established in eastern Ethiopia is assumed to have already developed resistance to these groups of insecticides (Goftishu *et al.,* 2016). Globally *T. urticae* is known for its ability to develop rapid resistance to pesticides (Van Leeuwen *et al*., 2010). Rapid development of populations, high fecundity and haplo-diploid sex determination were the factors that facilitated rapid evolution of pesticide resistance in red spider mite (Grbic *et al*., 2011). Pesticide use constitutes one of the components of an integrated pest management, miticides and insecticides that can effectively control red spider mite need to be identified and used in a way that reduces resistance development.

There are miticides registered in Ethiopia for the control of mites in flower, tomato, strawberry and cotton. In India, mineral oils were reported to suppress mite populations with in short period of time (Prasad *et al*., 2008). However, in Ethiopia none of the registered miticides were tested on potatoes as it was only recently that TSSM was observed on this crop. There is, therefore, a need to screen the available miticides, insecticides and other organics against the red spider mite in an attempt to identify those with the highest efficacy and make the information available to farmers so that they use the right product for controlling the mite pest.

2. Materials and Methods

Description of the Study Area

The study was conducted at the Plant Protection Research Laboratory and Greenhouse of Haramaya University, Ethiopia. It is located at $42^{0}3$'E longitude and $9^{0}26$'N latitude and at an altitude of 1980m above sea level. Average temperature and relative humidity in the laboratory was 25^{0}C and 62.5%, respectively, while that of the greenhouse was 34^{O} C $\pm$ 5^{o}C.

Source of Tetranychus Urticae

Population of red spider mites, *T.urticae,* were obtained from wild solanaceous plants and were maintained on young haricot bean plants (*Phaseolus vulgaris* L) grown indoors. Young bean plants were infested with red spider mite infested leaves and fresh bean plants were provided at regular intervals to maintain the populations of red spider mites.

Pesticides

Nine pesticide treatments along with water as a control were used (Table 1). One miticide (Amitraz), six insecticides (Chlorantroniliprole, Chlorantrniliprole + Lambdacyhalothrin, Spinosad, Flubendiamide, Profenofos, and Profenofos "Q" 720g/l), Paraffinic oil, liquid soap and control were included. Manufacturer rate were

employed for the common ready to use pesticides while 2.5% of paraffin oil and liquid soap were used.

Treatments and Experimental Procedures

Efficacy of pesticides in greenhouse

Sprouted potato tubers of the variety Gudiene were planted (20th of June 2016) individually in pots 18 cm long, diameter at top and bottom was 20 cm and 14 cm, respectively. Standard nursery soil was used. Ten treatments (Table 1) considered in this experiment were replicated three times in completely randomized design. Three weeks after planting, potato plants were innoculated with red spider mite infested potato leaves. To ensure uniform and quick infestation of the mites two successive inoculations were made. Treatments were mixed with 100 ml of tap water for application to individual plants. Mite counts, under a stereomicroscope, were performed on three leaf samples taken from different parts of the plant before and after the first, second and third sprays. Sprays were applied at weekly intervals. Mortality was recorded 24 and 48 hours after treatment application and mites were considered dead if their appendages did not move when prodded with a fine hair brush.

Table 1. Pesticide treatments and their application rates.

S.N	Trade name	Common name	Rate/ha	Rate/plant
1	Mitac 20 EC	Amitraz	2.5lt	60µl
2	Coragen 200 Sc	Chlorantroniliprole	250ml	5µl
3	Ampligo 150	Chlorantrniliprole +	300ml	7µl
4	Tracer 480 SC	Spinosad	300ml	7µl
5	Belt SC 480	Flubendiamide	120ml	5µl
6	Profit 72 EC	Profenofos	1.0lt	25µl
7	Selecron	Profenofos "Q" 720g/l	1.0lt	25µl
8	Paraffinic oil	Paraffin	2.5%	2.5 ml
9	Liquid soap	---	2.0%	2.0 ml
10	Control	Water	Untreated	Untreated

Laboratory evaluations of pesticides on adult *T.urticae* with leaf dip bioassay

Aqueous dispersions of commercial pesticide formulations (five pesticides) were used in a leaf dip bioassay (Cahill *et al.*,1995). A 4cm x 4cm bean leaf disc (Recep *et al.*, 2005), with 20 adults, was dipped for 5 seconds in 100 ml aqueous solution of the pesticide while control was dipped in tap water. Treated leaves were placed on wet cotton wool surrounded by moistened tissue paper inside Petri-dishes and then were placed at room temperature. Tissue paper was moistened with water when dried. Mortality was recorded 24 and 48 hours after treatment. Mites were considered dead if appendages did not move when probed with a fine paint brush.

Laboratory evaluation of pesticides on adult *T.urticae* with leaf disc spray

Aqueous dispersions of commercial pesticide formulations (five pesticides) were used in a leaf disc spray method (Helle and Overmeer, 1985). Twenty adult red spider mites were placed onto each 4cm x 4cm leaf disc (Roopa, 2005) on wet cotton wool surrounded by moistened tissue paper in petri-dishes. Tissue paper was moistened with water when dried. Leaf discs containing twenty adults were treated with five compressions (0.5ml) of the pesticide in a spray bottle from a distance of 20 cm and an angle of 90 degrees. The sprayed leaf discs inside the petri dishes were kept at room temperature. Numbers of dead or alive adults were counted under a dissecting microscope 24 and 48 hours after treatment. Mites were considered dead if appendages did not move when probed with a fine brush.

Data Collection

The numbers of dead adults/immatures recorded from the greenhouse and laboratory experiments were converted into percentage mortality. Pre- and post-spray counts of eggs, immatures and adults per leaf were also recorded from the greenhouse experiment and percent reduction in infestation (efficacy %) was computed following Henderson and Tilton (1955) equation. Any change in color and texture of leaves due to probable phytotoxicity of the pesticides and plant mortality, if any due to the tested pesticides, were recorded. Percent mortality (adults/immatures) was corrected using Abbott's formula (Abbott, 1925).

$$\% \text{ Corrected Mortality} = \frac{(\% \text{ mortality in the treatment} - \% \text{ control mortality}) \times 100}{(100 - \% \text{ control mortality})}$$

Percent reduction in infestation (% efficacy) of mites was calculated using (Henderson and Tilton, 1955).

$$\text{Reduction (\%)} = \frac{(1 - n \text{ in Co before treatment} \times n \text{ in T after treatment})}{(n \text{ in Co after treatment} \times n \text{ in T before treatment})} \times 100$$

Where; n = number, Co = Control and T = Treatment.

Data Analysis

Data on mite count before and after spray from the greenhouse and laboratory experiments were converted into mortality percentages. Efficacy (%) of the pesticides generated using Henderson and Tilton (1955) formula were neglog transformd (Whittaker *et al.*, 2005) and were subjected to analysis of variance GLM procedure using IBM SPSS Statistics version 20 (IBM SPSS, 2011). Mite mortality from the laboratory experiments were adjusted with logistic transformation (Johnson, 1949) and subjected to ANOVA. As control mortality was less than 10%, there was not need to correct the

values with Abott's formula (Abbott, 1925). Means were separated with Least Significant Difference when they show a significant ANOVA (Snedecor and Cochran, 1980).

Logit p = log (p / (100 - p)) for percent,

where p is a proportion or percent----(Johnson, 1949)

Neglog= sign(x) ln(|x| + 1)----------Whittacker *et al.* (2005).

3. Results

Efficacy of pesticides against red spider mites in the Greenhouse

There was significant difference in the efficacy of pesticides tested against adults and immatures of the red spider mite in greenhouse. In fact, the efficacy of these pesticides against the eggs of the red spider mites showed highly significant differences (Table 2). These results indicate that there were some promising pesticides that might form part of the integrated mite management program.

Table 2. F-statistics values on efficacy of pesticides against adults, immatures and eggs.

Efficacy against	Source of variation	df	Mean Square	F	Prob.
Adults & immatures	Pesticides	9	16.636	2.864	0.024*
Eggs	Pesticides	9	14.971	4.010	0.005**

***, significant at 0.01; *, significant at 0.05.*

Significant differences in efficacy among the pesticides against immature and adult red spider mites were observed (Table 2). More than 97% of efficacy was recorded for Amitraz, Chlorantrniliprole + Lambdacyhalothrin, Profenofos, Profenofos"Q" 720g/l, and Paraffin oil. Beside high efficacy, these pesticides were significantly different from Chlorantroniliprole, Flubendiamide and the control. Negative efficacy and eventual plant death, similar to the control, was noted in Flubendiamide. Spinosad and liquid soap had fair efficacies but could not provide protection of the plants from the red spider mite damage. The kind of liquid soap used in this experiment was toxic to the potato plants though sprayed plants was seen producing new leaves in between spray intervals.

Differences in efficacy among the pesticides against eggs of red spider mites were also recorded (Table 3). Chlorantrniliprole+ Lambdacyhalothrin, Profenofos, Profenofos"Q" 720g/l, and Paraffin oil showed efficacy greater than 99% and were significantly different from the control and liquid soap. Chlorantroniliprole, Spinosad and Flubendiamide had efficacy in the range of 86.7-91.7% while Amitraz had lower efficacy, not different from the control and the liquid soap.

Looking the combined effects of the pesticides against the adults and eggs of the red spider mites, four pesticides (Chlorantrniliprole+ Lambdacyhalothrin,

Profenofos, Profenofos"Q" 720g/l, and Paraffin oil) had high and consistent efficacies. Amitraz was effective in killing the adults and immatures while having lower efficacy against the egg. The liquid soap showed a similar trend to that of Amitraz. Chlorantroniliprole, while having very good action against the eggs, was ineffective against the adults and the nymphs. Spinosad had a similar tendency to that of Chlorantroniliprole. Negative efficacy noted for Flubendiamide indicates that the pesticide led to an increase in the population of mites.

Table 3. Mean % efficacy of the pesticides against eggs, immatures and adults of red spider mite in a greenhouse.

		Percent efficacy against	
S.N.	Treatment	Adults & immature*	Eggs*
1	Amitraz	97.7 (4.6)a	30.0(1.5)ab
2	Chlorantroniliprole	5.9 (1.1)b	91.7(4.5)a
3	Chlorantrniliprole+Lambdacyhalothrin	100.0 (4.6)a	100.0 (4.6)a
4	Spinosad	60.1(3.3)ab	86.7(4.5)a
5	Flubendiamide	-59.3 (-1.7)b	91.7(4.5)a
6	Profenofos	99.8 (4.6)a	100.0(4.6)a
7	Profenofos"Q" 720g/l	99.9 (4.6)a	99.3(4.)a
8	Paraffin oil	99.9 (4.6)a	100.0 (4.6)a
9	Liquid soap	78.2 (4.3)a	-10.0 (-1.1)b
10	Control	0.0(0.0)b	0.0(0.0)b
	CV (%)	80.3	59.8
	LSD (5%)	4.105	3.291

**Means in columns with the same letter are not significantly different at a=0.05. Numbers in parenthesis are the Neglog transformed values. CV (%)= coefficient of variation; LSD (5%), least significant difference.*

The number of red spider mite adults and nymphs were also monitored over a three weeks period before and after the application of pesticides (Figure 1). The red spider mite adult and nymph population was suppressed one week after the application of Amitraz, Chlorantrniliprole+ Lambdacyhalothrin, Profenofos and Profenofos"Q" 720g/l. Adult and immatures were not however, suppressed and instead was kept constant by Paraffin oil one week after the first spray. The effect of paraffin oil was at par with Amitraz, Chlorantrniliprole+ Lambdacyhalothrin, Profenofos and Profenofos"Q" 720g/l after the second spray and they all suppressed the mite populations. Chlorantroniliprole, Spinosad, Flubendiamide and Liquid soap application at weekly intervals increased the mite population till the second and third weeks.

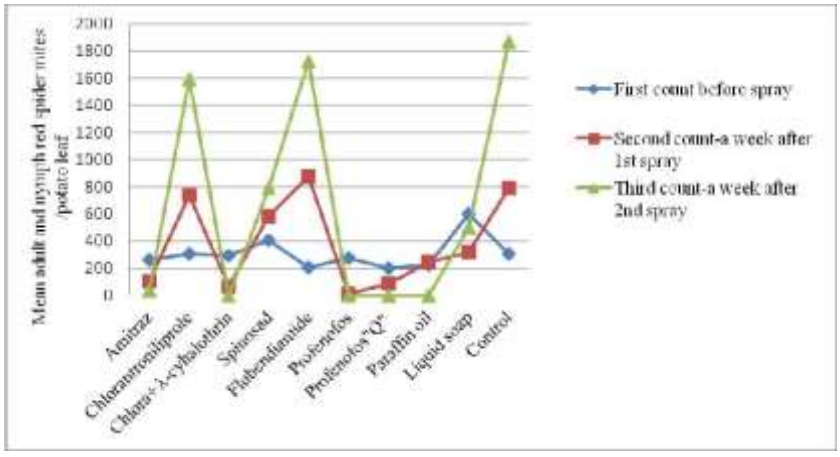

Figure 1. Mite population dynamics after treatment with pesticides over a three week period.

However, the eggs of red spider mites monitored over a three weeks period, at weekly intervals, following the application of the pesticides revealed variable responses (Figure 2). Chlorantrniliprole + Lambdacyhalothrin, Spinosad, Profenfos, Profenfos "Q" 720g/l, and Paraffin oil decimated red spider mite eggs considerably a week after the first spray and had their final impact following the second spray. While Amitraz, Chlorantroniliprole, and liquid soap had reduced the number of eggs reasonably while the egg counts at Flubendiamide treated plants were comparable to that of the control a week after the first spray. After the second spray, a number of pesticides had the lowest egg count, indicating appreciable level of egg mortality.

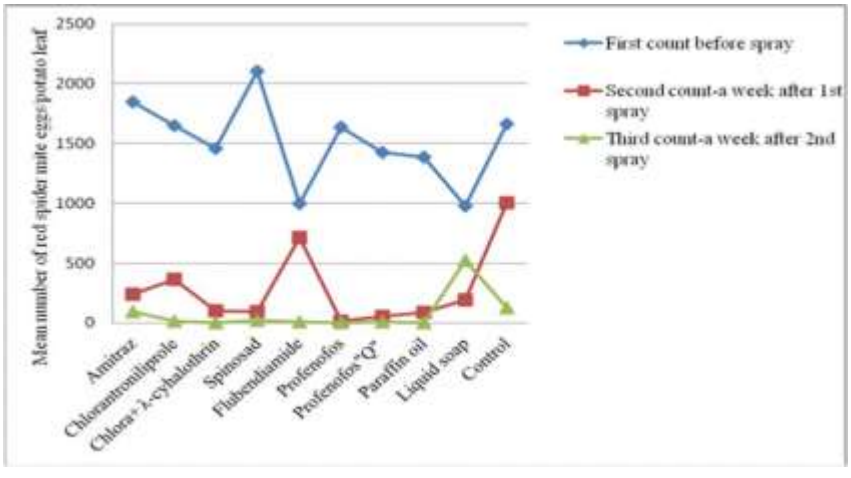

Figure 2. Red spider mite egg counts in treated plots over a three week period.

Laboratory evaluation of pesticides on adult *T. urticae* with leaf disc spray

Analysis of variance for mortality of red spider mite adults in a leaf disc spray method (after 24 and 48 hrs) due to the selected pesticides in the laboratory yielded highly significant differences (Table 4). Amitraz, Chlorantrniliprole+

Lambdacyhalothrin, Profenofos, and Profenofos"Q" 720g/l produced mortality of above 98% 24 hrs. after treatment that was significantly different from Paraffin oil and the control (Table 4). Paraffin oil was at par with the control. For the effective pesticides, mortality was raised to 99.9% 48 hrs later. Though significantly lower than the effective pesticides, mortality by paraffin oil was doubled 48 hrs. later.

Table 4. F-statistics values on mortality of adult red spider mites in leaf disc spray.

Mortality after	Source of variation	df	Mean Square	F	Prob.
24 hrs	Pesticides	5	22.2061	53.78	<0.001**
48 hrs	Pesticides	5	21.07507	833.30	<0.001**

***, significant at a=0.001.*

Table 5. Mean mortality of red spider mites in leaf disc spray.

S.N	Pesticide	Mortality after 24	Mortality after 48
1	Amitraz	98.92 (2.66) a	99.90 (3.0) a
2	Chlorantrniliprole+	98.92 (2.66) a	99.90 (3.0) a
3	Paraffin oil	8.00 (-1.08) b	16.00 (-0.8)b
4	Profenofos	99.90 (3.00) a	99.90 (3.0) a
5	Profenofos"Q" 720g/l	98.92 (2.66) a	99.90 (3.0) a
6	Control	5.02 (-1.56) b	7.00 (-1.2)
	CV (%)	46.3%	9.5
	LSD (5%)	0.839	0.21
	SE	0.643	0.16

**Means in columns with the same letter are not significantly different at a=0.05; number in parenthesis are the logistic transformed values.*

Laboratory evaluations of pesticides on adult *T. urticae* with leaf dip bioassay

Analysis of variance for mortality of adult red spider mites in a leaf disc dip method (after 24 and 48 hrs) due to the selected pesticides in the laboratory yielded highly significant differences (Table 6). All pesticides had high mortalities of red spider mite adults (24 hrs. later) that were significantly higher from the control (Table 7). The mortality due to Paraffin oil was; however, significantly lower than that of Amitraz, Chlorantrniliprole+ Lambdacyhalothrin, Profenofos, and Profenofos"Q" 720g/l. 48 hrs later, all pesticides had mortalities significantly different from the control though the magnitude was slightly lower for paraffin oil. Comparing the suitability of both the leaf disc spray and leaf disc dip as be?? methods of testing effectiveness of pesticides against the red spider mite, it was found that the leaf disc dip method is more robust in showing quick results though there is the possibility that mites might get dislodged and fall to the solution during dipping.

Table 6. F-statistics values on mortality of adult red spider mites in leaf disc dip method.

Mortality after	Source of variation	df	Mean Square	F	Prob.
24 hrs	Pesticides	5	22.7056	70.48	<0.001**
48 hrs	Pesticides	5	18.9757	49.96	<0.001**

***, significant at a=0.001.*

Table 7. Mean mortality of red spider mites in a leaf disc dip method.

S.N	Pesticide	Mortality after 24 hrs*	Mortality after 48 hrs*
1	Amitraz	99.90 (3.00) a	99.90 (3.00) a
2	Chlorantrniliprole+	99.90 (3.00) a	99.90 (3.00) a
3	Paraffin oil	89.50 (1.30) b	96.46 (2.21) a
4	Profenofos	99.90 (3.00) a	99.90 (3.00) a
5	Profenofos"Q" 720g/l	99.90 (3.00) a	99.90 (3.00) a
6	Control	2.54 (-2.29) c	4.87 (-1.87) b
	CV (%)	30.9%	30.0%
	LSD (5%)	0.742	0.804
	SE	0.568	0.616

**Means in columns with the same letter are not significantly different at a=0.05; number in parenthesis are the logistic transformed values.*

4. Discussion

Among pesticides tested against red spider mite in the greenhouse, Amitraz (Recep *et al.*, 2005; MoA, 2016) and Profenfos (Venugopal *et al.,* 2003) are the only known miticides while the remaining pesticides including Chlorantrniliprole, Chlorantrniliprole+ Lambdacyhalothrin, Spinosad, Profenfos "Q" 720g/l and Flubendiamide are insecticides (MOA 2016). In Ethiopia; however, Profenfos was registered for the control of pea aphids (*Acyrtosiphon pisum*) on field pea in Ethiopia (MoA, 2016). Paraffin oil, commonly used against soft scale insects, is also known for having miticidal effects (Prasad *et al.,* 2008). The results obtained from the efficacy test in the greenhouse indicated that besides, the known miticides, Amitraz and Profenfos, insecticides like Chlorantrniliprole+ Lambdacyhalothrin and Profenfos "Q" 720g/l gave an excellent control of the red spider mite adult, nymph and egg s tages. Chlorantrniliprole+ Lambdacyhalothrin was registered in Ethiopia for the control of tomato leaf miner and fruit borer (*Tuta absoluta*) while Profenfos "Q" was indexed by the Ministry of Agriculture for the control of maize stalk borer on maize (MoA, 2016).

Chlorantrniliprole, Flubendiamide and Spinosad are new generation insecticides with translaminar mode of action recommended for the control of tomato leaf miner in Ethiopia (MoA, 2016). The selective effectiveness of Chlorantrniliprole and Flubendiamide to the eggs rather than the adult red spider mites, recorded in this study,

might indicate their potential for the management of red spider mites when applied for the control of tomato leaf miner. The moderate efficacy of Spinosad to eggs, nymphs and adults might also indicate its potential use in synergistic interactions. Mixture of Spinosad and Abamectin increased adult mortality (74%), reduced fecundity and egg hatching rate of red spider mites in a leaf disc trial (Ismail *et al.*, 2007).

Paraffin oil is one class of mineral oil often used for the control of insect and mite pests in other parts of the world. Mineral oils are preferred because there are no reported cases of resistance and that might be due to its modes of action (including hypoxia) or its relatively low selection pressure against pests (Fernandez *et al.*, 2005). Mineral oil is not; however, widely used in Ethiopia and there is only a single white oil (Medopaz) product registered in the country for the control of red scale, orange scale, purple scale and black scale on citrus (MoA, 2016). Paraffin oil is available in Ethiopia, though its use is limited to medical purposes. The excellent performance of the paraffin oil against the red spider mite might indicate its potential use for integration with other methods like in rotation with other pesticides.

Red spider mites are known for developing resistance to pesticides (Van Leeuwen *et al.,* 2010). Rotation of pesticides year to year is often regarded as one strategy for the management of resistance in pests against pesticides (Mallet, 1989). From the greenhouse study, we identified suitable miticides, insecticides and mineral oils that would suppress mite population. This might lead to a separate investigation on how to use the candidate pesticides in rotation so as to slow or prevent the development of resistant mite population.

Leaf disc spray and dip methods identified best pesticides for the management of red spider mites that could form part and parcel of integrated pest management. Results were comparable between the methods except that Paraffin oil gave higher mortalities 24 and 48 hours after application with the leaf disc dip method. Oils need complete coverage of the target pest and the host plant (Flint, 2014). Because oils kill insects and mites by blocking spiracles thus reducing availability of oxygen and interfering with various metabolic processes and penetrate egg shells and kill developing embryo (Flint, 2014). Leaf disc dip method ensures more complete wetting of the leaf and the mites on it compared to the leaf disc spray and this might be the reason for the elevated mortalities in the leaf dip.

5. Conclusion

From this study, two miticides (Amitraz and Profenfos), two insecticides (Profenfos"Q" and Chlorantrniliprole + Lambdacyhalothrin) and paraffin oil were identified as promising pesticides for the management of red spider mites on potatoes. All of them are available in the country but it is recommended an on-farm verification of the pesticides before large scale use.

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12. Multilocation Yield Trial of Shallot (*Allium cepa var. ascalonicum* Backer) and Onion (*Allium cepa* L.) Varieties in eastern Ethiopia

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Abstract: It has been tried to produce seeds from shallots but the success history of seed production was not as other crops and entirely the crop is produced from bulbs that requires average of 1.2 t ha^{-1}. The large amount of bulbs required for planting and the difficult in keeping the bulbs for long period make this crop less preferable by the producers and the production of seed from this crop remains the horticulturist challenge in the world. The production of the crop from seed also helps to create variation through artificial or natural outcrossing that gives a chance for breeders to improve the crop. Keeping in view the problem, Haramaya University initiated research project with the objectives of seed production from Huruta (DZ-SHT-91) shallot variety, released by Debre Zeit Agricultural Research Center and to improve the variety for bulb yield through seed to bulb to seed method. The project started during 2004/2005 cropping season and continued for the last 12 years in which Huruta was essentially improved as seed producing shallot variety in eastern Ethiopia. Then after the improved variety was evaluated for bulb and true seeds yields production over years (2010 to 2017) and locations (12) as well as 28 farmers' fields along with three onion (Adama Red, Bombay Red and Kelafo hybrid) and three shallot (Huruta produced from bulb, Atilase and Dz-94) varieties. The variety had an average advantage of 321.43% true seeds yield increase from the three onion and shallot varieties and it had average advantages of 35.03 and 31.4% marketable bulb yield and marketable bulb weight (g), respectively, over three onion varieties. Moreover, the improved shallot variety had an advantage of 9.66 and 10.01% marketable bulb yield and marketable bulb weight, respectively, increase from the commercial hybrid onion variety (Kelafo) which is popular in eastern Ethiopia. The improved Huruta shallot variety had dynamic stability (respond to the environment with increased marketable bulb weight and yield as compared to the three commercial onion varieties. The essentially improved Huruta shallot variety had many other bulb quality traits than commercial onion varieties and proposed for verification trial to be released as essentially improved variety to be cultivated in eastern Ethiopia and areas having similar agroecologies in the country.

Keywords: Bulb; Essentially improved variety; marketable bulb weight; true seed and stability.

1. Introduction

Shallot and onion belong to the genus Allium, which is the only genus of importance in the family Alliaceae to vegetable producers. Shallot was formerly considered as Allium ascalonicum L., a separate species from onion (George, 1999). But latter, it was identified as Shallots *Allium cepa var. ascalonicum*. Backer is the most important subgroup of the Aggregatum group and the only one grown commercially (Rabinowitch, 1990). Shallots are known as vegetative propagated varieties of Allium cepa. Though it has been tried to produce seeds from these crops, the success history of seed production was not as other crops. Therefore, shallot is mainly propagated vegetatively by bulb. However, the use of bulbs as planting material has many problems. A large quantity (1.2 t ha^{-1}) of bulbs are required as a planting material (Jackson et al., 1985) which is expensive, bulky to transport and needs well ventilated storage. Bulbs keep for short period and carry fungal diseases (Mengistu and Seid, 1990) and latent viruses (Proctor, 1987) from generation to generation.

Multiplication of shallot from true seeds has an advantage of ease of propagation and solves the disease problems transmitted through bulbs as planting material. Propagation of shallot from true seeds also increases the sizes of bulbs and enables genetic improvement through natural outcrossing or planned hybridization program. However, bolting does not occur rapidly in many shallot varieties (Currah and Proctor, 1990). Therefore, production of shallot seeds requires studying the flowering of the crop. The effort can be made to regulate flowering either to abbreviate or extend vegetative phase, or to induce or repress flowering (Van Nocker, 2001) through regulating flowering by application of plant hormone or identifying the season with temperature that leads to flowering of the crop.

Shallot is one of the most widely cultivated bulb crops in Ethiopia under rain-fed conditions by small farmers as income generating spice crop for flavoring local dishes. The crop has a wide range of climatic and soil adaptations and is cultivated both under rain-fed and irrigated conditions but mostly the production of bulb shallot is at highland areas under rain-fed conditions (Shimeles, 2014). The major production areas in the country are characterized by a bi-modal rainfall distribution. The main rainy season occurs between July and September, followed by a long dry period that is interrupted by small rains (short season) peaking in April. Most growers plant shallot bulbs at the onset of the small rains (Kebede et al., 2003). But it has been observed that the cultivation and distribution of the crop to new areas showed its potential for further expansion and improvement in the country (Lemma and Shimeles, 2003). However, the main constraint to shallot production in the country is the need of high amount of planting material of 1.5 - 2 t ha^{-1} of edible bulbs which comprise about 40% of cost of production compared to 4–5 kg ha^{-1} of true seed (Lemma and Yayeh, 1994). Moreover, diseases, insects and lack of improved pre and post-harvest management practices have also contributed to low yield and quality (Getachew and Asfaw, 2004). Therefore, the production of true

seeds from shallot has multiple advantages. Realizing this fact, Haramaya University has initiated the true seeds production from Huruta shallot variety released in 1997/98 (MoA, 2016) by Debre Zeit Agricultural Research Center and evaluated the subsequent bulb yield produced from true seeds for several years. The yield stability of the improved variety need to be tested under multilocation test and this research was initiated to evaluate the true seed and bulb yields of Huruta shallot variety over locations and determine its stability for both seed and bulb yields.

2. Materials and Methods

Haramaya University started seed production from Huruta variety starting from 2004/2005 that continued for 12 years. During the first season, the trial was conducted at Haramaya, Chelenko and Kulubi with different planting dates and with or without supplements of GA3 sprays to identify optimal conditions for bolting of the plants. Among the locations, it was at Kulubi and Haramaya sites that few bolter plants (12%) were recorded. Unfortunately, the bolted plants at Kulubi did not produce seeds as the maturity season was extended to Belg rainy period that caused 100% loss by downy mildew. Thus, the study was restricted to Haramaya site, involving selection of bolter plants and also plants that produced quality bulbs and better yield than the original variety.

The bulb to seed mass improvement method was used to improve the crop by exploiting the created variation through natural outcrossing. In the subsequent seasons, selection was made until more than 50 % bolters were achieved. In 2010/11, bulb yield and seed yield trial was done at three locations (five trails) where two shallot and one onion variety were included for comparison. However, a directive was given at national level to make the trial along with onion varieties as the improved Huruta bulbs were found to be more similar to onion than shallot bulbs. Meanwhile seed production and selection for uniform Huruta bulbs proceeded following seed to bulb to seed method at Haramaya University. Finally, the work was redesigned and undertaken in three locations (Haramaya, Dire Dawa and Hirna) as well as under farmers' field around Haramaya University. The process of true seed production and bulb yield evaluation is presented in Table 1.

Table 1. Test years and locations for assessment of true seeds production and subsequent bulb yield of *Huruta* variety

Year	No of locations	No of trials
2004/2005	1	3 (planting time combined with GA_3 spray experiment to determine the seed yield production potential of shallot variety at Haramaya Chelenko and Kulubi)
2005-2007	1	1 (planting time to determine the seed yield production potential of shallot variety at Haramaya)
2010-2011	1	1 (to evaluate bulb yield of shallot variety)
2011	3	5 (to evaluate seed yield potential of Huruta shallot variety in comparison with other shallot and onion varieties)
2014	5	4 (to evaluate seed yield of shallot variety)
2015	1	1 (seed production of Huruta shallot variety at Haramaya)
2014 to 16	3 + 2 kebeles on 28 farmers' fields	4 (to evaluate bulb yield of shallot variety)

The multilocation bulb yield evaluation was conducted for two consecutive seasons (2014/15 and 2015/16) at Haramaya, Dire Dawa and Hirna. The bulb yield of plants obtained from seeds of Huruta variety were evaluated with onion commercial varieties of Adama Red, Bombay Red and commercial hybrid onion variety of Yemen known with local name Kelefo in eastern Ethiopia including Somali Regional state. The true seed yield of improved Huruta shallot variety and three commercial (Adama Red, Atilase and Dz-94) onion varieties were evaluated over five locations for one year in 2014.

3. Results

Bulb yield and average bulb weight

Analysis of variance was computed for bulb yield and bulb weight for each location and over locations. The combined analysis of variance results for marketable bulb yield (t/ha) and total bulb yield (t/ha) (Table 2), marketable bulb weight (g) and average bulb weight (g/plant) (Table 3) are presented. The results showed that the mean squares for main factors of genotype, location and year as well as interaction of location x year were significant for marketable and total bulb yield as well as marketable bulb weight (g) and average bulb weight (g/plant).

Table 2. Combined analysis of variance for marketable and total bulb yield (t/ha) of improved *Huruta* shallot variety and three commercial onion varieties in onion regional variety trial over three locations and two years (2014/15 and 2015/16)

	Marketable bulb yield (t/ha)					Total bulb yield (t/ha)			
Source of variation	DF	Sum of square	Mean square	F-value	Pr>F	Sum of square	Mean square	F-value	Pr>F
Replication	2	495.48	247.74	3.91		285.5	142.8	1.39	
Genotype (G)	3	798.85	196.28	3.098	0.007	982.3	297.4	2.904	0.022
Location (L)	2	2861.27	1430.63	22.58	<.001	6913.7	3456.8	33.74	<.001
Year (Y)	1	5210.77	5210.77	82.25	<.001	3128.9	3128.9	30.54	<.001
G x L	6	329.95	54.99	0.87	0.526	1072.5	178.8	1.74	0.132
G x Y	3	451.34	150.45	2.37	0.082	160.1	53.4	0.52	0.67
L x Y	2	3640.49	1820.25	28.73	<.001	2139.9	1069.9	10.44	<.001
G x L x Y	6	514.07	85.68	1.35	0.254	295.8	49.3	0.48	0.819
Error	46	2914.14	63.35			4712.5	102.4		

DF= degree of freedom. For marketable bulb yield, CV (%)= 17.25 and Grand mean=30.88 t/ha and for total bulb yield, CV (%)= 11.58 and Grand mean=40.51 t/ha.

Table 3. Combined analysis of variance for marketable bulb weight (g) and average bulb weight (g/plant) of improved *Huruta* shallot variety and three commercial onion varieties in onion regional variety trial over three locations and two years (2014/15 and 2015/16).

	Marketable bulb weight (g)					Average bulb weight (g/plant)			
Source of variation	DF	Sum of square	Mean square	F-value	Pr>F	Sum of square	Mean square	F-value	Pr>F
Replication	2	1933.9	966.9	3.81		1142.1	571.1	1.39	
Genotype (G)	3	3274.6	1091.5	4.3	0.009	3929.1	1309.7	3.2	0.032
Location (L)	2	11084.6	5542.3	21.84	<.001	27654.7	13827.3	33.74	<.001
Year (Y)	1	20638.9	20638.9	81.35	<.001	12515.5	12515.5	30.54	<.001
G x L	6	1313.1	218.9	0.86	0.529	4290.2	715	1.74	0.132
G x Y	3	1909	636.3	2.51	0.071	640.4	213.5	0.52	0.67
L x Y	2	14210.8	7105.4	28.01	<.001	8559.4	4279.7	10.44	<.001
G x L x Y	6	2207.3	367.9	1.45	0.217	1183.2	197.2	0.48	0.819
Error	46	11671.1	253.7			18849.9	409.8		

DF= degree of freedom. For marketable bulb weight (g), CV (%)=16.27 and Grand mean=60.85g, and for average bulb weight (g/plant), CV (%)= 11.46 and Grand mean=80.94g/plant.

The improved *Huruta* shallot variety showed its superiority in marketable and total bulb yields over the commercial onion varieties in Ethiopia (Adama Red and Bobay Red) and over the commercial hybrid onion variety in Yemen (known in eastern Ethiopia as Kelafo). The superiority of improved *Huruta* shallot variety showed superiority over three onion varieties over locations and years in the range between 9.66 (Kelafo) and 52.68% (Adama Red) with the overall marketable and total bulb yields advantages of 35.03 and 22.37% over the three commercial onion varieties, respectively (Table 4).

The improved *Huruta* shallot variety also showed its superiority in marketable bulb weight and average bulb weight (g/plant) as compared to the standard check commercial onion varieties. The improved *Huruta* shallot variety had 10.01(Kelafo) to 46.71% (Adama Red) with the overall marketable bulb weight advantage of 31.40%. It had also advantage of average bulb weight (g/plant) in the range between 7.5 to 33.52% with overall advantages of 18.29% over locations and years (Table 5).

Table 4. Marketable and total bulb yield (t/ha) advantage of improved Huruta shallot candidate variety over three commercial (Adama Red, Bombay Red and Kelafo) onion varieties at three locations over two years (2014/15 and 2015/16).

		Marketable bulb yield (t/ha)				Percent increase over varieties			
Location	Year	Huruta	Adama Red	Bombay Red	Kelafo	Adama Red	Bombay Red	Kelafo	Mean
Haramaya	2015	67.08	49.12	51.22	62.21	36.56	30.96	7.83	25.12
	2016	26.82	16.99	20.74	20.55	57.86	29.32	30.51	39.23
	Mean	46.95	33.06	35.98	41.38	47.21	30.14	19.17	32.17
Dire Dawa	2015	30.21	28.71	24.47	27.81	5.22	23.46	8.63	12.44
	2016	26.19	23.17	20.49	33.14	13.03	27.82	-20.97	6.63
	Mean	28.2	25.94	22.48	30.48	9.13	25.64	-6.17	9.53
Hirna	2015	40.3	22.75	32.5	31.32	77.14	24	28.67	43.27
	2016	29.84	13.19	13.5	28.89	126.23	121.04	3.29	83.52
	Mean	35.07	17.97	23	30.11	101.69	72.52	15.98	63.4
Overall men		36.74	25.66	27.15	33.99	52.68	42.77	9.66	35.03
		Total bulb yield (t/ha)				Percent increase over varieties			
Location	Year	Huruta	Adama Red	Bombay Red	Kelafo	Adama Red	Bombay Red	Kelafo	Mean
Haramaya	2015	76.39	54.61	75.01	65.4	39.88	1.84	16.8	19.51
	2016	47.86	34.03	45.51	33.51	40.64	5.16	42.82	29.54
	Mean	62.13	44.32	60.26	49.46	40.26	3.5	29.81	24.53
Dire Dawa	2015	36.21	35.79	33.62	35.5	5.24	23.46	8.65	12.45
	2016	32.19	30.04	31.84	41.9	13.06	27.84	-20.96	6.65
	Mean	34.2	32.92	32.73	38.7	9.15	25.65	-6.15	9.55
Hirna	2015	43.6	27.92	39.34	38.82	56.16	10.83	12.31	26.43
	2016	34.56	21.5	21.44	35.61	60.74	61.19	-2.95	39.66
	Mean	39.08	24.71	30.39	37.22	58.45	36.01	4.68	33.05
Overall		45.14	33.98	41.13	41.79	35.95	21.72	9.45	22.37

Table 5. Average marketable bulb weight (g) and average bulb weight (g/plant) advantage of improved Huruta shallot candidate variety over three commercial (Adama Red, Bombay Red and Kelafo) onion varieties at three locations over two years (2014/15 and 2015/16)

		Average marketable bulb weight (g)				Percent increase over varieties			
Location	Year	Huruta	Adama Red	Bombay Red	Kelafo	Adama Red	Bombay Red	Kelafo	Mean
	2015	134.17	98.23	99.54	124.42	36.59	34.79	7.84	26.4
Haramaya	2016	53.65	33.97	41.47	41.1	57.93	29.37	30.54	39.28
	Mean	93.91	66.1	70.51	82.76	47.26	32.08	19.19	32.84
	2015	60.42	57.41	48.94	55.61	5.24	23.46	8.65	12.45
Dire Dawa	2016	52.39	46.34	40.98	66.28	13.06	27.84	-20.96	6.65
	Mean	56.41	51.88	44.96	60.95	9.15	25.65	-6.15	9.55
	2015	81.48	45.49	64.99	62.65	79.12	25.37	30.06	44.85
Hirna	2016	49.68	26.38	26.99	47.79	88.32	84.07	3.95	58.78
	Mean	65.58	35.94	45.99	55.22	83.72	54.72	17.01	51.82
Overall mean		71.97	51.3	53.82	66.31	46.71	37.48	10.01	31.4
		Average bulb weight (g/plant)				Percent increase over varieties			
Location	Year	Huruta	Adama	Bombay	Kelafo	Adama	Bombay	Kelafo	Mean
	2015	152.79	109.22	150.03	130.79	39.89	1.84	16.82	19.52
Haramaya	2016	95.71	68.06	91.02	67.02	40.63	5.15	42.81	29.53
	Mean	124.25	88.64	120.53	98.91	40.26	3.5	29.81	24.52
	2015	72.42	71.59	67.25	70.99	1.16	7.69	2.01	3.62
Dire Dawa	2016	64.39	60.08	63.69	83.81	7.17	1.1	-23.17	-4.97
	Mean	68.41	65.84	65.47	77.4	4.17	4.39	-10.58	-0.67
	2015	87.2	55.83	78.68	77.65	56.19	10.83	12.3	26.44
Hirna	2016	67.13	43.01	42.89	71.22	56.08	56.52	-5.74	35.62
	Mean	77.17	49.42	60.79	74.44	56.13	33.67	3.28	31.03
Overall mean		89.94	67.97	82.26	83.58	33.52	13.85	7.5	18.29

Seed Yield

Analysis of variance over five locations revealed those highly significant differences among improved *Huruta* shallot variety and two commercial onion varieties and one shallot variety (Adama Red, Atlas and Dz-94) for seed production while location had significant effect of on seed yield. The interaction of genotype x location had also highly significant effect of on seed yield (Table 6). The mean seed yield (kg/ha) of Huruta shallot variety was significantly higher than the three commercial onion varieties (Table 11). Improved Huruta shallot variety had 953.4 ka/ha while Adama Red, Dz-94 and Atilase had 193.4, 223.6 and 276 kg/ha, respectively (Table 7).

Table 6. Analysis of variance for seed yield (kg/ha) of improved *Huruta* shallot variety and three commercial (Adama Red, Atlas and Dz-94) varieties over five locations in 2014.

Source of variation	Degree of freedom	Sum of square s	Mean square	F-value	Pr>F
Replication	2	105437	52718	1.09	
Genotype	3	5922043	1974014	41	<.001
Location	4	507300	126825	2.63	0.049
Genotype x Location	12	2589506	215792	4.48	<.001
Error	38	1829727	48151		

CV (%) =53.3 and Grand mean =411.72 kg/ha.

Table 7. Mean seed yield (kg/ha) and seed yield advantage of improved *Huruta* shallot variety over three commercial (Adama Red, Atlas and Dz-94) varieties over five locations in 2014.

	Mean seed yield (kg/ha) of four varieties over five locations					
Genotype	Batte	Batte II	Haramaya	Tinke	Tinke II	Genotype mean
Huruta	1510a	1306.83ab	366.67cd	523.67c	1060.0b	953.4a
Adama Red	178.333cd	160.0d	265.56cd	231.67cd	131.667d	193.4b
Atlas	201.67cd	208.33cd	205.56cd	383.33cd	383.33cd	276.4b
Dz-94	183.33cd	183.33cd	214.44cd	268.33cd	268.33cd	223.6b
Location mean	518.3a	464.6a	263.1b	351.8ab	460.8a	
SD	661.19	561.82	73.96	131.57	412.48	362.76
Increase (%) seed yield of Huruta over	Batte	Batte II	Haramaya	Tinke	Tinke II	Genotype mean
Adama Red	746.73	716.77	38.08	126.04	705.06	392.97
Atlas	648.76	527.28	78.38	36.61	176.52	244.93
Dz-94	723.64	612.82	70.98	95.16	295.03	326.39
Overall mean	706.38	618.96	62.48	85.94	392.2	321.43

The advantage of improved *Huruta* shallot variety was the seed production potential which is difficult to produce in many shallot *(Allium cepa* var. *ascalonicum* Backer) cultivars as compared to onion (*(Allium cepa* L.) varieties. This variety also showed its superiority in producing seeds over onion varieties under study. It had average advantages of three folds of seed yield of commercial onion varieties. The seed yield advantage ranged between 244.93 (Atlas) and 392.97% (Adama Red) with overall mean advantage of 321.43% (Table 7).

Stability of improved *Huruta* Shallot variety for bulb and seed yield

The regression computed for marketable bulb yield and marketable bulb weight to visualize the stability of improved *Huruta* shallot variety and other three commercial onion varieties to changing environments are presented in Figure 1 and 2. The improved *Huruta* shallot variety better performed than three commercial onion varieties both under favorable and unfavorable environment for marketable bulb yield and marketable bulb weight. The shallot variety respond to environments with coefficient of determination of 95.57% (R^2=0.9557) and 96.71 (R^2 = 0.9671) for marketable bulb yield (Figure 1) and marketable bulb weight (Figure 2), respectively. The correlation of environments and the marketable bulb yield of improved *Huruta* shallot variety was strong and significant (r = 0.9776) and marketable bulb weight (r = 0.9837). Kelafo onion hybrid variety was second to improved *Huruta* shallot variety for marketable bulb yield and marketable bulb weight than other to commercial onion varieties and better responded to change in environment.

The improved *Huruta* shallot variety respond to unfavorable environment for total bulb yield was lower than Kelafo onion hybrid but better performed towards favorable environments than all onion varieties. However, this variety and Bombay Red commercial onion variety responded same to extreme favorable environments (Figure 3). The environment determined 95.26% (R^2 = 0.9526) variation of total yield of improved *Huruta* shallot variety with strong and significant correlation (r = 0.976) of environments and total yield of this variety. Bombay Red commercial onion variety produced lowest total bulb yield under unfavorable environment but responded to favorable environments than two other onion varieties. The total bulb yield of Bombay Red variety was determined by changing environments up to 97.31% (R^2 = 0.9731) with strong and significant correlation (r = 0.9864) of environments and total yield of this variety.

Improved *Huruta* shallot variety produced seed yield lower than other varieties under unfavorable environments but produced highest seed yield under favorable environments where all the three varieties produced lower seed yield under favorable environments than under unfavorable environments (Figure 4). The growing environment much determined the seed yield of improved *Huruta* shallot variety up to 93.46% (R^2 = 0.9346) with strong and significant correlation (r = 0.9667) of environments mean values and seed yield of this variety. The only Atilase shallot variety was responded better to the growing environments for seed yield production in which 75.49% (R^2 = 0.7549) the seed yield variation of this variety was determined by the

growing environments while other two onion varieties (Dz-94 and Adama Red) failed to do.

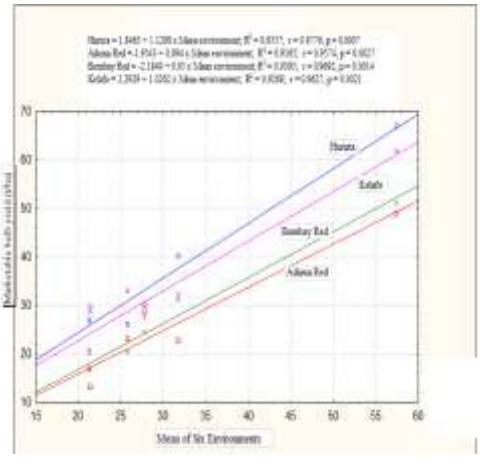

Figure 1. Improved Huruta shallot variety & three onion varieties response to six environments for marketable bulb yield (t/ha).

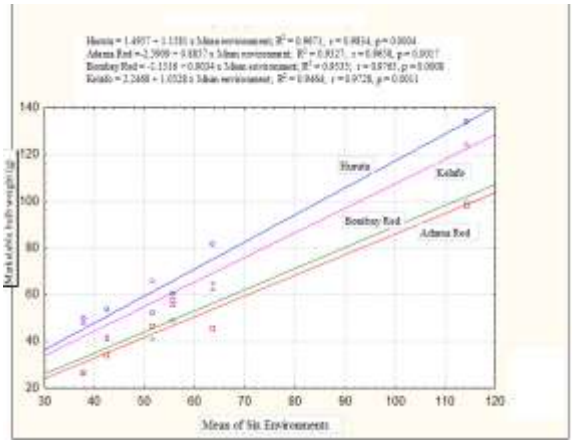

Figure 2. Improved Huruta shallot variety & three onion varieties response to six environments for marketable bulb weight (g).

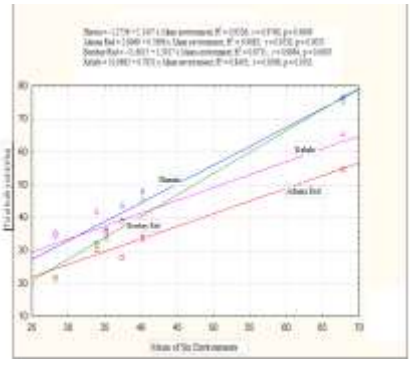

Figure 3. Improved Huruta shallot variety & three onion varieties response to six environments for total bulb yield (t/ha).

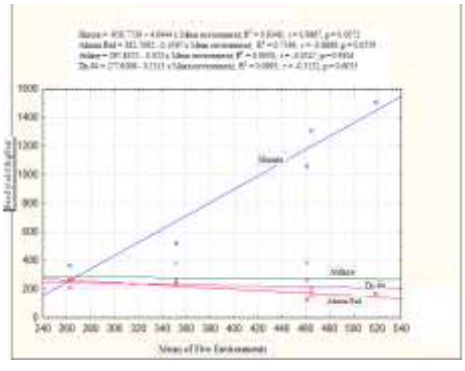

Figure 4. Improved Huruta shallot variety & three onion varieties response to five environments for seed yield (kg/ha).

4. Discussion

Improved *Huruta* shallot variety was evaluated with three onion varieties because of the preference of farmers is producing onions from true seeds of onions and the improved shallot variety need to be superior over commercial onion varieties to be accepted for production. In addition, the onions are producing better national average yield of 10.02 t ha^{-1} (Sara *et al..,* 2015) as compared to the national average yield of bulb shallot (7 t ha^{-1}) (Shimeles. 2014). Therefore, the improved shallot variety needs to exceed the yields of onion varieties to be competent and to increase the average national bulb yields of Allium species in the country. In addition, improved shallot variety will have additional

advantage since it can be grown where the cultivation of common onion is unsuccessful. It is has been proved that shallot is high tolerance to low and high temperature as well as to poorer quality soil (Permadi 1994; Pham *et al*., 2006; Brink and Basuki, 2012). Shallot is relatively tolerant to purple blotch disease and better grow in areas where the climate is humid (rainy season) and the growing season is short than onions. Shallot has very short growing season of not more than three months, which allows it to be grown between other crops or during the short rains in the dry season (Getachew and Asfaw, 2004).

Huruta shallot variety had 7.5 to 9 t ha^{-1} bulb yield when it produced from bulbs (EARO, 2004) while it produce 45.14 t ha^{-1} when it produced from true seeds with yield advantages of 402 to 502% or four to five folds of bulb yield. The increased bulb size of shallot and yield from true seeds propagation was suggested (Currah and Proctor, 1990) due to genes recombination resulted from the outcrossing of the variety. Shallot produced from true seeds has several advantages since it helps to obtain more vigorous plant, early harvest and simply agronomical practices. However, shallot propagation by using the bulb will cause neither segregation nor variability. The continuous cultivation of shallot from bulbs can cause the decreasing of yield and its quality due to the accumulation of pest and disease population (Andy *et al*., 2011). Shimeles and Lemma (2015) reported better mean marketable bulb yields of 16.1 t ha^{-1} for seven shallot varieties produced from true seeds as compared to 14.4 t ha^{-1} from bulbs while 19.8 and 14.8 t ha^{-1} mean total bulb yields were obtained from true seeds and bulbs propagation, respectively, at Melkassa Agriculture Research Center.

The weight of improved *Huruta* shallot variety bulbs was greater than onion varieties and more importantly it was greater than hybrid onion variety (Kelafo) of Yemen and grown in eastern Ethiopia. Shallots grown by dividing the bulbs into small "cloves" are smaller than onions (Marr, 1994). However, seed-sown shallots produce a single bulb during their first growing season. The possibility of obtaining larger bulbs of shallot in the yield compared to vegetative propagation by planting bulbs increased interest in the cultivation of shallot from seeds. Moreover, shallots grown from seeds produce more healthy bulbs with good storage life (Tendaj *et al.,* 2013).

One of the achievements in the process of improving *Huruta* shallot variety was the production of seed which is difficult to produce as compared to onion varieties. Moreover, this improved shallot variety produce three folds of seed yield of commercial onion varieties and one shallot variety. The main constraint to shallot production in Ethiopia is the need of high amount of planting material of edible bulbs which comprise about 40% of cost of production compared to true seed (Lemma and Yayeh, 1994) and bulbs are more exposed for diseases and insects that contributed to low yield and quality (Getachew and Asfaw, 2004). Production of shallot from true seeds solves the disease problems transmitted through bulbs as planting material, increases the sizes of bulbs and enables genetic improvement through natural outcrossing or deliberate crossing of plants in a planned hybridization program (Currah and Proctor, 1990).

Improved *Huruta* shallot variety had highest marketable, total bulb yield, and marketable bulb weight and seed yield. Moreover, the improved shallot variety

performed better than onion varieties for marketable and marketable bulb weight under favorable and unfavorable environments. For farmers working in unfavorable environments, it can be very important that the variety performed better than lowest average values of environments. The cultivars which have good average performance in the worse conditions could be identified by plotting the minimum yield against the average yield (Mustăţea *et al.*, 2009). Though the total bulb yield and seed yield of improved *Huruta* shallot variety had lower than the average values of the environments, it had highest total bulb and seed yields and responded better than other varieties under favorable environments.

The yield Stability of performance is one of the most desirable properties of a genotype to be released as a variety for cultivation. However, stability of genotypes for yield may have low yield. In practice, genotypes showing higher yield may be less stable (Venugopalan and Pitchaimuthu, 2009). Therefore, the cultivar stability need to be evaluated along with yield potential and a cultivar with high yield and average stability or less stability can be recommended for production. In this regard, the improved *Huruta* shallot variety with highest total bulb and seed yields and large proportion (>90%) of the variations were explained by change to growing environment can be recommended. Regression analysis on an environmental index can be useful if regressions explain a large part of total yield variation (Mustăţea *et al.*, 2009). Shimeles (2014) reported 15.1 to17.5 t ha^{-1} with overall mean yield of 16.5 t ha^{-1} for seven true seed shallot lines that were evaluated for three years at three locations in which 'Yeras' was recommended to be grown in Rift Valley and similar areas in Ethiopia as widely adaptable since it showed small deviation from regression.

5. Summary and Conclusion

The improved *Huruta* shallot variety had highest marketable, total bulb and seed yields as well as average marketable bulb weight as compared commercial onion varieties. Moreover, it was superior over the onion hybrid "Kelafo" widely grown in eastern Ethiopia from non-formal seed introduction and purchase from Yemen. The improved *Huruta* shallot variety better performed both under favorable and unfavorable environments for marketable and average marketable bulb weight. It was highly responsive to favorable environments for total bulb and seed yields. Therefore, this variety can be recommended for cultivation in eastern Ethiopia. The true seeds production from the variety also helps the breeders to further improvement through the planned crossing program or exploiting the variation that will be created through natural outcrossing. Therefore, it can be recommended as improved shallot variety for the country due to the advantage of true seeds production potential and highest marketable and total bulb yields as well as marketable bulb weight.

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13. Characterization and Evaluation of Okra [*Abelmoschus esculentus* (L.) Moench] Collections in Eastern Ethiopia

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Abstract: Ethiopia is considered as origin and center of diversity for okra; however, the country has not benefited from the crop due to low attention in research. This research was initiated with the objectives of characterization and evaluation of okra genotypes for tender fruit yield, yield related and fruit quality traits, to estimate genetic variability and to assess the genetic diversity of genotypes. Three experiments were conducted at Dire Dawa in which the first experiment consisted of 64; the second experiment consisted of 25 selected from the first experiment and the third experiment consisted of 81 genotypes. The first experiment was conducted in 2015 and the other two were conducted in 2016. The 14 genotypes from 25 were obtained from Ethiopia which had 6.83 to 138.59% yield advantage over the mean yield of commercial varieties from other countries. Two of 11 commercial varieties from other countries were registered varieties in Ethiopia. Genotypes were evaluated for 9 and 29 qualitative and quantitative traits, respectively. The analysis of variance revealed highly significant ($P<0.01$) differences among genotypes for all quantitative traits. Tender fruit yield ranged from 9.27 to 41.79 t ha^{-1} with mean yield of 23.61 t ha^{-1}. Ten genotypes from Ethiopia had yield advantages of 10.22 to 112.56 and 1.12 to 95.01% over mean yield of exotic varieties and better yielding registered commercial variety, respectively, while eight genotypes had yield advantages of 7.33 to 68.24% over commercial variety of USA. In addition, 14 and 12 genotypes from Ethiopia had advantages of 11.54 to 95.05 and 8.25 to 61.5% for fruit diameter and fruit weight over the best yielding exotic variety, respectively. Most of okra genotypes from Ethiopian had mean values higher than exotic varieties for most of desirable fruit traits. The phenotypic and genetic coefficients of variations ranged from 12.87 to33.39% and 9.96 to 32.36%, respectively, while heritability in broad sense and genetic advance as percent of mean ranged from59.8 to 95.2% and 15.9 to 65.15%, respectively, for fruit yield, yield related and fruit traits. All estimates of variability components were moderate to high for all traits except for one trait suggested selection is effective to develop varieties for traits of interest. Genetic distances measured from 29 quantitative traits ranged from 3.1 to 12.6 in which okra genotypes from Ethiopia and varieties from other countries showed highest genetic

distances. Dendrogram constructed by Unweighted Pair-group Method with Arithmetic Means grouped the 25 genotypes in to seven major clusters in which the six varieties from other countries constructed Cluster I. Generally, genotypes showed wide range of variations and genetic diversity for yield, yield related and fruit quality traits sufficient to develop varieties through further evaluation.

Keywords: Cluster; Genetic advance; Genetic distance; Heritability and Tender fruit

1. Introduction

Okra [*Abelmoschus esculentus* (L.) Moench] is widely distributed from Africa to Asia, in Southern Europe, the Mediterranean and all of the America (Reddy *et al*., 2012). It is cultivated as an important vegetable crop mainly grown for its young immature fruits in tropical, subtropical and warm temperate regions of the world (Arapitsas 2007; Saifullah and Rabbani 2009). Okra is nutritionally rich vegetable which provides an important source of carbohydrates, protein, vitamins A, B_1 and Calcium, Potassium, dietary fiber, and mineral matters (Tripathi *et al*., 2011; Maurya *et al.,* 2013). The high mucilagein content of immature fruits has many health benefits, confectionery use and used for paper production (Ndaeyo *et al.* 2005; Saifullah and Rabbani, 2009). Dry pods used for crafting (Benchasri, 2012; Ahiakpa *et al*., 2013; Maurya *et al*., 2013), used as a cure for ulcers, relief for haemorrhoids, against chronic dysentery and genito-urinary disorders (Prasad *et al.,* 2010) and plasma replacement (Benchasri, 2012). The oil content of the seeds is as high as 40% (Anwar *et al*., 2011; Tripathi *et al*., 2011), rich in unsaturated fatty acids such as linoleic acid (Savelli *et al.,* 1980), and seeds are rich tryptophan with balanced lysine amino acids (NRC, 2006).

The total area of okra and its production has increased in the world over years although it has been given little attention in research worldwide (Werner *et al*., 2016). In 1991-1992, the total area and production was 0.22 million hectares and 1.88 million tons, respectively, but both area and the production of the crop was double (0.43 million hectares & 4.54 million tons) in 2009-2010 and boost to 1,085,146 hectares and 8,359,944 tons in 2012 (FAO, 2014). There is no complete record on production area and production of okra in Ethiopia, but it is a traditional crop in Southwestern, Western and Northwestern Ethiopia (Miheretu *et al*., 2014a&b). The species is also found as wild plant with low human intervention in natural population. The crop has not given attention in research which has been cultivated from landraces for several years (Tesfa and Yosef, 2016; Miheretu *et al*., 2014a&b), and only very recently one variety has been recommended for cultivation (MoANR, 2016).

Inclusion of a wide array of indigenous vegetable species in cereals, tubers and livestock based agriculture is crucial to contribute to food security and income diversification in the subsistence farming system that predominate in the underdeveloped and developing world. Therefore, improving the genetic potential of indigenous vegetables like okra is of paramount importance (Kumar *et al*., 2010).

Ethiopia is argued to be the origin of okra, but the economic importance of the crop is negligible. The species is cultivated and utilized as vegetable in some parts of the country while in other parts of the country, it is grown as wild plant and its utilization is very limited. However, the crop has a potential to be used for food security and tackling the crucial malnutrition problem. It has also a potential to be export commodity to the neighboring and Arab countries which are known as a heavy consumers and importers of the crop.

Ethiopia as center of origin and/or diversity of okra is expected to have rich genetic diversity in the species. The availability of genetic variability among population is the most important for judicious selection and breeding to desired plant genotypes (Singh *et al.,* 2006). Okra breeding activity in Ethiopia to exploit the rich genetic resource is very limited and little works have been conducted in collection and characterization of landraces and wild plants (Tesfa and Yosef, 2016; Muluken *et al*., 2016 &2015; Miheretu *et al*., 2014a,b). Therefore, characterization and evaluation of genotypes for different morphological, agronomic and quality traits is necessary to develop varieties either through direct selection and/or crossing of genotypes to develop hybrid varieties or lines from segregate generations. Therefore, this research project was initiated with objectives of, i) characterizatiing and evaluatiing okra genotypes for tender fruit yield and yield related traits, ii) evaluating the okra genotypes collected from Ethiopian for tender fruit quality in comparison to commercial okra varieties of other countries, iii) estimating genetic variability component, and iv) assessing the genetic diversity of okra genotypes collected from Ethiopian and varieties of other countries.

2. Materials and Methods

Experimental Materials

A total of 64 okra genotypes were evaluated in 2015 of which 29 and 28 genotypes were obtained from Institute of Biodiversity and Research (IBCR) and Pawe Agriculture Research Center, respectively, and seven commercial varieties were introduced from India (six) and United States of America (one). The list of genotypes is presented in Table 1. In this field evaluation, the mixed genotypes as one accession were identified and separate identity codes were given. Based on the tender fruit yield, desirable fruit traits and accessions not containing mix of genotypes, 14 okra genotypes from Ethiopia were selected for further evaluation. These genotypes and 11 commercial varieties from other countries (eight varieties from India, one from USA and two registered commercial varieties in Ethiopia by companies) were evaluated in 2016. The list of okra genotypes, origin of collection and tender fruit yield selected from 2015 field experiment at Dire Dawa is presented in Table 2. In 2016, a total of 81 genotypes were evaluated of which the 64 genotypes were evaluated in 2015 and 17 genotypes newly introduced and identified as separate genotypes from the 2015 field experiment. The list of 81 genotypes and data are not presented.

Table 1. Okra genotypes evaluated in 2015 at Dire Dawa

	Accession from IBCR				From Pawe Agriculture Research Center				From other countries
No	Accession	No	Accession	No	Genotype	No	Genotype	No	Variety
1	92203	16	240609	30	Dangur 40	45	Guba 21	58	Anoop
2	240201	17	240615	31	Dangur 41	46	Guba 23	59	ArkaAnamica
3	240204	18	240784	32	Dangur 42	47	Guba 27	60	Clemson spineless
4	240207	19	240786	33	Dangur 45	48	Guba 47	61	Dhenu
5	240209	20	242203	34	Guba 03	49	Mand 24	62	NamdHari
6	240583	21	242433	35	Guba 04	50	Mand 25	63	SOH 701
7	240585	22	242443	36	Guba 05	51	Mand 29	64	SOH 714
8	240586	23	242444	37	Guba 06	52	Mand 30		
9	240587	24	242445	38	Guba 07	53	Mand 31		
10	240591	25	242449	39	Guba 08	54	Mand 33		
11	240592	26	242451	40	Guba 09	55	Mand 34		
12	240599	27	245157	41	Guba 11	56	Mand 37		
13	240600	28	245161	42	Guba 12	57	Mand 39		
14	240601	29	245162	43	Guba 14				
15	240602			44	Guba 18				

Table 2. List of 25 okra genotypes, origin of collection and tender fruit yield from 2015 evaluation at Dire Dawa

No	Genotype	t ha^{-1}	Origin	No	Genotype	t ha^{-1}	Origin
1	Guba 12	24.544	Metekel	14	242444	9.924	Benishangul
2	Guba 05	24.44	Metekel	15	Vellayani	New	India
3	Guba 07	20.439	Metekel	16	Mythri	New	India
4	240204	18.874	Benishangul	17	Kiran	New	India
5	240609	17.305	Gambella	18	Clemson spineless	16.721	USA
6	Guba 04	13.588	Metekel	19	ArkaAnamica	17.57	India
7	Guba 21	13.081	Metekel	20	NamdHari	6.192	India

8	242443	12.523	Benishangul	21	Dhenu	2.321	India
9	Guba 47	12.416	Metekel	22	Anoop	15.064	India
10	240600	11.797	Gambella	23	SOH 701	11.527	Registered
11	Guba 14	10.99	Metekel	24	SOH 714	10.578	Registered
12	Guba 08	9.951	Metekel	25	Arcanamica	New	India
13	Dangur40	9.482	Metekel				

Experimental Design and Field Management

Genotypes were planted in 8 x 8 and 5 x 5 triple lattice design in 2015 and 2016, respectively. Each plot was 0.8 m x 7.2 m (5.76 m^2) consisting of one row and a total of 12 plants per row. The spacing between plots and adjacent replications were 0.8 and 2 m, respectively. Three seeds per hill were sown and thinned to one plant per hill when plants reached 3-4 leaves stage. Fertilizer was not applied; irrigation water was applied every three days up to the establishment of the crop in the field (3-4 leaves stage) and every week after this period, the experiment farm made free from weed throughout the experiment period and no chemical or cultural practices have been applied to control insect pests and diseases.

Land was prepared using tractor and human labor. The soil was leveled to permit furrow irrigation. The rows were raised to increase soil surface area, aeration and drainage. The ridges were made according to the planting spacing's by hand. Okra seeds were planted directly in the field. Furrow irrigation was applied throughout the growing season. Different cultural practices were applied for weeding, cultivation, watering and earthing-up. The immature tender fruit and mature fruit were harvested to collect data for different parameters. Tender fruits were harvested two times per week to estimate fruit yield while mature fruits were harvested when fruits turned to loss green color and dry pods were harvested when turned to gray for seed yield estimation.

Data collection

International Plant Genetic Resources Institute (IPGRI, 1991) descriptor list for okra species were used to register data for quantitative and qualitative traits. Quantitative traits were registered from 10 plants per row leaving the two plants grown at both end of the row as boarder plants and to collect data for mature fruits and seed traits. Five randomly selected tender fruits from each harvest in each plot were used to register tender fruit traits. Based on the above-mentioned procedure and International Plant Genetic Resources Institute (IPGRI, 1991) descriptor the following quantitative and qualitative traits were registered.

Table 3. List of 29 quantitative traits and nine qualitative traits.

No.	Quantitative trait	No.	Quantitative trait	No.	Qualitative trait
1	Days to 50% emergence	16	Fruit diameter in centimeter	1	Plant habit
2	Days to first flowering	17	Fruit weight in gram	2	Flower color
3	Days to 50 % flowering	18	Number of fruit per plant	3	Leaf color
4	Days to pod formation	19	Number of fruit ridge	4	Leaf petiole color
5	Days to maturity	20	Fruit yield per plant in kilogram	5	Pod color
6	Plant height in centimeter	21	Fruit yield per plot in kilogram	6	Stem color
7	Stem diameter in centimeter	22	Fruit yield ton hectare	7	Leaf Shape
8	Number of primary branch	23	Number of mature pod	8	Fruit Position
9	Number of inter node	24	Fresh weight of mature pod in gram	9	Fruit shape
10	Inter node length in cent meter	25	Dry weight of mature pod in gram		
11	Leaf length in centimeter	26	Dry matter content in percent		
12	Leaf width in centimeter	27	Number of seed per plant		
13	Number of epicalyx	28	Hundred seed weight in gram		
14	Peduncle length in centimeter	29	Mucilage content in percent		
15	Fruit length in centimeter				

Data analysis

The quantitative data were subjected to analysis of variance (ANOVA). The ANOVA was computed with SAS statistical software (9.2) (SAS, 2008). Descriptive statistics was used to describe qualitative data. The comparison of mean performance of genotypes was done following the significance of mean squares using Duncan's Multiple Range Test (DMRT).

The traits that exhibited significant mean squares in general ANOVA was further subjected to genetic analyses. Phenotypic and genotypic variance and coefficient of variation, heritability, and genetic advance were computed using the excel Microsoft

program. Genetic diversity was estimated from quantitative traits of genotypes using Euclidean distance computed by STATISTICA 7 statistical software.

3. Results

Analysis of Variance

Analysis of variance computed for tender fruit in 2015 revealed that the presence of highly significant (P<0.01) differences among 64 okra genotypes (Table 4). The 25 okra genotypes selected from 2015 experiment also showed significant (P<0.01) differences for 29 quantitative traits (Table 5). Both analysis of variance results indicated the presence of significant (P<0.01) differences between introduced commercial varieties and okra genotypes from Ethiopia.

Table 4. Analysis of variance for tender fruit yield of 64 okra genotypes in 2015 at Dire Dawa.

Source of variation	DF	SS	MS
Replication	2	9.871	4.936
Genotype	63	8743.083	138.779**
Error	126	310.443	2.464
Total	191	9063.398	

DF = degree of freedom, SS = sum square, and MS = mean square. Grand mean =11.45 t ha^{-1}, CV (coefficient of variation) (%)=13.7 and LSD (least significant difference) (5%)= 2.54.

Table 5. Mean squares from analysis of variance for 25 quantitative traits of 25 okra genotypes evaluated at Dire Dawa in 2016.

Trait	Replication(2)	Blocks within Replication (Adj.) (12)	Treatment (Unadj.) (24)	Intra BlockError (36)	Treatment (Adj.) (24)	CV (%)
Days to 50% emergency	1.01	0.49	0.89	0.24	0.79**	6.63
Days to 50 % flowering	217.97	26.94	27.31	12.34	45.91**	8.35
Days to pod formation	46.36	6.75	31.74	3.78	32.5**	4.02
Days to first pod set	44.81	5.52	42.97	4.13	41.42**	3.79
Days to maturity	12.65	6.05	52.93	4.43	48.75**	3.36
Plant height (cm)	72.3	22.94	1783.52	33.99	1387.59**	5.41
Stem diameter(cm)	0.06	0.02	0.19	0.02	0.17**	7.49
Number of primary branches	0.27	0.24	3.75	0.13	2.92**	9.35
Number of internodes	23.81	5.62	72.1	8.77	60.15**	12.35
Inter node length(cm)	0.49	0.09	2.18	0.08	2.02**	5.77
Leaf length(cm)	22.35	0.79	22.5	0.42	23.55**	3.4
Leaf width(cm)	5.13	0.17	51.39	0.13	52.64**	1.71
Number of epicalyx	0.44	0.02	2.23	0.05	1.94**	1.98
Peduncle length(cm)	0.02	0.02	0.61	0.02	0.50**	5.85
Fruit length(cm)	0.8	1.4	4.2	0.8	4.4**	8.2
Fruit diameter(cm)	0.03	0.02	0.38	0.01	0.31**	4.45
Fruit weight (g)	3.21	2.92	100.62	2.02	77.49**	6.2
Number of fruit per plant	0.22	7.59	159.92	12.14	130.01**	10.99
Number of fruit ridge	0.05	0.06	3.19	0.04	3.03**	2.77
Fruit yield per plant (kg)	0.003	0.02	0.53	0.01	0.43**	9.18
Fruit yield per plot(kg)	2.27	3.04	46.97	1.79	38.687**	11.78
Fruit yield per hectare(t ha^{-1})	9.8	13.78	207.19	7.32	170.27**	11.46
Number of mature pods/plant	8.08	7.79	95.98	2.99	76.79**	11.6
Fresh weight of mature pod(g)	69.77	152.18	671.74	56.48	644.45**	10.61
Dry weight of mature pod(g)	69.77	152.18	671.74	54.24	545.81**	11.69

Dry matter content of fruits (%)	397.41	176.43	144.11	57.42	155.82**	21.92
Number of seed per pod	40.91	27.94	1263.94	36.32	926.80**	6.82
Hundred seed weight(g)	0.16	0.09	3.43	0.14	2.92**	6.02
Mucilage content of fruit (%)	3.9	1.0	62.6	0.8	51.1**	7.2

***, significant at P<0.01.*

Mean performance of genotypes for quantitative traits

The 25 okra genotypes were evaluated for 29 quantitative traits in 2016; however, the mean performance of introduced commercial varieties and okra genotypes from Ethiopia are presented for most economic importance traits such as tender fruit yield and fruit traits (Table 6). The comparison of mean performance showed that 14 okra genotypes from Ethiopia had mean values greater than 11 commercial exotic varieties except for fruit length and number of fruits per plant.

Table 6. Mean performance for selected tender fruit traits and yield of 14 okra genotypes from Ethiopia and 11 varieties from other countries evaluated at Dire Dawa in 2016.

Trait	14 genotypes from Ethiopia					11 varieties from other countries				
	Min	Max	Mean	SD	CV (%)	Min	Max	Mean	SD	CV (%)
Fruit length (cm)	6.88	12.16	10.18	1.29	12.67	10.04	13.19	11.94	0.92	7.66
Fruit width (cm)	2.03	3.55	2.51	0.36	14.44	1.78	2.37	1.98	0.2	9.91
Fruit weight(g)	15.11	33.47	25.82	5.67	21.96	12.17	28.15	19.17	5.27	27.49
Number of fruits/plant	12.13	38.8	30.2	7.48	24.78	27	59.87	33.64	9.03	26.85
Fruit yield/plant (kg)	0.45	2.05	1.32	0.5	37.91	0.66	1.93	0.97	0.38	38.7
Fruit yield/plot (kg)	4.45	19.54	12.83	4.64	36.15	6.77	19.27	9.47	3.57	37.68
Fruit yield (tha^{-1})	9.27	41.79	26.92	9.89	36.73	14.11	40.15	19.66	7.45	37.9

Min= minimum, Max= maximum, SD= standard deviation and CV (%)= coefficient of variation.

The comparison of better performing okra genotypes from Ethiopia over varied performances of exotic commercial varieties for fruit yield and fruit traits is presented in Table 7a-d. A minimum of one and a maximum of 10 okra genotypes from Ethiopia had advantage of 1.84 to 112.56% over mean of 11 commercial exotic varieties (Table 7a). Moreover, 14 and 12 okra genotypes from Ethiopia showed fruit width and fruit weight advantages over best performing exotic commercial variety (Kiran) in the range between 14.54 to 95.05% and 8.25 to 61.5%, respectively. One genotype also exhibited fruit yield advantage of 4.08% over high yielding exotic commercial variety (Kiran) (Table 7b). A minimum of five and a maximum of 11 okra genotypes from Ethiopia had advantage of 1.12 to 95.01% over registered high yielding commercial variety (SOH 701) for selected four traits (Table 7c). In addition, a minimum of two and a maximum of 10 okra genotypes from Ethiopia had advantage of 2.11 to 68.24% over USA commercial variety (Clemson spineless) for selected four traits (Table 7d).

Table 7. Advantage of okra genotypes from Ethiopia over exotic varieties from 25 okra genotypes evaluation in 2016 at Dire Dawa.

Trait	Number of genotypes	Minimum (%)	Maximum (%)	Mean (%)
a. Advantage of okra genotypes from Ethiopia over mean exotic varieties				
Fruit length (cm)	1	1.84		
Fruit width (cm)	14	2.53	79.29	26.64
Fruit weight(g)	10	17.01	74.6	34.7
Fruit yield (t ha^{-1})	10	10.22	112.56	36.94
b. Advantage of okra genotypes from Ethiopia over best yielding exotic variety (Kiran)				
Fruit length (cm)	0	---------	----------	----------
Fruit width (cm)	14	11.54	95.05	37.99
Fruit weight(g)	12	8.25	61.5	24.62
Fruit yield (t ha^{-1})	1	4.08	---------	---------
c. Advantage of okra genotypes from Ethiopia over best yielding registered commercial variety (SOH 701)				
Fruit length (cm)	9	2.49	21.12	1.43
Fruit width (cm)	11	5.88	60.63	13.64
Fruit weight(g)	5	10.83	18.9	-8.27
Fruit yield (t ha^{-1})	10	1.12	95.01	25.63
d. Advantage of okra genotypes from Ethiopia over Clemson spineless, USA commercial variety				
Fruit length (cm)	2	4.75	9.06	6.91
Fruit width (cm)	10	2.11	49.79	5.97

Fruit weight(g)	6	3.48	36.89	5.61
Fruit yield (tha^{-1})	8	7.33	68.24	8.39

The mean comparison between okra genotypes from Ethiopia and exotic commercial varieties presented in Table 6 and Table 7a-d was for 25 okra genotypes evaluated in 2016. This did not include the comparison of mean performance between 64 okra genotypes evaluated in 2015, after refining of these to 81 okra genotypes in 2016 and the registered high yielding commercial variety. But the yield advantages of okra genotypes from Ethiopia over exotic commercial varieties are determined based on the mean yield advantages of genotypes from the three experiments. Therefore, the mean yield advantages of okra genotypes from Ethiopia over high yielding exotic commercial variety from the three experiments are presented in Table 8. A total of 14 okra genotypes from Ethiopia had mean yield advantages of 12.5 to 72.57% over high yielding registered exotic commercial variety (SOH 701) and 4.78 to 60.78% had mean yield advantages over Clemson spineless (USA) commercial variety. Clemson spineless had mean yield advantage of 1.26 t ha^{-1} over high yielding registered exotic commercial variety (SOH 701). Among the 14 okra genotypes, 11 (78.57%) genotypes were identified as different genotypes obtained as a mix in okra genotypes obtained from IBCR and Pawe Agriculture Research Center evaluated in 2015.

Table 8. Advantage of okra genotypes from Ethiopia over exotic high yielding commercial registered variety (SOH 701) and Clemson spineless (USA) commercial variety from three experiments of okra genotypes in 2015 and 2016 at Dire Dawa.

Genotype	Mean TFYt ha^{-1}	Advantage (%) over SOH 701	Advantage (%) over Clemson spineless
240586 A	29.07	69.5	57.90
Guba 12	29.6	72.57	60.78
245162 A	28.94	68.73	57.20
240599 B	25.25	47.25	37.15
240592 A	26.62	55.22	44.60
242203 A	26.25	53.04	42.59
240204	28.22	64.58	53.29
240615 B	25.32	47.62	37.53
Guba 05 A	23.54	37.27	27.87
Guba 07	22.59	31.72	22.71
240583	25.1	46.34	36.34
Clemson spineless	18.41	7.35	------
240209 A	21.61	26.01	17.38
240207 A	21.5	25.38	16.78

240599 A	21.85	27.41	18.69
Humera 2	19.29	12.5	4.78
SOH 701	17.15	------	-6.84

Okra genotypes for pod and tender fruit quality

The comparison between okra genotypes from Ethiopian and commercial varieties from other countries, SOH 701 and Clemson spineless for selected tender fruit and pod quality on basis of mean values from the three experiments is presented in Table 9. Data for tender fruit mucilage content (%) was obtained from 25 okra genotypes evaluated in 2015 in which data for 64 and 81 genotypes was not included. At least seven and maximum 31okra genotypes from Ethiopian had mean advantages of 0.02 to 194.53% over the registered high yielding commercial variety (SOH 701) while a minimum of one and maximum of 29 okra genotypes from Ethiopian had mean advantages of 0.09 to 94.39% over Clemson spineless commercial variety of USA. Comparatively the tender fruits width of okra genotypes from Ethiopian was higher than the exotic commercial varieties but the commercial varieties had longer fruits than okra genotypes from Ethiopian.

Table 9. Advantage of okra genotypes from Ethiopia for fruit quality over exotic high yielding commercial registered variety (SOH 701) and Clemson spineless (USA) commercial variety from three experiments in 2015 and 2016 at Dire Dawa

	Advantage over SOH 701				Advantage over Clemson spineless			
Trait	Number of genotype	Minimum (%)	Maximum (%)	Mean (%)	Number of genotype	Minimum (%)	Maximum (%)	Mean (%)
Dry pod weight (g)	22	0.02	56.59	25.99	29	0.09	81.51	31.73
Fruit width (cm)	31	1.08	65.32	20.50	3	5.84	94.39	31.06
Fruit length (cm)	7	1.89	84.59	21.48	1	18.85	46.88	32.87
Number of seeds/pod	18	0.04	20.71	7.46	29	0.76	33.69	13.61
Fruit weight(g)	23	1.31	51.38	23.46	7	6.03	14.00	9.25
Mucilage content (%)	7	0.81	194.53	61.18	1	58.31	------	------

Qualitative traits of genotypes

Thirteen (52%) genotypes had densely branched at base of which eight and five genotypes were from India and Ethiopia, respectively. Eight of which 6 and 2 genotypes from Ethiopia and other countries, respectively, had densely branched all over. Two genotypes obtained from Metekel had densely branched at apex. Three (12%) and 22 (88%) genotypes had flowers with red color inside only and red color at both sides, respectively, while 10 (40%) and 15 (60%) genotypes had totally green and green with red vein leaf color, respectively. All introduced commercial varieties except one had leaves with totally green color. Two (8%) and four (16%) genotypes had leaf petiole with red on both sides and red above but green below, respectively, while 19 (76%) genotypes had leaf petiole with green color. Nine out of 11 introduced varieties had leaf petiole color with red above but green below. Eight (32%), six (24%) and 11 (44%) genotypes had stem with green, green with red patch and red or purple, respectively. One, four and six introduced varieties had red/purple, green and green with red patch stem color, respectively.

Estimate genetic variability

Estimates of variability components for nine selected traits are presented in Table 10. The genetic coefficient of variations (GCV) and phenotypic coefficient of variations (PCV) ranged from 9.96 to 32.36% and 12.87 to 33.39%, respectively. Heritability in broad sense (H^2) and genetic advance as percent of the mean (GAM) ranged from 59.8 to 95.2% and 15.9 to 65.15%, respectively. All the lowest and highest values for all variability components estimates were computed for fruit length and tender fruits mucilage content, respectively, except the highest PCV was computed for fruit yield per plant. Fruit width had < 20% for both GCV and PCV, while number of fruits per plant and number of seeds per pod had < 20% only for GCV. All traits had H^2 values of >75% and GAM values of >27% except for fruit length.

Table 10. Estimates of variability components for selected fruit traits and tender fruit yield of 25 okra genotypes evaluated at Dire Dawa in 2016.

Traits	σ^2g	σ^2e	σ^2p	GCV (%)	PCV (%)	H^2 (%)	GA	GAM (5%)
Fruit length (cm)	1.19	0.8	1.99	9.96	12.87	59.8	1.74	15.9
Fruit width (cm)	0.1	0.01	0.11	13.81	14.49	90.8	0.62	27.1
Fruit weight(g)	25.16	2.02	27.17	21.91	22.77	92.6	9.96	43.5
Number of fruits/plant	39.29	12.14	51.43	19.77	22.62	76.4	11.3	35.6
Fruit yield/plant	0.14	0.01	0.15	32.26	33.39	93.3	0.75	64.3

(kg)								
Fruit yield (tha^{-1})	54.32	7.32	61.64	31.22	33.26	88.1	14.27	60.46
Dry pod weight (g)	163.86	54.24	218.1	20.31	23.44	75.1	22.89	36.3
Number of seeds/pod	890.48	36.32	333.15	19.49	20.64	89.1	33.55	37.9
Mucilage content (%)	50.28	0.84	17.6	32.36	33.16	95.2	8.24	65.15

σ^2p = Phenotypic variance, σ^2g = Genotypic variance, σ^2e = Error variance, PCV= Phenotypic coefficient of variations, GCV= Genotypic coefficient of variations, H^2 (%)= Broad sense heritability, GA= Expected genetic advance and GA (%)= Genetic advance as percent of the mean.

Genetic diversity

Euclidean distance was computed from 29 quantitative traits to estimate genetic distances of 14 okra genotypes from Ethiopia and 11 commercial varieties of other countries. The Euclidean distances of 300 pair of genotypes is presented in Table 11. The genetic distance was ranged from 3.1 to 12.6 with 7, 2.2 and 27.85% mean, standard deviation and coefficient of variation, respectively. The highest genetic distance was observed between Guba-12 and NamdHari (12.6) followed by Guba-12 and Vellayani (12.3) and Mythri and Guba-12 (11.8). Guba 47 and Guba 08 (3.1) followed by NamdHari and Arcanamica (3.3), and Anoop and Arcanamica (3.6) showed the lowest genetic distances. Nine (64.29%) out of14 okra genotypes from Ethiopia and two out of 11 (18.18%) commercial varieties from other country had genetic distances above average distance (>7.2) with 12 to 18 genotypes, while 14.29% (2) and 27.27% (3) genotypes from Ethiopia and other countries, respectively, had genetic distances above average distance with 4 to 6 genotypes.

The mean genetic distances of genotypes (Table 12) showed that Guba 12 (8.5) followed by Vellayani and Kiran both with mean Euclidean distance of 8.4 were the most distant to others. In contrast, Dhenu (5.9) followed by T240600, Clemson spineless, SOH 701 and T242444 with mean Euclidean distance in between 6 to 6.2 were closest to others. Five okra genotypes from Ethiopia and four from other countries had mean Euclidean distances above average distances (7.4 to 8.3) and other three genotypes from Ethiopia had average or near to average distances of 7.2 and 7.1.

Table 11.Genetic distances of 25 okra genotypes estimated from 29 quantitative traits

	Mythri	T240600	Guba 47	Guba 12	ArkaAnamica	NamdHari	Dangur 40	Clemson	T240204	Dhenu	Vellayani	Guba 21
T240600	7.63											
Guba 47	10.5	5										
Guba 12	11.8	5.8	5									
ArkaAnamica	4	6.2	8.5	10.1								
NamdHari	2.9	8.2	11.1	12.6	4.8							
Dangur 40	9.5	5.8	6.8	7.8	7.6	10.3						
Clemson	5.61	4.09	6.64	8.01	4.77	6.23	6.93					
T240204	10	4.7	4.1	6	7.6	10.4	5.7	6				
Dhenu	6.26	4.45	6.87	8.46	5.29	6.96	4.9	4.7	5.92			
Vellayani	6.6	7.6	11.1	12.3	6.8	7.4	8.5	7.3	9.6	5.9		
Guba 21	10.8	6.6	4.8	6.6	9.4	11.6	8.2	7.1	4.7	7.5	11.1	
Guba 04	7.4	7	9.5	10.7	6.9	8.3	7.9	6.9	8.7	5.5	7	9.9
T240609	10.4	6.1	6.9	7.7	8.6	11.1	4.4	6.8	5.2	6.1	9	7.6
Guba 05	8.19	5.74	5.87	7.74	6.53	9.01	7.01	5.13	5.09	4.9	8.69	5.64
Anoop	4.3	7.5	10.4	11.4	5.1	3.9	9.6	6.1	9.5	6.5	6.4	10.4
T242443	8.53	4.69	5.84	6.92	6.63	9.16	4.66	5.56	5.29	3.81	8.2	7.53
SOH 701	6.63	4.31	5.9	7.34	5.59	7.4	6.33	3.99	5.79	4.82	7.99	6.61
SOH 704	5.94	5.62	6.59	9.08	4.75	6.41	7.43	4.38	6.58	4.77	7.78	6.99
Arcanamica	4	7.2	9.9	11.3	4.6	3.3	8.9	6.5	9.5	6	7	10.6
Guba 08	10.6	5.4	3.1	4.9	8.8	11.4	6.8	6.9	4.1	6.5	10.8	4.2
Guba 14	9.4	7	9	9.6	8.6	9.9	5.6	7.7	7.2	6	8.3	9.8
Kiran	7.8	6.8	7.8	9.8	7	7.8	10.2	6.1	7.5	8.2	9.6	7.9
Guba 07	10.4	6.2	6.1	6.5	8.8	11.4	5.1	7.3	5.1	6.5	10	7.1
T242444	8.03	4.97	6.07	7.65	6.67	8.62	5.65	5.02	5.13	3.89	7.72	7.01

Table 11. Continued.

	Guba04	T240609	Guba 05	Anoop	T242443	SOH 701	SOH 704	Arcanamica	Guba 08	Guba 14	Kiran	Guba 07
T240609	8.9											
Guba 05	6.26	7.23										
Anoop	7.2	10.2	7.8									
T242443	7.39	4.56	6.01	8.72								
SOH 701	7.45	6.32	6.06	6.84	4.85							
SOH 704	7.61	7.83	5.91	6.51	5.51	3.72						
Arcanamica	7.6	10.3	8.5	3.6	8.1	6.6	5.6					
Guba 08	9.6	6.2	5.6	10.5	5.5	6.1	7.1	10.2				
Guba 14	8.6	5.9	8.9	9.7	5.9	6.7	8.2	9.5	8.6			
Kiran	10.8	10.2	8	7.5	9.4	7	6.7	7.9	8.4	10.4		
Guba 07	9.8	3.9	7.3	10.5	5.2	6.5	8.3	10.5	5.3	6.6	9.6	
T242444	5.62	5.39	4.52	7.8	3.81	5.41	5.92	7.92	5.77	6	8.8	6.19

Table 12. Mean genetic distances of 25 okra genotypes as measured by Euclidean distance from 29 quantitative traits.

Genotype	Minimum	Maximum	Mean	SD	CV (%)
Mythri	2.9	11.8	7.8	2.5	32.06
T240600	4.09	8.18	6.0	1.2	19.48
Guba 47	3.1	11.1	7.2	2.3	31.60
Guba 12	4.9	12.6	8.5	2.3	26.99
ArkaAnamica	4.0	10.1	6.8	1.7	25.28
NamdHari	2.9	12.6	8.3	2.7	32.94
Dangur 40	4.4	10.3	7.1	1.8	24.53
Clemson	3.99	8.01	6.1	1.2	19.10
T240204	4.1	10.4	6.6	2.0	29.90
Dhenu	3.81	8.46	5.9	1.2	21.01
Vellayani	5.9	12.3	8.4	1.7	19.90
Guba 21	4.2	11.6	7.9	2.1	26.77
Guba 04	5.5	10.8	8.0	1.5	18.33
T240609	3.9	11.1	7.4	2.1	28.40
Guba 05	4.52	9.01	6.7	1.4	20.23
Anoop	3.6	11.4	7.8	2.3	29.12
T242443	3.81	9.41	6.3	1.7	26.84
SOH 701	3.72	7.99	6.1	1.1	18.40
SOH 704	3.72	9.08	6.5	1.3	20.56
Arcanamica	3.3	11.3	7.7	2.3	30.33
Guba 08	3.1	11.4	7.2	2.4	33.38
Guba 14	5.6	10.4	8.0	1.5	18.84
Kiran	6.1	10.8	8.4	1.3	15.82
Guba 07	3.9	11.4	7.5	2.1	28.50
T242444	3.81	8.80	6.2	1.4	22.91

SD = standard deviation and CV (%) = coefficient of variation in percent.

The distance matrix of 300 pair of genotypes computed from mean values of genotypes for 29 quantitative traits was used to construct dendrogram based on the Unweighted Pair-group Method with Arithmetic means (UPGMA) and presented in Figure 1. The cluster analysis grouped the 25 okra genotypes into seven major clusters in which the three clusters (Cluster II, III and V) were solitary consisted of one genotype each. Cluster IV and I comprised of 7 (28%) and 6 (24%), respectively, while Cluster VI and VII consisted of 5 (20%) and 4 (16%), respectively. Cluster I consisted of six Indian commercial varieties, Cluster IV comprised of seven genotypes (three okra genotypes from Ethiopia, one variety from USA and three from India), while Cluster VI comprised of genotypes from northwestern, Metekel zone. The genotypes obtained from the same

regions or countries tend to be grouped together though admixture of genotypes from different regions grouped in two clusters. However, the two clusters, Cluster IV comprised of 57.14 and 42.86% genotypes from other countries and Assosa zone, respectively, while Cluster VII contained 75 and 25% genotypes obtained from Metekel zone and Gambella, respectively.

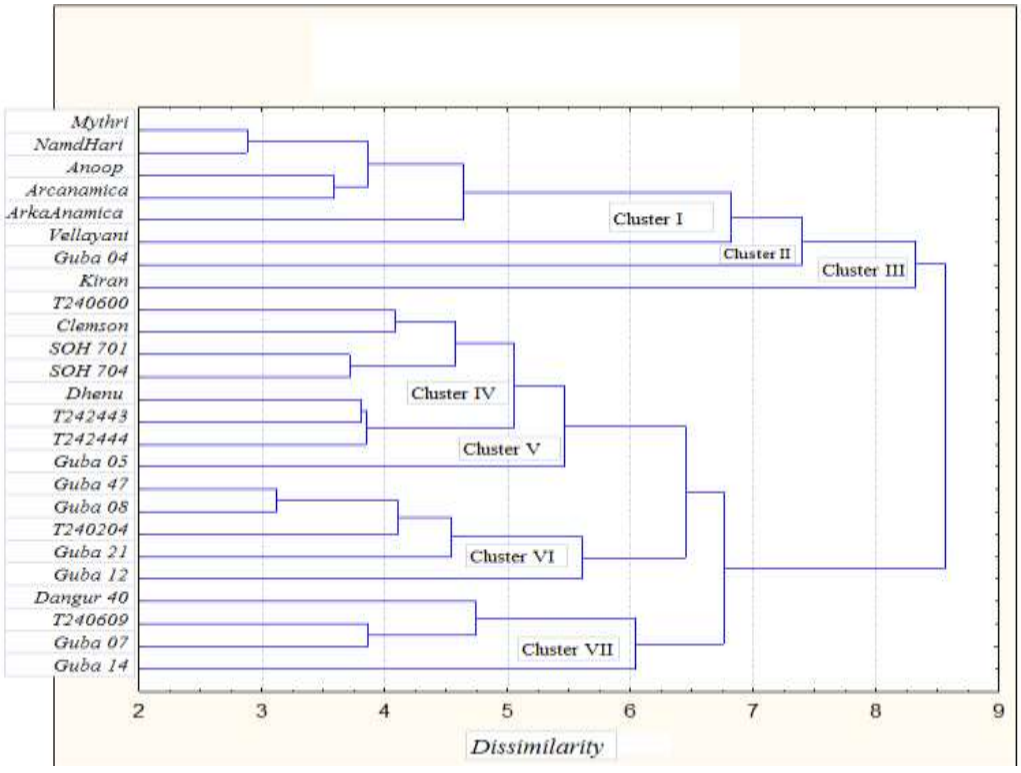

Figure 1. Dendrogram constructed using Unweighted Pair-group Method with Arithmetic means (UPGMA) depicting seven major clusters of 25 okra genotypes.

The genotypes grouped under seven clusters had distinguishing characters, for instance genotypes under Cluster I had longer fruit length, many number of fruit per plant and higher dry matter content of fruits, Cluster II consisted of genotype with higher fresh and dry weight of fruits, higher dry matter and mucilage contents of fruits, while Cluster III consisted of genotype with all desirable traits including high fruit yield per plant and per hectare. Cluster IV consisted of genotypes with heavy fruit weight and many number of matured pod per plant, Cluster V consisted of genotype with tender fruits with high mucilage content and Cluster VII consisted of genotypes with many number of matured pod, number of seed per pod and fruits with high mucilage content of fruits (Table 13).

Table 13. Distinguishing quantitative characters of seven clusters consisting 25 okra genotypes.

Cluster	Genotype	Distinguishing character
I	Mythri, NamdHari, Anoop, Arcanamica, ArkaAnamica, Vellayani	Early flowering, pod formation and maturity, longer fruit length, more number of fruit per plant, higher dry matter content of fruitsand longer internodes length than the overall mean values of genotypes but had mean values lower than overall mean values for all other traits.
II	Guba 04	Delayed days to emergence, flowering, pod formation and maturitywith higherfresh and dry weight of fruits,higher dry matter and mucilagecontents of fruits,long and wide leaves, but lower mean values for other traits than the overall mean values.
III	Kiran	Early days to emergence, flowering, pod formation and fruit maturity, long fruits and highest number of fruits per plant with greater mean values than overall mean values of genotypes for many other traits including high fruit yield per plant and per hectare.
IV	T240600, Clemson, SOH 701, SOH 7014, Dhenu, T242443, T242444	It had average mean values of genotypes for many other traits but had higher fruit weight and higher number of matured pod per plant.
V	Guba-05	Early days to emergence and first flowering but it had late days to 50% flowering, days to pod formation, days to maturity higher than the genotypes overall mean values. It had short internode length, lowest number of matured pod per plant and dry matter content but higher fruit mucilage contentand for many other traits than overall mean values of genotypes.
VI	Guba 47, Guba 08, T240204, Guba 21, Guba 12	Early days to emergence, lower dry matter and mucilage contents of fruitthan the genotypes overall mean values, but it had mean values greater than overall mean values of genotypes for most of the traits.
VII	Dangur 40, T240609, Guba	Delayed days to emergence, flowering, pod formation and maturity than the genotypes overall mean values. It had longest plant height, and highest number of epicalyx,

	07, Guba 14	number of matured pod, and number of seed per pod and fruit mucilage content as well as mean values greater than overall mean values of genotypes for many other traits.

4. Discussion

Okra genotypes evaluated in all three experiments showed wide ranges of variations for all quantitative traits. The research conducted on 14 and 11 okra genotypes from Ethiopia and other countries, respectively, indicated the presence of variations between the two groups of genotypes for all traits. All the three experiments results suggested the higher chance of developing okra varieties for tender fruit yield and other desirable traits either through selection breeding and/or crossing of genotypes. Tesfa and Yosef (2016), Mihretu *et al.* (2014a&b) found significant differences among okra genotypes for quantitative traits. Muluken *et al.* (2016) also reported the presence of significant differences among 25 okra genotypes for all traits except for internode length, number of number of epicalyx per flower and peduncle length.

The mean performance comparison showed that okra genotypes from Ethiopia were superior over exotic commercial varieties for tender fruit yield, fruit traits including fruit quality, growth traits and other agromorphology traits. However, the commercial okra varieties introduced from other countries were early flowering, pod formation and maturity than okra genotypes from Ethiopia. Other researchers also reported wide range of variations among okra genotypes collected from different regions of Ethiopia (Muluken *et al.*, 2016 & 2015; Tesfa and Yosef, 2016; Mihretu *et al.*, 2014a&b). The variations observed among okra genotypes for plant habit, flower, leaf, petiole and stem colors will allow breeders to identify genotypes when they need to use them in breeding activities. Some of the traits also related to high production such as erect plants and densely branched allover type are advantageous to okra production, since uniform distribution of leaves result in an increase in dry matter production, increase yield and production of good quality of pods (Shujaat *et al.*, 2014). Fruits with green color are preferred by consumers since tender fruits are utilized as vegetable throughout the world (Eshiet and Brisibe, 2015).

The observed medium to high phenotypic and genetic coefficient of variations coupled with high heritability and genetic advance values indicated that the expression of traits in genotypes was less influenced by environments. Many authors suggested that the high phenotypic and genotypic coefficient of variations are an indication of the less influence of environmental factors on the expression of such traits and the higher chance to improve them through selection breeding (Swati *et al.*, 2014; Bharathiveeramani *et al.*, 2012; Nwangburuka *et al.,* 2012; Salesh *et al.*, 2010).Shujaat *et al.* (2014) indicated that the significant variations among okra genotypes may be due to either environmental factors or variations in the genetic potential of genotypes. He further suggested genetic variations are an important feature to achieve the diversified goals of plants breeding through selection. Muluken *et al.* (2015) and Mihretu *et al.* (2014b) reported high values both for heritability and

genetic advance for most of growth, tender fruit and fruit yield related traits in okra genotypes collected from different parts of the country.

This research results showed the presence of diverse okra genotypes with wide range of genetic distances which enables the researchers to improve the okra tender fruit yield and other desirable traits either through direct selection of genotypes or crossing of okra genotypes having different desirable traits. Moreover, the genetic distances between okra genotypes from Ethiopia and commercial varieties from other countries showed the two groups of genotypes were distant than genotypes obtained from the same country. The okra genotypes obtained from the same or different regions of Ethiopia were also distant. Genetic diversity in okra collections can give breeders and geneticists' important information on the allelic diversity present in gene bank materials and may help to identify genetically diverse pools for use in cross combinations to improve important agronomic traits or to better exploit heterosis (Naser, 2014). Shujaat *et al.* (2014) and Pradip *et al.* (2010) suggested that genetic variation is an important feature to get together the diversified goals of plant breeding including higher yield, resistance to diseases, advantageous qualities and wider adaptations. Muluken *et al.* (2016) reported that the two registered commercial varieties and genotypes from Ethiopia were more distant. Researchers reported the presence of diversity in okra genotypes obtained from different regions of Ethiopia (Muluken *et al.*, 2016; Tesfa and Yosef, 2016; Mihretu *et al.*, 2014a&b). The results of current research and research conducted by other researchers suggested the need to conduct further research on okra genotypes in Ethiopia and commercial varieties of other countries to develop varieties and to generate sufficient information on the genetic diversity of okra genotypes.

5. Summary and Conclusion

The observed significant variations, genetic distances and diversity among okra genotypes obtained from Ethiopia and other countries could be exploited in breeding activities to develop varieties either through selection breeding and/or hybridization. Moreover, 15 okra genotypes obtained from Ethiopia showed superiority for tender fruit yield over the high yielding registered commercial variety and commercial variety from USA. At least one and a maximum of 31 okra genotypes obtained from Ethiopia had mean values for quality traits of fruits greater than high yielding registered commercial variety and commercial variety from USA. This showed the higher chance of selecting okra genotypes from Ethiopia to release as varieties than introducing commercial varieties from other countries. Therefore, it is recommended to further evaluate best performing genotypes at varied environments of the country to recommend varieties for production in Ethiopia.

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14. Genotype x Environment Interaction and Stability of Potato (*Solanum tuberosum* L.) Varieties for Late blight [*Phytophthora infestans* (Mont.) de Bary] Resistance in Eastern Ethiopia

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Abstract: Potato is second next to Khat in the economy of eastern Ethiopia; however, late blight caused by the *Phytophthora infestans* (Mont.) de Bary is one of the major constraints of production in the region. The disease could be better managed by growing varieties with a high rating for disease resistance. This research was conducted to determine the degree of late blight resistance in potato varieties; to assess the genotype x environment interaction (GEI) effect on varieties resistance, and to identify stable varieties resistant to late blight disease across locations in eastern Ethiopia. The experiment consisted of 16 released and two farmers' varieties, laid out in randomized block design with three replications at three locations (Haramaya, Hirna and Arberkete) in 2013 and 2014 cropping seasons. General analysis of variance (ANOVA) and ANOVA from Additive Main Effects and Multiplicative Interaction (AMMI) model revealed the significant effect of genotype, environment and GEI on all disease ratings. The treatment sum of squares had the highest contribution for total sum squares ranged from 74.74 to 89.01% while error sum squares contributed less in the range between 7.35 and 15.28%. The inherent disease resistance of varieties accounted the highest proportion of the observed variations for late blight disease susceptibility score values, late blight disease severity score and days to onset of late blight disease ranged from 39.65 to 51.43% while environment sum squares contributed the highest share of 35.32 and 32.68% for treatment sum squares of Relative Area under the Disease Progress Curve (rAUDPC) and Area under the Disease Progress Curve (AUDPC), respectively. The GEI sum square only contributed higher share than environment sum square to treatment sum square of days to onset of late blight disease. The first principal component axis (IPCA 1) sum square was significant and contributed the largest share to GEI sum square for all late blight disease ratings. The total sum contribution of IPCA 1 and IPCA 1I ranged from 84.18 to 99.06% while the residual sum square was contributed 0.94% to 15.82 to GEI sum square. The varieties except few showed differential disease ratings and resistance levels over locations and seasons. Moreover, only 2 and 4 varieties were found to be resistant and

moderately resistant, respectively, at Haramaya during 2014 where the disease intensity was very high. Only Bubu, Bulle and Belete were found as resistant varieties to late blight disease by considering the mean disease ratings over locations, stability and resistance levels in a location and season where the disease intensity was very high. The results indicated the resistant gene(s) the varieties carry followed by environment were more important in reducing disease ratings and suggested the varieties to be recommended as resistant to late blight disease in the target area need to be based on the resistance levels of varieties both at location where the environment is favourable for the pathogen and consistent performance over locations and seasons. It is concluded that the varieties identified as resistant to late blight need to be considered for cultivation in eastern Ethiopia due to the high disease pressure in the region and the high mutation rate of the pathogen to overcome resistant gene(s) with short period.

Keywords: AMMI; AUDPC; Disease susceptibility score values and Disease ratings

1. Introduction

Potato is used as co-staple food in East Hararghe (ORARI, 2007) and it accounts about 3% of the total number of potato growers (CSA, 2008) in the country. Potato is second next to *Khat* in the economy of eastern Ethiopia. It is produced both for local consumption and export to Djibouti and Somalia (Adane *et al*., 2010). In East Hararghe, potato is grown by 52,710 farmers with a total area of 2,507.12 hectares in 2013/2014 *Meher* season with the average yield of 19.3 t ha^{-1} (CSA, 2014) which is by far greater than the national average yield of 12.66 t ha^{-1} (CSA, 2016). The increases in potato production in Hararghe is spurred by ever-increasing population pressure, land fragmentation and the impossibility of sustaining farm families' livelihoods from cereal production (Eshetu *et al*., 2005). However, late blight is one of the major problems which reduce the production and productivity of potato in the region. The disease occurs almost everywhere where potatoes are grown, attack all parts of the plant, and if not controlled, yield losses may reach 100 percent (Rubio-Covarrubias *et al*., 2005) and even with low infection levels, the crop may be unsuitable for storage (Fernández-Northcote *et al*., 2000). The pathogen spreads like a wild fire under congenial weather conditions and wipes out the entire crop within a few days (Sundaresha *et al*., 2014). In Ethiopia, the disease caused an estimated yield loss of up to 70% (Mekonen*et al*., 2011).

A number of management techniques of late blight have been developed and used throughout the world. Repeated application of fungicides is one of the management options of late blight disease;however, it increased production costs and environmental risk as well as a slow erosion of disease control due to a gradual loss of sensitivity of the targeted pathogen population to the fungicide (Davidse *et al*., 1981; Goodwin *et al*., 1992). Host resistance is better controled measure as compared to fungicidal sprays but

the disease mutable features make resistant cultivars no longer resistant to the disease in subsequent season (Song *et al.*, 2003). Potato varieties with R-gene (s) may be considered resistant to late blight in one area because the meteorological conditions are not suitable to the pathogen to occur (Hansen *et al.*, 2005). Even when conditions for infection and disease development are favorable, a plant may develop no disease, only mild disease, or severe disease, depending on the specific genetic makeup of the plant and of the pathogen that attacks it. The variety developed as horizontal resistance may be susceptible because the resistance may also be contributed by *R* genes that have residual effects against virulent pathogens or defeated *R* genes (Gebhardt, 2013). The pathogen *P. infestans* is an extraordinarily virulent and adaptable pathogen which reproduces by asexual and sexual means (Haas *et al.,* 2009; Fry, 2008) and resistant varieties for one race such as A1 become susceptible to the other race or natural selection may results to overcome resistance (Jones and Dangl, 2006). Therefore, no potato varieties can be considered as fully resistant or immune to late blight but possess varying degrees of resistance to various races of the pathogen (Popokova, 1972).

Most of the potato varieties in Ethiopia have variations in resistance to late blight because they possess genes for either vertical resistance or horizontal resistance to late blight in the presence of unknown resistance major R genes (Gebremedhin, 2013). Therefore, testing of potato varieties resistant to the pathogen over locations and years is necessary to identify resistant varieties for the target area(s). The varieties cultivated as resistant to late blight in different agroecological areas of the country may not be resistant in other areas either due to the presence of virulent races of the pathogen and/or environment favorable to the pathogen (Wassu, 2014). Identification of new source of resistance genes is a major challenge (Sundaresha *et al.*, 2014) due to mutable features of the pathogen, the presence of crossover type of genotype x environment interaction (GEI) and the time cost it required to develop new varieties. Therefore, testing known varieties resistant to late blight in the target area make easy, cost and time effective as compared to searching new genotypes resistant to *Phytophtora infestans*. Analyzing the late blight resistance helps not only to determine differences in disease development among various potato cultivars, but also to find differences in the same potato cultivar every separate research year (Razukas *et al.*, 2008). The direct comparison of new and old varieties for yield/disease resistance at one location cannot be an indicator of the contribution of specific varieties to the productivity of the crop (Silvey, 1981) due to the crossover GEI that leads to differential disease resistance ranks of potato varieties (Kang, 2002). This needs to evaluate the varieties across varied environments to identify varieties either adapted to specific environment or wide range of environments. Therefore, this research was conducted at different locations in eastern Ethiopia; i) to determine the degree of late blight resistance in released potato varieties over locations, ii) to assess the GEI effect on resistance of varieties to late blight, and iii) to identify varieties resistant to late blight across locations in the region.

2. Materials and Methods

Description of the Study Sites

The field experiment was carried out at three locations namely; Haramaya, Hirna and Arbarakkate which are considered as the representative mid and highland potato growing areas of eastern and western Hararghe Zones in the country. The experiment was conducted for one cropping season in 2013 in all the three locations and it was conducted in 2014 at Haramaya in which the location was identified as favorable environment for late blight.

Haramaya University, Rare research farm is located at 2002Ms above sea level, 9°42'32"N latitude and 42°03"85'E longitude. The area has a bimodal rainfall distribution and is representative of a sub-humid mid-altitude agro-climatic zone. The mean annual rainfall is 760 mm. The short rainy season extends from March to April and constitutes about 25% of the annual rainfall whereas the long rainy season extends from June to October and accounts for about 45% of the total rainfall (Belay *et al*., 1998). The mean maximum temperature is 23.4^{0}C while the mean minimum annual temperature is 8.25^{0}C. The soil of the experimental site is a well-drained deep alluvial with a sub-soil stratified with loam and sandy loam (Tekalign, 2011).

Hirna research sub-station of Haramaya University is located at 9 ^{o}12' North latitude, 41 ^{o} 4' East longitude, and at an altitude of 1870Ms above sea level. The area receives mean annual rainfall ranging between 990 to 1010 mm (HURC, 1996). The mean maximum and minimum annual temperatures are 21.8°C and 8.6°C, respectively (Tekalign, 2011). The soil of Hirna is *Vertisol* with a silty clay texture (Nebret, 2011). The third site is Arbarakkate on farmer's field, which is situated at a distance of about 171 km to the west of Haramaya and 339 km to the east of Addis Abeba. The site is located at 9 ^{o}14' North latitude, 41 ^{o}2' East longitude, and at an altitude of 2280 meters above sea level.

Experimental Materials

Eighteen (18) potato varieties were evaluated, of which 16 were improved varieties released by five research centers and Haramaya University from 1987 to 2011 and two farmers' varieties. The description of the varieties is given in Table 1.

Table 17. Name, accession code, year of release, breeding/maintainer centre of potato varieties.

Variety	Accession code	Year of release	Breeding center	Recommended Altitude (m a.s.l.)
Alemaya 624	Al-624	1987	Haramaya University	1700 - 2400
Chiro	AL-111	1998	Haramaya University	2700 - 3200
Zemen	AL-105	2001	Haramaya University	1700 - 2000
Badhasa	AL-114	2001	Haramaya University	2400 - 3350
Gorebela	CIP-382173.12	2002	Sheno Research Centre	1700 - 2400
Guasa	CIP-384321.9	2002	Adet Research Centre	2000 - 2800
Jalenie	CIP-37792-5	2002	Holeta Research centre	1600 - 2800
Gera	KP-90134.2	2003	Sheno Research centre	2700 - 3200
Chala	CIP-387412-2	2005	Haramaya University	1700 - 2000
Bulle	CIP-387224-25	2005	Hwassa Research centre	1700 - 2700
Gabbisa	CIP-3870-96-11	2005	Haramaya University	1700 - 2000
Mara Charre	CIP-389701-3	2005	Hwassa Research centre	1700 - 2700
Gudanie	CIP-386423.13	2006	Holeta Research centre	1600 - 2800
Araarsaa	CIP-90138.12	2006	Sinnana Research centre	2400 - 3350
Belete	CIP-393371.58	2009	Holeta Research Centre	1600 - 2800
Bubu	CIP-384321-3	2011	Haramaya University	1700 - 2000
Batte	Farmers' variety			
Jarso	Farmers' variety			

Source: Ministry of Agriculture (MoA, 2013 and 2012). m a.s.l = Metres above sea level.

Experimental Design and Procedures

The experiment was laid out as a Randomized Complete Block Design (RCBD) with three replications in each environment. Each potato variety was assigned to one plot in each replication and six rows with 12 plants. The gross plot size was 16.2 m^2 with spacing of 75 cm between rows and 30 cm between plants in each row. The spacing of 1.5 m and 1 m was maintained between plots and blocks, respectively.

The experimental fields except at Arbarakkate were cultivated by a tractor to the depth of 25-30 cm and levelled. Then ridges were made by hand. Medium sized (39-75

g) and well sprouted seed tubers were planted at the sides of the ridges. Tubers were planted at the end of June at Haramaya and first week of July at Hirna and Arbarakkate during the main growing season after the rain commenced and when the soil was moist enough to support emergence and growth. The planting depth was maintained at about 5 to 10 cm.

Fertilizer was applied at the rate of 75 kg N and 92 kg P_2O_5 ha^{-1}. The sources of nitrogen and phosphors were Urea (46% N) and DAP (18% N, 46% P_2O_5), respectively. The entire DAP fertilizer was applied at the depth of 10 cm below the seed tuber at planting, while urea was applied 7-10 cm away from the plant as two side dressings for in split application (50% + 50% 30 and 50 days after planting). Other agronomic managements (earthing up/cultivation, weeding) were applied as per the recommendation made for the crop.

Data Collection and Analysis

Disease assessment

Disease assessment was conducted starting from end of August after 46 to 50 days of planting as soon as disease symptoms appeared in susceptible varieties and then after every 14 to 20 days until the varieties attained physiological maturity. Onset of disease was registered for each variety as the days after planting to the occurrence of disease in each plot. Disease incidence and severity were assessed following CIP (2006) guideline and other established procedures. Assessment of severity of late blight under field conditions in percent was recorded on a plot basis taking into account the number of plants developing disease symptoms on a leaf and/or many leaves and plants free from disease as described in Table 2 (Henfing, 1987). Disease assessment was done by the same three evaluators without knowing the value given in the previous reading (CIP, 2006).

Table 2. Assessment of severity of late blight under field conditions

Phytophthora infestans (%)		Symptoms
Average	Boundaries	
0	0	*P. infestans* not observed
2.5	Trace < 5	*P. infestans* present. Maximum 10 injuries per plant
10	5 < 15	Plants seem to be healthy, but injuries can be easily observed. There are no more than 20 affected leaves
25	15< 35	*P. infestans* is easily observed on the plants. About 25% of the leaf area is affected by injuries.
50	35< 65	Plants look green, but each one is affected by the pathogen, lower leaves are necrotic. About 50% of the leaf area is destroyed
75	65< 85	Plants look green with brown spots. About 75% of the leaf area is affected. Leaves in the middle of the plant are

		destroyed
90	85< 95	Only upper leaves are green. Most of leaves are affected and many stems have external injuries
97.5	95< 100	Plants look brown, few upper leaves are green and most of the stems are hardly affected or dead
100		Leaves and stems are destroyed

Source: (Henfing, 1987)

Late blight intensity (percent severity index) was calculated on the basis of the intensity of foliar blight that was expressed in percent of the infected leaf area as suggested by Mohan and Thind (1999) as follows.

$$\text{Late blight intensity \%} = \frac{\text{Summation of numerical rating}}{\text{No. plants examined} \times \text{Maximum disease score}} \times 100$$

The intensity of foliar blight that was expressed in percent of the infected leaf area was used for the disease rating scale as suggested by Mohan and Thind (1999). Depending on the final record of disease intensity (%), the genotypes were classified as resistant, moderately resistant, and susceptible as per the scale (Anonymous, 1997) (Table 3).

Area under the Disease Progress Curve (AUDPC) was calculated from disease intensity recorded at different fixed date intervals. The AUDPC value was calculated using the following formula (Campbell and Madden, 1990) and it was interpreted directly without transformation as the higher the AUDPC, the more susceptible is the genotype (CIP, 2006).

$$\text{AUDPC} = \sum_{i=1}^{n-1}\left(\frac{y_i + y_i + 1}{2}\right)\left(t_{i+1} - t_i\right)$$

Where "t" is the time of each reading, "y" is the percent of affected foliage at each reading and "n" is the number of readings. The variable "t" can represent Julian days, days after planting.

Relative Area under the Disease Progress Curve (rAUDPC**)** was calculated by dividing AUDPC by the number of days from first disease severity evaluation to final day of evaluation and susceptibility score values were calculated for each cultivar in terms of the susceptible cultivar as to the CIP guide for field evaluation of potato clones for late blight (Forbes *et al.*, 2014).

Table 3. Disease score and description, intensity (%), and resistance category.

Disease Score	Score description in terms of foliage infected (%)	Disease intensity (%)	Category
0	No visible symptoms	Up to 5	Highly Resistant
1	1-10	5-20	Resistant
2	11-25	21-40	Moderately Resistant
3	26-50	Above 40	Susceptible

4	51-75
5	>75

Data Analysis

Data for onset of disease**,** disease severity, AUDPC, Relative Area under the Disease Progress Curve **(**rAUDPC**)**, and susceptibility score values (SS value) parameters were subjected to analysis of variance (ANOVA) for each location and combined over environments following the standard procedure for RCBD given by Gomez and Gomez (1984) using the General Linear Model (GLM) of the SAS procedure of version 9.1 (SAS, 2007). Least significant difference (LSD) at 5% probability was computed to compare the mean values of the varieties for disease scores.

Additive Main Effects and Multiplicative Interaction (AMMI) (Zobel *et al.*, 1988) model --analysis of variance was conducted for four environments considering each location and one season as one environment. Stability parameters of AMMI model, the interaction principal component axes (IPCA) scores of a genotype and an environment were computed. In addition, AMMI stability value (ASV) was calculated as proposed by Purchase *et al.* (2000) as follows:

$$ASV = \sqrt{\left[\frac{IPCA1SS}{IPCA2SS}\left(IPCA1score\right)\right]^2 + [IPCA2score)^2}$$

Where, ASV=AMI stability value; SS = sum squares of IPCA1 and IPCA 2 (the first and the second interaction principal component axes, respectively), and thus varieties with lower ASV was considered more stable than those with higher ASV values.

Regression analysis was used to estimate the relationship between potato varieties release year and disease ratings to evaluate the potato breeding program in progressing to release resistant varieties in successive years of release. In this regression analysis, year of release was considered as independent variable while disease parameters were considered as dependent variables. Correlation of year of release and mean value of each variety for each disease rating was also calculated to understand the association of year of release and the mean performance of varieties. The results of regression analysis are presented as scattered plot in figures along with the regression equation, coefficient of determination (R^2), correlation coefficient and probability values.

3. Results

Analysis of Variance and Mean Performance of Varieties

Analysis of variance

The general analysis of variance results for each location revealed highly significant ($P<0.01$) differences among varieties for all late blight disease ratings in all locations except nonsignificant difference was observed at Arbarakkate for AUDPC and rAUDPC (Table 4). The combined analysis of variance conducted over seasons at Haramaya also revealed the presence of significant differences among varieties for all

late blight disease ratings (Table 5). The combined analysis of variance over locations and seasons also revealed the significant effects of the three main factors (genotype, location and season) and significant influence of genotype x location and genotype x season interactions on all late blight disease ratings of varieties (Table 6).

Table 4. Mean squares from analysis of variance for late blight disease ratings of 18 potato varieties tested at three locations in 2013.

Location and year	Source of variation	Onset of disease	AUDPC	SS value	Severity	rAUDPC
	Replication (2)	20.52	14551	0.118	15.7	0.001008
Hirna 2013	Variety (17)	745.49**	1516731**	12.3032**	1889.3**	0.105037**
	Error (34)	68.99	44994	0.365	252	0.003116
	CV (%)	14.1	44	44	53.5	44
	Replication (2)	66	123137938	11.284	2558.9	6.6281
Arbarakkate 2013	Variety (17)	595.7**	128762955ns	11.896**	1954.6**	0.7168ns
	Error (34)	104.3	430787177	1.983	432.9	0.8925
	CV (%)	18	65	68.4	62.6	66.1
	Replication (2)	6	184348	1.4954	267.13	0.012767
Haramaya 2013	Variety (17)	271.059**	2720649**	22.069**	2430.94**	0.188411**
	Error (34)	6	67872	0.5506	62.23	0.0047
	CV (%)	5.2	18.2	18.2	15.2	18.2

ns and **, nonsignificant and significant at P<0.01, respectively. Numbers in parenthesis are degree of freedom, AUDPC = Area under Disease Progress Curve, rAUDPC = Relative Area under the Disease Progress Curve, SS value = susceptibility score value and Severity = late blight disease severity score as percentage.

Table 5. Mean squares from analysis of variance for late blight disease ratings of 18 potato varieties tested at Haramaya in 2014 and combined ANOVA for 2013 and 2014.

Location and year	Source of variation	Onset of disease	AUDPC	SS value	Severity	rAUDPC
Haramaya 2014	Replication (2)	152.94	88959819	32.596	182.9	9.6293
	Variety (17)	95.67**	18447347**	13.487**	3320.8**	1.8498**
	Error (34)	82.58	3342952	2.207	227.1	0.3781
	CV (%)	16.3	60.4	55	27	64.4
Combined 2013 and 2014	Replication (2)	35.15	39882377	21.057	133.4	4.0815
	Variety (V) (17)	206.34**	17440782**	25.784**	4522**	1.6509**
	Season (S) (1)	3582.26**	121386963**	92.849**	564.9*	15.967**
	V x S (17)	127.28**	5275643*	4.11**	618.5**	0.6182*
	Error (70)	24.48	2475165	1.108	137.4	0.2582
	CV (%)	9.4	63.2	33.4	21.6	66.8

*ns, * and **, nonsignificant, significant and significant at P<0.05 and P<0.01, respectively. Numbers in parenthesis are degree of freedom, AUDPC = Area under Disease Progress Curve, rAUDPC = Relative Area under the Disease Progress Curve, SS value = susceptibility score value and Severity = late blight disease severity score as percentage.*

Table 6. Mean squares from combined analysis of variance over locations and seasons for late blight disease ratings of 18 potato varieties tested at four environments

Source	DF	AUDPC	rAUDPC	SS value	Severity	Onset of disease
Replication	2	20324286	2.0727	11.4602	115.8	56.72
Genotype (G)	17	14123940**	1.2463**	1.2463**	6165.2**	991.93**
Location (L)	2	105673932**	10.5845**	10.5845**	19916.1**	793.42**
Season (S)	1	121386963**	15.9676**	15.9676**	564.9ns	3582.26**
G x L	34	2898959*	0.2882*	0.2882**	778.1**	338.55**
G x S	17	5275643**	0.6182**	0.6182**	618.5**	127.28**
Error	142	1525098	0.1576	0.1576	156.8	47.24

*ns, * and **, nonsignificant, significant and significant at P<0.05 and P<0.01, respectively. DF= degree of freedom, AUDPC = Area under Disease Progress Curve, rAUDPC = Relative Area under the Disease Progress Curve, SS value = susceptibility score values and Severity = late blight disease severity score as percentage.*

The AMMI model analysis of variance was also conducted to partition the genotype x environment interaction (GEI) to its components. The combined analysis of variance results from AMMI model revealed the significant effect of all sources of variation (genotype, environment and genotype x environment interaction) on all disease ratings of varieties (Table 7a, 7b and 7c).

The treatment sum of squares had the highest contribution for total sum squares ranged from 74.74 (AUDPC) to 89.01% (late blight disease severity score) while error sum squares contributed less in the range between 7.35 (late blight disease susceptibility score values) and 15.28% (days to onset of late blight disease). Genotype sum squares accounted the highest proportion of treatment sum squares for late blight disease susceptibility score values (51.43%), late blight disease severity score (51.21%) and days onset of late blight disease (39.65%) while environment sum squares contributed the highest share for treatment sum squares of rAUDPC (35.32%) and AUDPC(32.68%). The genotype x environment interaction (GEI) sum squares had the lowest share of treatment sum squares for all disease ratings except its contribution for sum square of days to onset of late blight disease which was higher than the contribution of environment sum squares (Table 7a, 7b and 7c).

The first principal component axis (IPCA 1) sum square was significant for all late blight disease ratings while second principal component axis (IPCA I1) sum square was significant for days to onset of late blight disease, disease severity and disease susceptibility score value. The residual sum square was significant only for days to disease onset. The IPCA 1 sum square had the largest contribution to GEI sum square ranged from 51.8% (days to disease onset) to 95.86% (rAUDPC). The total sum contribution of the two principal component axis ranged from 84.18 to 99.06% while the residual sum square contribution was in the range between 0.94% (rAUDPC) to 15.82% (days to onset of disease) (Table 7a, 7b and 7c).

Table 7a. AMMI analysis of variance for days onset of late blight disease in 18 potato varieties tested at four environments.

		Onset of disease		Percent contribution	
Source of variation	DF	SS	MS	TSS	GEI
Total	215	42528	197.8		
Treatment	71	35706	502.9**	83.96	
Genotype (G)	17	16863	991.9**	39.65	
Environment (E)	3	5169	1723**	12.15	
Block	8	324	40.5	0.76	
G x E Interaction	51	13675	268.1**	32.16	
IPCA I	19	7084	372.8**		51.80
IPCA II	17	4427	260.4**		32.37
Residuals	15	2163	144.2*		15.82
Error	136	6497	47.8	15.28	

** and **, significant at P<0.05 and P<0.01, respectively. DF= degree of freedom, Onset of disease = days to onset of late blight disease, IPCA 1 and IPCA 2, interaction principal component axis one and two, respectively.*

Table 7b. AMMI analysis of variance for AUDPC and late blight disease severity ratings of 18 potato varieties tested at four environments.

	AUDPC			Percent contribution		Severity		Percent contribution	
Source of variation	DF	SS	MS	TSS	GEI	SS	MS	TSS	GEI
Total	215	1018304812	4736301			204679	952		
Treatment	71	761092318	10719610**	74.74		182177	2566**	89.01	
Genotype (G)	17	240106973	14123940**	23.58		104809	6165**	51.21	
Environment (E)	3	332734826	110911609**	32.68		40397	13466**	19.74	
Block	8	146098599	18262325	14.35		969	121	0.47	
G x E Interaction	51	188250519	3691187**	18.49		36970	725**	18.06	
IPCA I	19	176213942	9274418**	17.30	93.61	22482	1183**		60.81
IPCA II	17	9283099	546065ns		4.93	9967	586**		26.96
Residuals	15	2753478	183565ns		1.46	4521	301		12.23
Error	136	111113895	817014	10.91		21533	158	10.52	

*ns and **, nonsignificant and significant at P<0.01, respectively. DF= degree of freedom, AUDPC = Area under Disease Progress Curve, Severity = late blight disease severity score as percentage, IPCA 1 and IPCA 2, interaction principal component axis one and two, respectively.*

Table 7c. AMMI analysis of variance for rAUDPC and late blight susceptibility ratings of 18 potato varieties tested at four environments

	rAUDPC			Percent contribution		SS value		Percent contribution	
Source of variation	DF	SS	MS	TSS	GEI	SS	MS	TSS	GEI
Total	215	105.16	0.489**			1251.3	5.82**		
Treatment	71	78.63	1.108**	74.77		1097.6	15.46**	87.72	
Genotype (G)	17	21.19	1.246**	20.15		643.6	37.86**	51.43	
Environment (E)	3	37.14	12.379**	35.32		247.3	82.43**	19.76	
Block	8	15.18	1.898	14.44		61.6	7.7	4.92	
G x E Interaction	51	20.31	0.398**	19.31		206.7	4.05**	16.52	
IPCA I	19	19.47	1.025**	18.51	95.86	128.1	6.74**		61.97
IPCA II	17	0.65	0.038ns		3.20	65.5	3.85**		31.69
Residuals	15	0.19	0.013ns		0.94	13.1	0.87ns		6.34
Error	136	11.34	0.083	10.78		92	0.68	7.35	

*ns and **, nonsignificant and significant at P<0.01, respectively. DF= degree of freedom, rAUDPC = Relative Area under the Disease Progress Curve, SS value = late blight disease susceptibility score values, IPCA 1 and IPCA 2, interaction principal component axis one and two, respectively.*

Mean performance of varieties

All the varieties except few (Badhasa, Batte and Jarso as susceptible, Araarsaa as moderately resistant and Belete and Bubu as resistant) showed differential disease intensity ratings and disease resistant categories across locations. The disease resistant categories of potato varieties varied from being susceptible to resistant (Alemaya 624 at Haramaya, Arbarakkate and Hirna) susceptible, moderately resistant to resistant (Guasa at Haramaya, Arbarakkate and Hirna), susceptible, moderately resistant to highly resistant (Jalenie at Haramaya, Arbarakkate and Hirna) and other types of resistant ranks change (Table 8). In contrast, All the varieties except (Alemaya 624, Belete and and Mara Charre) did not show differential disease intensity ratings and disease resistant categories at Haramaya during the two years evaluation. On the mean disease intensity ratings over locations and seasons, only three varieties (Bulle, Bubu and Belete) were evaluated as resistant to late blight disease. Other five varieties (Alemaya 624, Jalenie, Gera, Mara Charre and Gudanie) were found as moderately resistant while all other varieties were categorized as susceptible.

Table 8. Disease intensity rating and disease resistant category of potato varieties in three locations

	Haramaya 2013		Haramaya 2014		Hirna 2013		Arbarakkate 2013		Mean over locations	
Variety	I(%)	RC	I(%)	RC	I(%)	RC	I (%)	RC	I (%)	RC
Alemaya 624	56	S	39	M	6	R	42	S	36	M
Chiro	100	S	100	S	44	S	71	S	80	S
Zemen	100	S	100	S	38	M	63	S	78	S
Badhasa	67	S	75	S	49	S	45	S	59	S
Gorebela	56	S	74	S	39	M	41	S	53	S
Guasa	90	S	65	S	9	R	24	M	47	S
Jalenie	61	S	61	S	5	HR	31	M	40	M
Gera	29	M	25	M	43	S	12	R	27	M
Chala	67	S	81	S	14	R	44	S	52	S
Bulle	14	R	12	R	19	R	21	M	16	R
Gabbisa	56	S	66	S	37	M	39	M	50	S
Mara Charre	29	M	54	S	15	R	11	R	27	M
Gudanie	38	M	25	M	17	R	15	R	24	M
Araarsaa	29	M	66	S	39	M	32	M	42	S
Belete	14	R	34	M	7	R	9	R	16	R
Bubu	14	R	13	R	10	R	6	R	11	R
Batte	100	S	69	S	94	S	49	S	78	S
Jarso	100	S	100	S	96	S	92	S	98	S

I (%) = disease intensity in percent, RC = disease resistance category, S =susceptible, M = moderately resistant, R = resistant, and HR =highly resistant.

On the basis of pooled mean over locations and seasons, the longest duration of onset of late blight disease after planting was observed in Belete (71 days) followed by Bulle, Bubu, Mara Charre and Gorebela all with 66 and 70 days but the onset of late blight disease took the shortest period of 45 days after planting in Jarso and Zemen followed by Batte and Chirro (46) (Table 9a). The highest AUDPC rating was computed for Jarso (4343) followed by Zemen, Chirro and Batte and lowest rating was calculated for Bubu (210) followed by Bulle, Gera, Gudanie and Belete all with <600 AUDPC rating. The highest late blight disease severity rating as percentage was registered for Jarso (93%) followed by Chirro, Zemen, Bete, Bedasa and Chala all with >50% while the lowest rating was estimated for Bubu (10%) followed by Bulle and Belete with <20%. Gera, Gudanie and Mara Charre also had 23 and 28% rating (Table 9b). The lowest rAUDPC rating was computed for Bubu and Bulle both with 0.06 rating followed by Gera and Belete both with <0.2 rating. The highest rAUDPC rating was calculated for Jarso (1.28) followed by Zemen, Chirro, Chala and Bete all with >0.5. The most late blight disease susceptible varieties were Jarso (7.33) followed by Batte, Chirro and Zemen all with >4.2 SS scores. Bulle (0.39) followed by Bubu and Belete with 0.4 and 0.54 ratings, respectively, were less susceptible to late blight disease. Gudanie, Gera and Mara Charre had also 1.02 to 1.19 late blight susceptibility values (Table 9c).

Stability of varieties

Gera, Bulle and Bubu had the lowest ASV with 1 to 3 ranks with low values for both IPCAs for days to onset of late blight disease while Araarsaa, Mara Charre and Gorebela had the highest ASV with 14 and 15 ranks. In terms of ranks on the basis of mean days to onset of late blight disease, Belete, Bulle and Bubu had 1 to 3 ranks for late onset of disease while the two farmers varieties, Batte and Jarso, and the three old varieties (Zemen, Chirro and Chala) released by Haramaya University had 11 to 13 ranks for early set of disease (Table 9a). Araarsaa, Mara Charre, Guasa and Bedasa had 1to 4 lowest rank of ASV while Bulle, Bubu, Jarso and Zemen had 15 to 18 highest ranks of ASV for AUDPC. Gabbisa, Bedasa, Belete and Gorebela had low ASV (1to 4 ranks) while Gera, Zemen, Chala and Batte had high ASV (15 to 18 ranks) for disease severity. Of which only Bubu, Bulle, Gera and Belete had low mean AUDPC and disease severity (Table 9b).

Araarsaa, Mara Charre and Guasa had mean rAUDPC lower than the overall mean values with lowest ASV ranks of 1 to 3. Jarso and Zemen had mean rAUDPC near to one and above one with highest ASV ranks of 17 to 18. Bubu and Bulle had also highest ASV ranks of 16 to 15, respectively, but both had the lowest mean rAUDPC (0.06). Bedasa, Al-624, Gabbisa with mean late blight disease susceptibility score values lower than the overall mean and also had the lowest ASV ranks of 1 to 3 while Batte, Zemen and Chirro had much higher mean late blight disease susceptibility score values than overall mean with highest ASV ranks of 14 to 16 (Table 9c).

Table 9a. Stability parameters from AMMI model for days to onset of late blight disease of 18 potato varieties tested at four environments.

Variety	Pooled mean	IPCA 1	IPCA 2	ASV
Al-624	48 (10)	0.19	1.32	1.36 (4)
Chirro	46 (12)	1.67	0.03	2.67 (9)
Zemen	45 (13)	1.33	-0.02	2.14 (5)
Bedasa	52 (7)	1.20	1.48	2.42 (7)
Guasa	56 (6)	-1.45	2.43	3.36(13)
Gorebela	66 (3)	-3.39	-0.81	5.48 (15)
Jalenie	59 (4)	-1.45	1.74	2.90 (10)
Gera	56 (6)	-0.40	0.37	0.74 (1)
Chala	47 (11)	2.01	0.08	3.21 (11)
Bulle	70 (2)	0.22	-0.88	0.95 (2)
Gabbisa	49 ((9)	1.43	0.75	2.41 (6)
Mara Charre	66 (3)	-3.39	-0.81	5.48 (15)
Gudanie	51 (8)	0.55	-2.46	2.61 (8)
Araarsaa	57 (5)	0.54	-3.86	3.95 (14)
Belete	71 (1)	-1.99	-0.56	3.23 (12)
Bubu	66 (3)	-0.09	1.21	1.22 (3)
Jarso	45 (13)	1.33	-0.02	2.14 (5)
Batte	46 (12)	1.67	0.03	2.67 (9)
Mean	55.36			
SD	9.19			
CV (%)	16.61			

Numbers in parenthesis are ranks of varieties, IPCA 1 and IPCA 2, interaction principal component axis one and two, respectively, ASV =AMMI stability value, SD =standard deviation and CV (%) =coefficient of variation in percent.

Table 9b. Stability parameters from AMMI model for AUDPC and late blight disease severity rating of 18 potato varieties tested at four environments

Variety	AUDPC				Severity			
	Pooled mean	IPCA 1	IPCA 2	ASV	Pooled mean	IPCA 1	IPCA 2	ASV
Al-624	961 (13)	13.44	-3.35	255.07 (9)	31 (10)	0.07	2.84	2.84 (5)
Chirro	2725 (3)	-22.87	-18.18	434.42 (13)	73 (2)	-2.58	1.05	5.91 (12)
Zemen	3219 (2)	-49.17	-1.75	933.43 (18)	65 (3)	-3.34	0.21	7.54 (16)
Bedasa	1812 (6)	-4.89	-0.30	92.85 (4)	59 (4)	-0.30	-0.83	1.07 (2)
Guasa	1274 (10)	4.46	-14.81	85.89 (3)	33 (9)	-1.29	3.29	4.38 (10)
Gorebela	1395 (9)	-6.18	1.56	117.28 (5)	41 (6)	-0.70	-1.69	2.32 (4)
Jalenie	1598 (7)	-10.36	-8.72	196.86 (7)	35 (8)	-2.85	1.16	6.54 (13)
Gera	533 (16)	23.67	2.61	449.30 (14)	23 (12)	3.30	-0.64	7.48 (15)
Chala	2054 (4)	-15.42	-10.00	292.92 (10)	51 (5)	-3.56	0.18	8.03 (17)
Bulle	219 (17)	25.49	7.13	483.98 (15)	13 (14)	2.97	0.05	6.70 (14)
Gabbisa	1572 (8)	-6.67	4.65	126.63 (6)	41 (6)	0.13	-0.57	0.64 (1)
Mara Charre	981 (12)	2.09	2.97	39.87 (2)	28 (11)	-1.26	-2.39	3.72 (6)
Gudanie	539 (15)	22.21	-2.00	421.60 (12)	23 (12)	1.65	1.72	4.10 (9)
Araarsaa	1115 (11)	-0.07	13.33	13.41 (1)	38 (7)	0.01	-4.03	4.03 (8)

Belete	542 (14)	11.42	8.75	216.99 (8)	15 (13)	0.12	-1.83	1.85 (3)
Bubu	210 (18)	25.90	3.76	491.65 (16)	10 (15)	2.19	0.10	4.94 (11)
Jarso	4343 (1)	-33.70	23.80	640.11 (17)	93 (1)	1.72	-0.49	3.92 (7)
Batte	1949 (5)	20.65	-9.46	392.08 (11)	65 (3)	3.72	1.88	8.59 (18)
Mean	1502.28				40.84			
SD	1084.94				23.21			
CV (%)	72.22				56.84			

Numbers in parenthesis are ranks of varieties for each disease score. AUDPC = Area under Disease Progress Curve, Severity = late blight disease severity score as percentage, IPCA 1 and IPCA 2, interaction principal component axis one and two, respectively, ASV = AMMI stability value, SD = standard deviation and CV (%) = coefficient of variation in percent.

Table 9c. Stability parameters from AMMI model for rAUDPC and late blight susceptibility value of 18 potato varieties tested at four environments.

	rAUDPC				SS value			
Variety	Pooled mean	IPCA 1	IPCA 2	ASV	Pooled mean	IPCA 1	IPCA 2	ASV
Al-624	0.28 (5)	0.24	-0.05	7.32 (9)	1.63 (8)	0.12	0.11	0.26 (2)
Chirro	0.81 (15)	-0.41	-0.30	12.39 (13)	4.23 (16)	-1.20	-0.39	2.38 (16)
Zemen	0.98 (16)	-0.88	-0.04	26.35 (18)	4.21 (15)	-1.12	0.43	2.23 (15)
Bedasa	0.54 (12)	-0.09	-0.01	2.75 (4)	2.81 (13)	-0.09	0.02	0.18 (1)
Guasa	0.38 (8)	0.09	-0.24	2.70 (3)	2.02 (10)	-0.57	-0.22	1.13 (8)

Gorebela	0.43 (9)	-0.10	0.02	3.03 (5)	1.80 (9)	-0.12	0.22	0.32 (4)
Jalenie	0.49 (11)	-0.17	-0.15	5.17 (7)	2.13 (11)	-0.65	0.13	1.27 (10)
Gera	0.15 (2)	0.43	0.05	12.79 (14)	1.05 (5)	0.59	-0.03	1.15 (9)
Chala	0.62 (14)	-0.27	-0.17	8.13 (10)	2.97 (14)	-0.76	0.06	1.49 (12)
Bulle	0.06 (1)	0.47	0.12	13.94 (15)	0.39 (1)	0.78	0.31	1.55 (13)
Gabbisa	0.48 (10)	-0.12	0.07	3.49 (6)	2.17 (12)	0.03	0.26	0.27 (3)
Mara Charre	0.30 (6)	0.05	0.04	1.51 (2)	1.19 (6)	0.09	0.34	0.38 (5)
Gudanie	0.16 (3)	0.40	-0.03	12.12 (12)	1.02 (4)	0.35	-0.06	0.69 (6)
Araarsaa	0.34 (7)	0.00	0.21	0.25 (1)	1.36 (7)	0.51	0.50	1.12 (7)
Belete	0.17 (4)	0.22	0.14	6.53 (8)	0.54 (3)	0.52	0.54	1.15 (9)
Bubu	0.06 (1)	0.47	0.06	14.20 (16)	0.40 (2)	0.64	0.22	1.27 (10)
Jarso	1.28 (17)	-0.67	0.40	20.04 (17)	7.33 (17)	0.63	-0.77	1.45 (11)
Batte	0.55 (13)	0.34	-0.13	10.12 (11)	4.23 (16)	0.24	-1.65	1.72 (14)
Mean	0.45				2.31			
SD	0.32				1.78			
CV (%)	71.91				77.04			

Numbers in parenthesis are ranks of varieties for each disease score. rAUDPC = Relative Area under the Disease Progress Curve, SS values = late blight disease susceptibility score values, IPCA 1 and IPCA 2, interaction principal component axis one and two, respectively, ASV = AMMI stability value, SD = standard deviation and CV (%) = coefficient of variation in percent.

Relationship between year of release and varieties disease scores

The 16 improved potato varieties were released mainly for tuber yield and late blight resistance that can be grouped into nine depending on the year of variety release (1997 to 2011). The varieties were released by five research centers and Haramaya University (Table 1) for the respective Agroecology the centers are located. The successive years of variety release not showed continuous progress in releasing of better resistant varieties than the older ones. The varieties released from 1998 to 2002 had highest disease scores than the oldest variety (Table 10 and Figure 1) while varieties released from 2003 to 2006 and the oldest variety (AL-624) had intermediate mean disease ratings. The recently released varieties (2009 and 2011) had the lowest mean disease ratings. The general trend showed that the varieties release during three successive years of variety release after the first potato variety release (1987) become susceptible and varieties release during three successive years after 2002 become moderately resistant to late blight (Table 10). The national potato research program or research centers were capable to release resistant varieties during the last two successive years of variety release.

Table 10. Mean late blight disease ratings of potato varieties in nine subsequent years of release tested at four environments.

No.	Year of release	Number of varieties	AUDPC	SS value	Severity	Onset of disease	rAUDPC	I (%)	RC
1	1987	1	961	1.63	30.58	48.33	0.28	36	M
2	1998	1	2725	4.23	73.33	46.17	0.81	80	S
3	2001	2	2515.5	3.51	61.88	48.42	0.76	69	S
4	2002	3	1422.33	1.98	36.25	60.22	0.43	46	S
5	2003	1	533	1.05	22.92	55.5	0.15	27	M
6	2005	4	1206.5	1.68	33.04	58.12	0.36	36	M
7	2006	2	827	1.194	30.83	53.835	0.2488	33	M
8	2009	1	542	0.54	15.33	71.33	0.17	16	R
9	2011	1	210	0.40	9.58	66.33	0.06	11	R
LSD (5%)			332.20	0.26	3.37	5.55	0.11		

AUDPC = Area under Disease Progress Curve, SS values = late blight disease susceptibility score values, Severity = late blight disease severity score as percentage, Onset of disease =days to onset of late blight disease, rAUDPC = Relative Area under the Disease Progress Curve, I (%) = disease intensity in percent, RC = disease resistance category, S =susceptible, M = moderately resistant, R = resistant, and LSD (5%) =least significant difference at P<0.05.

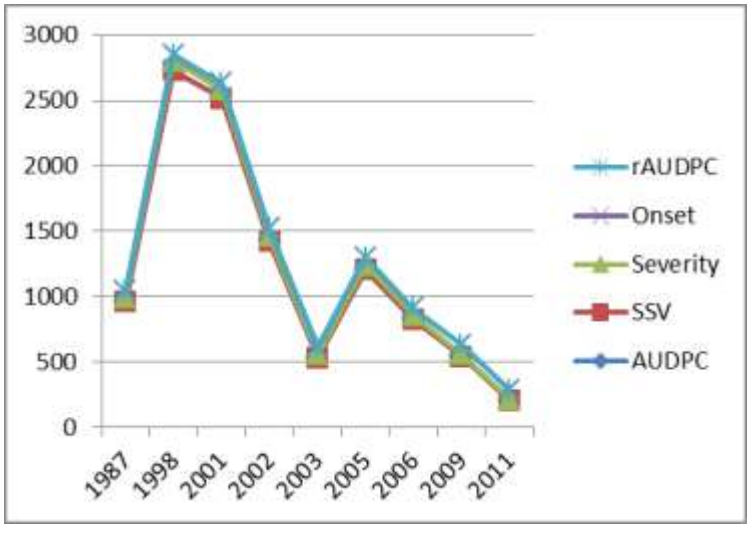

Figure 1. Trends in reducing mean disease scores in potato varieties released during nine years of variety release (1987 to 2011).

Cyclic trend of increased and then reduced was observed in all the disease ratings in varieties released in successive years of variety release (Figure 1). Therefore it was necessary to conduct regression analysis to evaluate the general trend in reducing the disease ratings in varieties released in successive years. The results are presented as scatter plot figure that showed the reduced disease ratings except days to onset of late blight disease over years of variety release (Figure 2a to 2d). The correlation coefficient between years of variety release and three disease ratings (AUDPC, late blight disease severity rating as percentage and late blight disease susceptibility rating) was negative and nonsignificant ranged from r =-0.35 to -0.42. The correlation between years of variety release and days to onset of late blight disease was positive and strong (r =0.52). On average, 12% (R^2 =0.12) to 27% ((R^2 =0.27) variations in reduction of disease ratings in potato varieties released in nine successive years were due to the breeding efforts made to release varieties with better resistance to late blight.

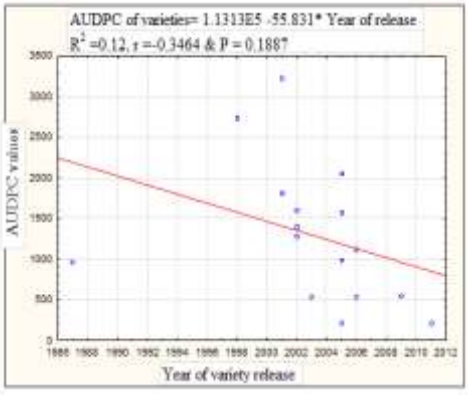

Figure 2a. AUDPC

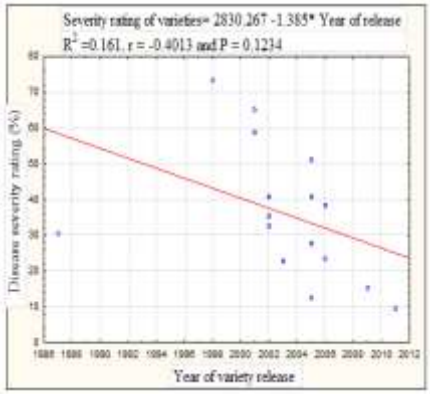

Figure 2b. Disease severity rating

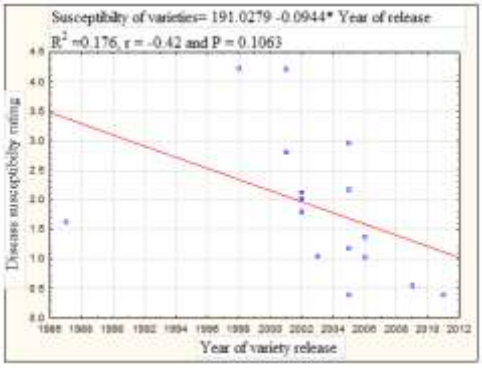

Figure 2c. Susceptibility of varieties for late blight disease

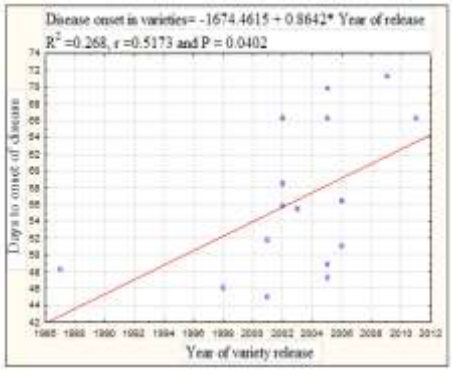

Figure 2d. Days to disease onset in varieties

Figure 2a-d. Late blight disease ratings in 18 potato varieties against to year of variety release.

4. Discussion

Highly significant differences among potato varieties for late blight resistance showed the presence of wide variations among the varieties for the reaction to the disease. The combined analysis of variance over locations and seasons also showed the significant influence of location, season, and genotype x location and genotype x season interactions on all disease scores of varieties indicating the differential response of varieties to resist the disease across locations and seasons. The presence of genetic variations among the released varieties for late blight resistance was reported (Wassu, 2014) and other authors also reported the significant influence of environment and genotype x environment interactions on late blight resistance of potato cultivars (Flis *et al.*, 2014; Mulugeta, and Dessalegn, 2013; Mulema *et al.*, 2008; Mateo *et al.*, 2007).

Varietal and the environment (locations and seasons) differences were more important than genotype x environment interaction (GEI) for the observed variations among varieties for all disease ratings except for days to onset of late blight disease. The inherent resistant to disease character of varieties and environment were most important three and two disease ratings, respectively. The GEI effect was more important than environment for days to onset of late blight disease. However, the highest contribution of IPCA 1 sum square (51.8 to 95.86%) to GEI sum square in all disease scores indicating the resistance gene(s) the varieties carry was more important to be resistant to late blight disease. Variations among different potato varieties in resistance to late blight due to varied major dominant resistance genes (***R*** genes) have been reported by several researchers (Stewart *et al.,* 2003; Wastie, 1991). Gebremedhin (2013) also reported that potato varieties in Ethiopia possess varied R-genes for vertical resistance or unknown resistance major R genes along with genes for horizontal resistance to late blight. The potato cultivars with varied R-genes for the resistance of late blight results differential level of field resistance at different environments (Stewart *et al*., 2003). This is because the varieties cultivated as resistant to late blight in different parts of the country may not be resistant in other areas due to the environment favorable to the pathogen (Wassu, 2014). Potato varieties with R-gene (s) may be considered resistant to late blight in one area because the meteorological conditions are not suitable to the pathogen to occur (Hansen *et al*., 2005).

This research results demonstrated the importance of testing varieties over varied locations and seasons though the highest contribution to be resistant was due to the gene(s) the variety carry. The pathogen spreads like a wild fire under congenial weather conditions and destruct potato within a few days when the environment is conducive (Sundaresha *et al*., 2014; Bekele and Hailu, 2001). The pathogen develops most rapidly at low temperatures and high humidity but if the mean atmospheric temperature exceeds 25^0C, in area with extended dry periods or rapid dehydration can quickly kill many sporangia (Fry and Mizubuti*,* 1998) and the disease is rare or unknown. This suggested the importance of identifying areas in the country where the environment favor the pathogen and testing potato genotypes in these areas to recommend as resistant variety to late blight disease. A group of scientists have opinioned that it is necessary to apply a few methods for potato cultivars evaluation for susceptibility to the late blight such as testing of all cultivars in areas where the environment favors the pathogen (Lee *et al*., 2001). Direct selection for stress conditions is more effective in the same environment than selection for the mean of both favorable and unfavorable environments (Kirigwi *et al*., 2004; Cecarelli *et al*., 1998; Calhoun *et al*., 1994). Analyzing the late blight resistance helps not only to determine differences in disease development among various potato cultivars, but also to find differences in the same potato cultivar every separate research year (Razukas *et al*., 2008). This may suggested nationally coordinated joint efforts of breeders to identify potato genotypes resistant to late blight disease in areas where the environment favor the pathogen as opposed to the past potato breeding approach in developing varieties by several research centers independently for different agro-ecologies.

The contribution of GEI on most of the disease scores of varieties is small as compared to the contribution of genotype and environment. However, it was suggested the evaluation of breeding materials across environments is the must if significant effect of GEI was evident on their performance that helps to select varieties that perform well consistently in all environments or to identify specific varieties for each environment (Gauch, 2006). It was also suggested the differential disease resistance ranks of varieties may be due to the presence of crossover GEI (Kang, 2002) and direct comparison of new and old varieties for yield/disease resistance at one location may not be good indicator of the contribution of the specific varieties to the productivity of the crop (Silvey, 1981). However, in the case of selection for stress conditions, the presence of genotype x environment interaction is greatly challenged the breeders. Therefore, the breeders would be more effective by direct selection of varieties in the same stress environment than selection for the mean of both favorable and unfavorable environments (Kirigwi *et al*., 2004; Cecarelli *et al*., 1998; Calhoun *et al*., 1994).

The reactions of varieties to late blight disease across locations were quite varied. On the basis of mean values the three varieties (Bubu, Belete and Bulle) were identified as resistant and other five varieties (Alemaya 624, Jalenie, Gera, Mara Charre & Gudanie) were evaluated as moderately resistant to late blight disease. But only the two varieties (Bubu and Bulle) were found as resistant while the four varieties (Belete, Alemaya 624, Gera, & Gudanie)were identified as moderately resistant to the disease at Haramaya in 2014 when the disease pressure was higher than during 2013 at all locations. Other than the four varieties (Bulle, Alemaya 624, Gera, & Gudanie) all varieties released before 2009 became susceptible to late blight disease at Haramaya in 2014. This might be due to the genetic structure of the genotypes with low levels of heterogeneity for resistance or they may not carry as many resistant R genes or the resistance gene were overcome by the pathogen or varieties were considered as resistant in the absence of the races or where the environment was not favorable for the pathogen (Beukema and Van Der Zaag, 1979). Therefore, testing of varieties in areas where the environment favors the pathogen (Lee *et al*., 2001) is sound recommendation to identify resistant varieties. The four older varieties became resistant and moderately resistant to the disease may be due to the resistant gene(s) they carry and pathogen interaction in that location. In the favorable conditions for infection and disease development, a plant may develop no disease, only mild disease, or severe disease, depending on the specific genetic makeup of the plant and of the pathogen that attacks it. The variety developed as horizontal resistance may be susceptible because the resistance may also be contributed by *R* genes that have residual effects against virulent pathogens or defeated *R* genes (Gebhardt, 2013).

In most cases, the varieties identified as susceptible to late blight disease across locations and seasons had lowest ASV, IPCA 1 and IPCA 2 scores for most of disease scores except Gera, Bulle and Bubu had the lowest ASV, IPCA 1 and IPCA 2 scores for days to onset of late blight disease. The varieties with lower ASV indicate the more stable (Purchase, 1997). The more the IPCA scores approximate to zero, the more stable the genotypes are over all environments sampled (Tarakanovas and Ruzgas, 2006; Gauch and Zobel, 1988). The more the stable the varieties with high mean

values above the average for all disease scores suggested the varieties were susceptible to late blight disease in all environments and not to be considered for cultivation. The stability alone has not practical utility as far as the varieties have low mean over environments (Dabholkar, 1998). On the other hand, high mean performance of the variety could not be the only criterion for selection since growing of varieties with performance is an advantage for farmers to obtain larger harvest due to large genotypic effect and small genotype x environment interaction (Flis *et al.*, 2014). In addition to these, selection of varieties for disease resistance/stress better to be based on the reaction to the disease in the environment favorable to the pathogen than selection for the mean of both favorable and unfavorable environments (Kirigwi *et al.*, 2004; Cecarelli *et al.*, 1998; Calhoun *et al.*, 1994). Therefore, the three varieties (Bubu, Bulle and Belete) could be recommended as resistant varieties over locations and seasons.

The general trend of developing more resistant varieties than older varieties in successive years of variety release is encouraging. However, the relationship between years of variety release and reduction of disease scores was not strong and highly significant differences were observed among the varieties for late blight resistance across locations and seasons. Not only among the varieties released by different centers for different agroecologies at different years observed significant differences for disease reaction at different locations and seasons but also among the varieties released by same centers during same years of release. Only the days to onset of disease showed positive and strong correlation with years of variety release. This indicated that potato breeders in the country were consistently selected genotypes with delayed late blight onset to release as varieties. Therefore, if national potato program consider the resistant varieties as better option to reduce yield loss due to late blight disease, it is necessary to identify environments favorable to the pathogen in the country and test potato genotypes for their reaction to the pathogen before they are released as varieties. This suggestion is supported by many researchers in case of selection of varieties for stress resistance such as late blight disease (Razukas *et al.*, 2008; Kirigwi *et al.*, 2004; Lee *et al.*, 2001; Cecarelli *et al.*, 1998; Calhoun *et al.*, 1994).

5. Summary and Conclusion

The potato varieties under cultivation in Ethiopia had significant variations for late blight resistance. Most of the varieties showed differential response to the disease across locations and seasons indicating the significant effect of environment and genotype x environment interaction (GEI) on disease ratings of varieties. However, late blight resistance of varieties was mainly a function of genetic factor and suggested the importance of selection resistant varieties in area where the environment is favourable to the pathogen along with mean ratings over location than selecting varieties based only on mean performance of varieties across locations and seasons. The three varieties (Bulle, Bubu and Belete) were evaluated as resistant to late blight disease. The varieties released in successive years of variety release were for delayed onset of disease but releasing of more resistant varieties was not consistent in successive years of variety release. This suggested the importance of selecting genotypes in areas favourable for the

pathogen to release as late blight disease resistant varieties rather than releasing varieties for each Agroecology areas. Generally, it is possible to recommend Bubu, Bulle and Belete for potato production in eastern Ethiopia even under high pressure of late blight.

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15. Multitraits Evaluation and Trends of Potato (*Solanum tuberosum* L.) Varieties Selection in Ethiopia (1998 to 2011)

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Abstract: Periodical evaluation of potato varieties for consistent rate of gain for yield and the fitness of varieties for the emerging economics of production in the country is necessary. However, such studies have not been conducted in Ethiopia, therefore, this study was conducted with the objectives to: i) identify potato varieties that fit all purpose end uses with other desirable agronomic traits, ii) evaluate the similarities, differences and consistency of variety selection criteria across research centers, and iii) estimate relative annual genetic gain rates for selected traits within and between varieties released by different research centers. A total of 16 potato varieties were released by five research centers and Haramaya University, and two local cultivars were evaluated for 58 traits at three locations starting 2011 to 2015 in eastern Ethiopia using randomized complete block (RCBD) and completely randomized block (CRD) designs with three replications. Analysis of variance results revealed the presence of significant differences among varieties for 51 (87.93%) out of 58 quantitative traits. The varieties were grouped under four clusters of which Cluster I subdivided into distinct Subgroup I and II consisted 5 and 4 varieties, respectively. Cluster II and IV each consisted of 4 varieties while Cluster III constructed with two farmers' cultivars and one improved varieties. The clusters consisted varieties released by different centers at different years. Varieties (Belete, Gera, Bubu and Gudanie) under Cluster IV were released from 2003 to 2011 by three centers and Haramaya University had highest mean values 37 (78.72%) of 47 quantitative traits in desired directions. The varieties had mean total and marketable tuber yield advantage of 48.55 and 67.28%, respectively, over the overall mean yield of varieties. The tubers of these varieties had physical and internal quality traits fit to all-purpose use except Belete due to its high dry matter content of tubers turned the chips color to white and made chips brittle. Potato variety selection at Holeta Center was consistent on the basis of increased mean values of tuber yield, yield related traits, tuber internal and physical quality traits, and resistant to late blight. The center was selecting varieties consistently with reduced number of tubers per hill but increased tuber size and weight. But other varieties released by centers (Haramaya, Hawassa and Adet/Sheno) lack

such consistent increase of mean values in successive released varieties even reduced in varieties released by Sinana agriculture research center. The overall mean relative annual genetic gain (RGG) was 5.08 and 5.38% for total tuber and marketable tuber yield, respectively. The RGG for tuber length, width and weight was also positive, and susceptibility of the varieties to late blight was reduced. However, mean RGG of 6.92 and 9.1% for total and marketable tuber yield, respectively, was highest for varieties released by Holeta agriculture research center. All other varieties released by other centers did not show consistent RGG for most of the traits as varieties released by Holeta. The research results suggested the strengthening of collective efforts of centers in selecting wide adaptable varieties in the country with a chance of selecting varieties adaptable to specific agroecologies in the process.

Keywords: All-purpose use; Cluster; Internal tuber quality traits; and Relative annual genetic gain

1. Introduction

Potato is introduced in Ethiopia was in 1858 (Pankhurst, 1964) but the adoption by farmers occurred very gradually for several decades (Kidane-Mariam, 1980). In 1975, the average yield was estimated 5 t ha^{-1} with the estimated 30,000 hectares of cultivated land (Medhin *et. al.* 2001). The late blight disease caused by the fungus *Phytophthora infestans* (Mont.) de Bary was widespread in the country in the early 1980s which resulted the declining of potato cultivation. The first organized potato research in Ethiopia was started in 1975 at Haramaya University and the first improved variety was released in 1987 (Alemaya 624). Since then, Haramaya University has released other six varieties and more than 23 varieties were released by other research centers (Gebremedhin, 2013**).** The varieties were developed for high yield and resistant to late blight. The high production of potato is serving to ensure food security in less developed country. In Ethiopia, the production and area covered with potato is increasing more than any other crop. Potato production reached to 3.66 million tons from 0.3 million hectares in 2015 as compared to 974 thousand tons from 0.16 million hectares in 2001 and number of households growing from 1.5 million in 2001to over five million in 2015 with average yield of 12.66 t ha^{-1}(CSA, 2016).

The strategic research for potato variety development and other agronomic managements began in 1975 (Gebremedhin, 2013).Starting the release of the first potato variety (1987) to 2013, potato varieties were released for high yield production to all-purpose use by different research centers and Haramaya University in their respective recommendation domains (Baye and Gebremedhin, 2013; MoA, 2013).Therefore, it is not far from truth to assume the variety development research has the lion share contribution for the observed double increase of the national average yield within three decades. The breeders at different research centers were developing varieties for their respective recommendation domains (agroecologies) as they evaluated the successive

varieties had better yield and resistant to late blight disease (Baye and Gebremedhin, 2013; Gebremedhin, 2013). The potato varieties developed in Ethiopia were through selection of germplasm obtained in the form of advanced clones, tuber families, and true potato seed from International Potato Center (CIP) breeding program in Peru (Gebremedhin, 2013) indicating all potato breeders in the country have the same source of germplasm. The introduced potato genotypes are available through the national coordination and breeders at different centers have less chance to obtain germplasm other the CIP materials distributed through national coordination.

All the breeders in the country have common objectives of selection of high yielding potato varieties and resistant to late blight disease. Potato varieties considered resistant to late blight in one area may not be resistant in other area(s) because the meteorological conditions are not suitable to the pathogen to occur (Hansen *et al.*, 2005). The pathogen *P. infestans* is an extraordinarily virulent and adaptable pathogen that overcomes resistance gene(s) in a short period of time (Haas *et al.,* 2009; Fry, 2008). Due to this considerable number of the varieties in Ethiopia have become susceptible to late blight and, hence, gone out of production (Gebremedhin, 2013; Wassu, 2014). A group of scientists suggested potato cultivars evaluation for susceptibility to the late blight in areas where the environment favors the pathogen (Lee *et al.*, 2001). Other researchers also suggested for stress conditions, direct selection is more effective in the same environment than selection for the mean of both favorable and unfavorable environments (Kirigwi *et al.*, 2004; Cecarelli *et al.*, 1998; Calhoun *et al.*, 1994). Therefore, the question is that the varieties released as resistant to late blight disease in different Agroecology could serve the purpose in the country due to planting material exchange of farmers by different means and the disease occurs almost everywhere where potatoes are grown and if not controlled, yield losses may reach 100 percent (Rubio-Covarrubias *et al.*, 2005). Therefore, periodic evaluation of potato varieties for yield, resistant to late blight disease and other desirable traits is necessary to assess breeding progress over time in the country as a whole and in different parts of the country by different research centers. Therefore, this research was conducted, i) to identify potato varieties fit all purpose or specific end use with other desirable agronomic traits, ii) to evaluate the similarities, differences and consistency of variety selection criteria across research centers, iii) to assess the genetic divergence of potato varieties developed by different research centers and Haramaya University, and iv) to estimate relative annual genetic gain rates for selected traits within and between varieties released by different centers

Description of the Study Sites

The field experiment was carried out at three locations namely; Haramaya, Hirna and Arberkete which are considered the representative potato growing areas of eastern Ethiopia. The research was conducted starting from 2011 to 2015 in which the experiment was conducted for two cropping seasons (2011 and 13) in all the three locations. In addition, at Haramaya, potato varieties were additionally evaluated during 2014 and 2015 cropping seasons. This made the total of eight environments considering one location and one cropping season as one environment.

Haramaya University research farm is located at 2022 m.a.s.l., 9°41"N latitude and 42°03"E longitude. The area has a bimodal rainfall distribution with mean annual rainfall of 760 mm. The long rainy season extends from June to October and accounts for about 45% of the total rainfall. The mean maximum temperature is 23.4^{0}C while the mean minimum annual temperature is 8.25^{0}C. The soil of the experimental site is a well-drained deep alluvial with a sub-soil stratified with loam and sandy loam. Hirna sub-station is situated at a distance of about 134 km to the west of Haramaya. The site is located at 9 °12' North latitude, 41 °4'East longitude, and at an altitude of 1870 meters above sea level. The area receives mean annual rainfall ranging from 990 to 1010 mm. The average temperature of the area is 24.0° C (Tekalign, 2011). The soil of Hirna is vertisol (HURC, 1996). Arberekete field experiment was conducted on a farmer's filed, which is located at a distance of about 171 km to the west of Haramaya. The site is located at 9 °14' North latitude, 41 °2'East longitude, and at an altitude of 2280 meters above sea level.

Experimental Materials

The experiment included 16 improved potato varieties released for different regions of Ethiopia by five Research Centers and Haramaya University that are under cultivation, one old variety (Alemaya 624) out of cultivation and two farmers' varieties were included for comparison purpose (Table 1).

Table 18. Name, accession code, year of release, breeding/maintainer center of potato varieties

No	Variety Name	Accession Code	Year of release	Average yield t ha^{-1} at RC	Breeding center	Recommended Altitude (m a.s.l.)
1	Alemaya 624	Al-624	1987	-----	Haramaya University	1700 - 2400
2	Chirro	AL-111	1998	37.2	Haramaya University	2700 - 3200
3	Zemen	AL-105	2001	28.7	Haramaya University	1700 - 2000
4	Bedasa	AL-114	2001	40.6	Haramaya University	2400 - 3350
5	Gorebela	CIP-382173.12	2002	41	Sheno Research Center	1700 - 2400
6	Guasa	CIP-384321.9	2002	36	Adet Research Center	2000 - 2800
7	Jalenie	CIP-37792-5	2002	40.3	Holeta Research Center	1600 - 2800
8	Gera	KP-90134.2	2003	47.2	Sheno Research Center	2700 - 3200
9	Chala	CIP-387412-2	2005	42	Haramaya University	1700 - 2000
10	Bulle	CIP-387224-25	2005	39.3	Hwassa Research Center	1700 - 2700
11	Gabbisa	CIP-3870-96-11	2005	40	Haramaya University	1700 - 2000
12	Mara Charre	CIP-389701-3	2005	33.3	Hwassa Research Center	1700 - 2700
13	Gudanie	CIP-386423.13	2006	29	Holeta Research Center	1600 - 2800

14	Araarsaa	CIP-90138.12	2006	31	Sinnana Research Center	2400 - 3350
15	Belete	CIP-393371.58	2009	47.2	Holeta Research Center	1600 - 2800
16	Bubu	CIP-384321-3	2011	40.5	Haramaya University	1700 - 2000
17	Moti	KP-90147-41	2012	42.7	Sinnana Research Center	2400-3350
18	Bete	Local cultivar				
19	Jarso	Local cultivar				

Source: Ministry of Agriculture (MoA, 2013 and 2012). Average yield t ha^{-1} at RC = Average total tuber yield t ha^{-1} at research center during release of varieties and m a.s.l = Meters above sea level.

Experimental Design and Procedures

The potato varieties were evaluated for; i) tuber yield and yield related traits starting 2012 to 2015, ii) tuber processing and quality related traits during 2011 at three locations, iii) tuber processing and quality related traits after storage in 2013 at Haramaya, and iv) late blight disease resistance it was conducted for one cropping season in 2013 in all the three locations and it was conducted in 2014 at Haramaya in which the location was identified as favorable environment for late blight. In all seasons and evaluations, the experiment was laid out as a Randomized Complete Block Design (RCBD) with three replications in each location and season. Each potato variety was assigned to one plot in each replication and six rows with 12 plants. The gross plot size was 16.2 m^2 with 75 and 30 cm between rows and within plant spacing, respectively. The spacing between plots and replications was maintained at1.5m and 1m, respectively. For yield estimation, tubers were harvested from forty plants from the four middle rows, leaving the plants growing in the two border rows as well as those growing at both ends of each row to avoid edge effects.

The experimental fields were cultivated by a tractor toadepthof25-30 cm and ridges were made by hand. Medium sized (39-75g) and well sprouted tubers were planted at the sides of ridges (Lung'aho *et al.*, 2007). Planting was at the end of June and first week of July during the main growing season after the rain commenced and when the soil was moist enough to support emergence. The planting depth was maintained at 5 to 10 cm. The whole recommended rate of Phosphorus fertilizer (92 kg P_2O_5 ha^{-1}) was applied at planting in the form of Diammonium Phosphate (DAP). Nitrogen fertilizer was applied at the rate of 75 kg N ha^{-1} in the form of Urea in two splits, half rate after full emergence (two weeks after planting) and half rate at the initiation of tubers.

Data Collection

Potato varieties were evaluated for a total of 58 traits during different experiments which are grouped in nine and list of traits is presented in Table 2. All data were collected according to the CIP guideline, IPGRI, and national potato data collection and measurements.

Table 2. List of 58 traits of potato varieties categorized into nine major groups of traits

Major trait group	Individual trait	Major trait group	Individual trait
	Days to 50% flowering		Peel content (%)
	Days to 90% maturity	5. Tuber physical Quality	Tuber geometric diameter (mm^3)
1. Phenology and growth	Plant height (cm)		Tuber sphercity (%)
	Main stem number per hill		Tuber surface area (mm^2)
	Leaf area index		Tuber length (mm)
	Tuber bulking rate		Tuber width (mm)
	Marketable tuber number		Length/width ratio
2. Yield and yield components	Unmarketable tuber number	6. Tuber qualitative traits	Tuber shape
	Total tuber number per hill		Tuber eye depth
	Above ground dry mass (g)		Tuber skin color
	Underground dry mass (g)		Tuber flesh color
	Small number tubers (%)		Total soluble solid (^{0}Brix)
	Medium size tubers number (%)	7. Tuber sugar content at different storage period	pH
	Large size tubers number (%)		Total sugar (%)
	Harvest index (%)		Reducing sugar (%)
	Total tuber yield t ha^{-1}	8. Chips quality of tubers	Chips sweetness
	Marketable tuber yield t ha^{-1}		Chips saltiness
	Unmarketable tuber yield t ha^{-1}		Chips sourness
	Average tuber weight (g)		Chips bitterness
3. Late blight	Disease severity		Chips color

disease	(%)		
	Disease intensity (%)		Chips crispness
	Disease susceptibility score		Chips flavor
	AUDPC		Chips texture
			Chips overall acceptance score
	Resistant level		
	Tuber dry matter content (%)		Initial tuber sprouting days
4. Tuber internal quality related traits	Specific gravity of tuber (g^{cm-3})	9. Storage of characters of tubers	Final tuber sprouting days
	Starch content (g/100g)		Initial tuber weight (g) at storage
			Intermediate tuber weight (g) at storage
			Final tuber weight (g) at storage
			Total tuber weight loss (g)

Data Analysis

All quantitative data were subjected to analysis of variance (ANOVA) for each location and combined over environments following the standard procedure for randomized complete block design (RCBD)and completely randomized design (CRD) given by Gomez and Gomez (1984) using the General Linear Model (GLM) of the SAS procedure of version 9.1 (SAS, 2007). Least significant difference (LSD) at 5% probability was computed to compare the mean values of the varieties for quantitative traits. However, all the ANOVA results of each location and over locations were not presented for two reasons, i) the results were reported in three MSc theses, six articles and five manuscripts of annual research report, and ii) the results had little importance to evaluate the breeding efforts and to estimate genetic dissimilarity of potato varieties since these analyses were depending on the mean performance of varieties. Therefore, for the experiments conducted over locations and seasons, the ANOVA results were conducted based on the pooled mean values of each variety in each replication over locations and seasons. Data collected for qualitative traits were subjected to descriptive statistics.

Genetic distance of 18 potato varieties was estimated using Euclidean distance (ED) calculated from mean values of genotypes for 51 quantitative traits. Euclidean distance matrixes for 153 pair varieties were calculated from quantitative traits after

standardization (subtracting the mean value and dividing it by the standard deviation) as established by Sneath and Sokal (1973) as follows:

$$EDjk = \sqrt{\sum_{i=1}^{n}\left(Xij - Xik\right)^{2}}^{\frac{2}{2}}$$

Where, EDjk = distance between varieties j and k; xij and xik = phenotype traits values of the i^{th} character for varieties and k, respectively; and n = number of phenotype traits used to calculate the distance. The distance matrix from phenotype traits was used to construct dendrogram based on the Unweighted Pair-group Method with Arithmetic Means (UPGMA). The results of cluster analysis was presented in the form of dendrogram. Mean Euclidian distances of each variety to other 17 varieties were calculated from the 153 pairs of varieties. This was calculated as the average distance between the value of particular variety to other 17 varieties to understand which varieties were most distant and closest to others.

Regression analysis was used to calculate the genetic gain of yield potential and disease resistance (disease severity reduction) over years of variety release. The average annual rate of genetic gain for each trait was estimated by regressing of the mean value of each trait against the corresponding year of release of each variety (Singh and Chaudhary, 2007). Regression analysis was also used to estimate disease severity as cause of genetic gain in tuber yield. In this regression analysis tuber yield and disease severity were considered as dependent variable while years of variety release was considered as independent variables. Correlation of year of release and mean value of each variety for each trait was also calculated to understand the association of year of release and the mean performance of varieties. The annual rate of genetic gain achieved over the last 25 years of potato improvement was determined as the ratio of genetic gain to the corresponding mean value of the oldest variety and expressed as a percentage.

Annual rate of gain = Cov (X, Y)/Var (X), where, Xis the year of variety release, Yis the mean value of each trait for each variety; Cov is the covariance of X and Y and Var is variance of X (year of variety release). Percent genetic gain per year for each variety was calculated as Percent Genetic Gain $Year^{-1}$ = {[(XG-XAL-624)/XOL]/YG-YAL-624*100, where, X is the mean value of observations for a given trait and Y is the year of release of each variety (G). The increment over farmers' cultivars for each trait was calculated as Percent Increment of Variety (%) = XG – XFC/XFC*100, where, XG is the mean value of each variety for each trait and XFC is the mean value of the two farmers' varieties (Jarso and Batte) in eastern Ethiopia. In this experiment, the oldest variety in each group of varieties was identified and Alemaya 624 the first variety released in the country in 1987 was considered as the oldest variety.

2. Results

Analysis of Variance

The analysis of variance conducted for each location, season and over locations and seasons years indicated the presence of significant differences among potato varieties for quantitative traits. The growing year and interaction of genotype x year also had significant influence on all traits except few processing quality parameters (data presented in different publication). The analysis of variance conducted based on the pooled mean values of each variety in each replication over locations and seasons also showed significant differences among potato varieties for quantitative traits (Table 3 and Table 4).

The 19 potato varieties had similar tuber flesh color (cream) and all varieties had white skin color except one variety (purple yellow). The varieties were grouped into 8 and 7 categories of tuber shape and tuber eye depth, respectively. Of which 4 (21.05%) and 5 (26.32%) varieties were grouped under long oval and oval to long tuber shape, respectively, four varieties each grouped under medium and medium to shallow tuber eye depth and five varieties grouped under shallow eye depth. The remaining varieties were distributed 6 and 4 categories of tuber shape and tuber eye depth, respectively, one (5.26%) to three (15.79%) varieties under each category (Table 5).

Table 3. Mean squares from pooled mean analysis of variance for 25 traits of 18 potato genotypes measured from field experiment (randomized complete block design).

Trait	Replication (2)	Genotype (17)	Error (34)	CV (%)
Days to 50% flowering	8.9	108.33**	2.2	3.07
Days to 90% maturity	1.33	515.44**	0.79	0.89
Plant height at flowering (cm)	3.3	392.33**	9.5	5.07
Main stem number per hill	0.55	12.38**	0.49	14.05
Leaf area index	0.15	3.65**	0.32	17.15
Marketable tuber number per hill	1.78	33.18**	2.36	14.8
Unmarketable tuber number per hill	0.13	12.61**	0.27	15.5
Total tuber number per hill	2.77	50.94**	1.42	8.68
Above ground dry mass (g)	108.65	1316.28**	24.61	10.66
Underground dry mass (g)	1061.83	23334.99**	3757.01	29.48
Small number tubers per hill (%)	9.02	820.26**	19.31	11.57
Medium size tubers number per hill (%)	14.36	88.86**	16.68	13.96
Large size tubers number per hill (%)	44.99	893.52**	13.08	11.04
Harvest index (%)	0.0096	0.0192**	0.0019	5.332
Disease severity (%)	213.27	2145.98**	68.32	16.4
Disease intensity (%)	169.44	2142.90**	73.61	16.1
Disease score	0.4286	3.83**	0.312	16.8

AUDPC	135887	2148278**	73263	20.5
Total tuber yield t ha^{-1}	69.99	212.50**	23.05	20.3
Marketable tuber yield t ha^{-1}	68.06	269.72**	20.06	22.5
Unmarketable tuber yield t ha^{-1}	0.464	9.629**	1.571	23.2
Average tuber weight (g)	16.25	992.23**	79.97	12.5
Tuber dry matter content (%)	1.18	35.50**	1.34	4.6
Specific gravity of tuber (g^{cm-3})	0.000558	0.0067342**	0.00107	0.3
Starch content (g/100g)	0.22	26.69**	0.42	4.4

** and **, significant at P<0.05 and P<0.01, respectively.*

Table 4. Mean squares from pooled mean analysis of variance for 26 traits of 18 potato varieties measured from laboratory experiment and panelist evaluation (completely randomized block design).

Trait	Genotype (17)	Error (34)	CV (%)
Peel content (%)	16.57**	2.239	9.28
Tuber geometric mean diameter (mm^3)	6198.4**	43.63	11.81
Tuber sphercity (%)	1122.3**	27.13	6.52
Tuber surface area (mm^2)	830836564**	5661983	18.35
Total soluble solid (^{0}Brix)	1.7788**	0.33	8.66
pH	0.0997*	0.02	1.92
Total sugar (%)	0.1106**	0.0092	21.54
Reducing sugar (%)	0.0142**	0.0012	19.59
Chips sweetness	1.24**	0.197	19.21
Chips saltiness	0.559**	0.172	21.53
Chips sourness	0.538**	0.213	26.97
Chips bitterness	1.114**	0.239	30.68
Chips color	34.18**	0.219	18.22
Chips crispness	7.3525*	0.183	16.93
Chips flavor	4.717**	0.221	15.22
Chips texture	1.623**	0.237	17.79
Chips overall acceptance score	2.2126*	1.289	16.05
Tuber length (mm)	279.76*	39.73	9.4
Tuber width (mm)	123.12*	30.08	10.1
Length/width ratio	0.028000*	0.006	6.2
Initial tuber sprouting days	145.076*	3.581	4.88
Final tuber sprouting days	328.483*	4.044	2.23
Initial tuber weight (g) at storage	1142.57*	3	2.55
Intermediate tuber weight (g) at storage	1126.22*	1.98	2.13
Final tuber weight (g) at storage	1201.73*	2.587	2.84
Total tuber weight loss (g)	6.23 *	1.1587	9.51

** and **, significant at P<0.05 and P<0.01, respectively.*

Table 5. Tuber shape, eye depth, skin color and flesh color.

Variety	Tuber shape	Tuber eye depth	Tuber skin color	Tuber flesh color
Moti	Long oval	Deep	White	Cream
Belete	Very long oval	Very deep to deep	White	Cream
Bubu	Long oval	Shallow	White	Cream
Araarsaa	Oval	Medium to shallow	White	Cream
Gudanie	Oval to long oval	Medium to shallow	White	Cream
Bulle	Round to short oval	Very deep to deep	Purple yellow	Cream
Gabbisa	Oval	Shallow	White	Cream
Marachere	Oval to long oval	Deep to shallow	White	Cream
Chala	Long oval to very long oval	Deep	White	Cream
Gera	Round	Very deep	White	Cream
Gorebella	Long oval	Shallow	White	Cream
Gusa	Round to short oval	Medium	White	Cream
Jalenie	Oval	Medium	White	Cream
Bedasa	Short oval	Medium to shallow	White	Cream
Zemen	Long oval	Shallow	White	Cream
Chirro	Oval to long oval	Medium to shallow	White	Cream
Al-624	Oval to long oval	Medium	White	Cream
Batte	Oval to long oval	Medium	White	Cream
Jarso	Round	Shallow	White	Cream

Gain in Yield and other Traits in Potato Varieties

The mean total yield (t/ha) comparison of 16 varieties released in eight years of release was made. The result showed that total tuber yield was ranged from 25.9 t/ha in varieties released in 2003 to 47.2 t/ha released in 2009. The total yield reduction was 13.2 t/ha in varieties released in 2003 and increased 17. 2 t/ha in 2009 depending on the mean yield registered during the varieties release (Figure 1).

Regression analysis of total tuber yield t/ha on year of variety release as registered during release of varieties indicated absence of significant linear relationship between successive years of variety release and total tuber yield of varieties though the general trend was the increased yields over two decades. The coefficient of determination was

5.63% and correlation (r =0.24) between years of variety release and total tuber yield of varieties was not strong (Figure 2).

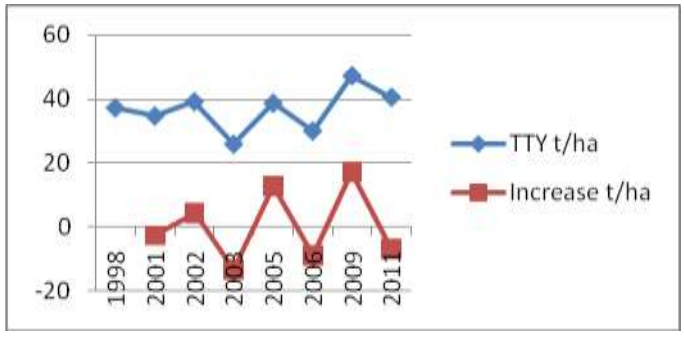

Figure 1. Mean total yield of varieties registered during release and increased in each successive year of variety release (released in eight release years starting 1998).

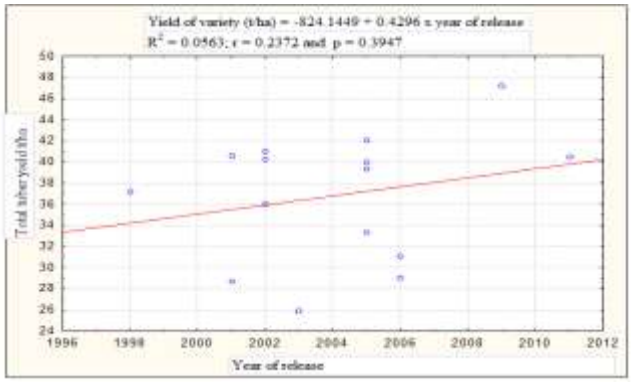

Figure 2. Mean total yield of varieties registered during release regressed on years of variety release (released in eight release years starting 1998).

Comparison of mean total and marketable yields of varieties released by different centers for different regions/agro-ecologies as compared AL-624 was also made based on mean yields of varieties evaluated in eastern Ethiopia over five years. The varieties released by the two centers Sheno and Adet for northern Ethiopia had mean total and marketable yields lower than the oldest variety (Figure 3).

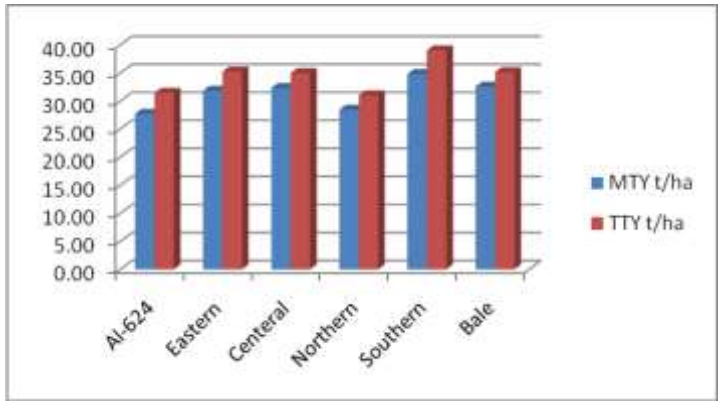

Figure 3. Mean total and marketable yields of varieties as compared to the oldest variety (AL-624) as evaluated in eastern Ethiopia

The Holeta Agriculture Research Center was capable to release potato varieties (2002-2009) with increased mean values for 17 selected traits (use commonly as selection criteria in variety development) in successive released potato varieties except reduced mean values for total tuber number per hill, Area under the Disease Progress Curve (AUDPC), reducing sugar after 15 days of curing (Redsugar) and overall quality (Overall). Reducing the AUDPC and reducing sugar content in successive released potato varieties were in a desired direction. The Haramaya University was capable to increase the mean values of potato varieties (1998-2011for total tuber yield ton per hectare (TTYt ha), marketable tuber yield ton per hectare (MTYt ha) and other eight traits but the increased mean performance of varieties not in each variety released in successive years of release. The mean increase ofTTYt ha and MTYt ha was low in successive released potato varieties released by two centers in the Northern part of Ethiopia, Adet and Sheno (2002 & 2003), southern Ethiopia, Hawassa (2005) and southeastern highlands, Sinna (2006-2012) (Table 6).

Table 6. Trend of potato variety selection criteria within the breeding center evaluated as increase of mean values from oldest to recent released varieties for selected traits.

Trait	Increase/decrease										
	Haramaya (1998-2011)			Holeta (2002-2009)			Adet/Sheno (2002 & 2003)			Hawassa (2005)	Sinna (2006-2012)
	Low	High	Mean	Low	High	Mean	Low	High	Mean	Mean difference	Mean difference
DMC	13.59	24.16	15.10	12.54	1.53	7.04	-4.99	-0.29	-2.64	-3.14	9.03
STN	-3.70	59.26	18.74	37.47	75.64	56.56	-22.92	-14.81	-18.86	26.08	-6.63
LAI	-4.95	19.08	8.41	15.10	34.69	24.90	10.82	47.19	29.00	-29.39	-23.02
HIR	-3.85	-12.18	-6.59	8.98	9.20	9.09	1.51	7.19	4.35	-35.53	0.92
TNhill	11.28	62.42	43.10	-14.40	-32.16	-23.28	-1.27	27.68	13.21	-56.00	-16.59
LSTN	-3.92	13.02	4.21	80.44	217.25	148.85	-12.7	9.26	-1.72	5.98	-10.55
TTYtha	-1.75	106.86	43.76	73.24	100.00	102.71	-19.99	47.66	13.84	2.33	-60.99
MTYtha	-14.93	140.34	42.50	104.50	168.94	136.72	-48.31	38.30	-5.01	6.84	-77.90
AUDPC	-15.21	-91.85	-48.48	-54.14	-85.34	-69.74	-51.99	36.45	-7.77	-488.80	-252.66
ATWg	-20.53	10.56	-4.79	14.11	38.62	26.36	0.20	1.66	0.93	8.62	5.91
TLength	8.55	37.04	20.48	28.82	45.11	36.97	-26.53	-10.27	-18.40	18.12	-15.86
TWidth	11.74	26.04	18.36	7.03	21.54	14.29	-14.97	9.25	-2.86	10.95	-15.06
TLWR	-3.45	8.58	1.73	18.99	19.79	19.39	-17.90	0.001	-8.95	8.06	-0.96
INSPR	-0.71	-28.06	-13.95	9.84	18.83	14.33	-7.04	-3.51	-5.27	-7.76	-15.16
DM%	-8.47	3.00	-2.79	1.77	7.73	4.75	-0.04	0.69	0.33	0.00	-4.20
Redsugar	-12.85	-71.88	-47.92	-64.23	-56.91	-60.57	82.22	235.56	158.89	-86.36	24.91
Overall	-2.64	2.64	-0.22	-1.40	-1.97	-1.69	-1.94	-1.94	-1.94	-0.72	-4.17

DMC = days to maturity of crop, STN = stem number, LAI = leaf area index, HIR = harvest index ratio, TNhill = total tuber number per hill, LSTN = large size tuber number, TTYtha = total tuber yield ton per hectare, MTYtha = marketable tuber yield ton per hectare and AUDPC =Area under the Disease Progress Curve,ATWg = average tuber weight, TLength = tuber length, TWidth = tuber width, TLWRAT = tuber length to width ratio, INSPR = Initial/ days to first tuber sprouting, DM% = tuber dry matter content, Redsugar = reducing sugar after 15 days of curing and overall quality = overall chips quality.

Annual relative genetic gain (RGG) for total tuber yield and marketable tuber yield ton per hectare was positive ranged from 0.98 to 6.92 and 1.7 to 9.1%, respectively, in all varieties released by different research centers. The annual relative genetic gain for Area under the Disease Progress Curve was negative in the range between -6,36 to 13.93% and reducing sugar after 15 days of curing was negative in all varieties except positive annual relative genetic gain of 0.33% in varieties released by Sinanna Agriculture Research Center (Table 7). The highest annual relative genetic gain for tuber yields was computed for varieties released by Holeta Agriculture Research Center and the highest reduction of disease susceptibility and reducing sugar were attained in varieties released by Adet & Sheno Agriculture Research Centers and Haramaya University, respectively. All Agriculture Research Centers selected varieties with delayed tuber sprouting, longer length and wider width tubers consistently in successive released potato varieties in desired direction for processing. However, the annual relative genetic gain for most of other traits was different in varieties released by different centers.

Table 7. Annual relative genetic gain (RGG) for selected traits across breeding centers as compared to the oldest variety (AL-624).

Trait	Haramaya	Holeta	Hawassa	Adet/Sheno	Sinanna	Overall
Days to maturity	1.18	0.34	-0.73	0.19	-0.41	0.11
Number of main stem/hill	2.78	0.14	-3.08	-4.68	-2.6	-1.49
Leaf area index	1.52	-0.63	-0.1	-0.98	-1.81	-0.4
Harvest index ratio	-1.14	-1.4	-2.13	-1.99	-0.66	-1.47
Total tuber number per hill	9.79	3.9	7.67	2.76	-2.21	4.38
Number of large size tuber	2.54	-2.35	-5.17	3.99	2.31	0.27
Total tuber yield ton per hectare	6.09	6.92	6.89	4.5	0.98	5.08
Marketable tuber yield ton per hectare	4.38	9.1	7.14	4.57	1.7	5.38
Area under the Disease Progress Curve	-8.11	-9.59	-12.06	-13.93	-6.36	-10.01
Average tuber weight (g)	-1.58	0.28	-0.98	-1.48	0.87	-0.58
Tuber length (cm)	3.18	2.23	2.51	2.04	0.77	2.14
Tuber width(cm)	3.19	3.16	3.69	4.02	2.2	3.25
Tuber length to width ratio	-0.01	-0.84	-1	-0.58	-1.19	-0.72
Initial/ days to first tuber sprouting	-3.66	-1.04	-1.9	-0.33	-2.34	-1.85

Tuber dry matter content (%)	-0.97	0.1	-1.01	-0.25	-0.82	-0.59
Reducing sugar after 15 days of curing	-10.87	-1.27	-1.79	-8.19	0.33	-4.36
Overall chips quality	-0.03	-0.32	0.13	-0.29	-0.48	-0.2

Dissimilarity of potato varieties

The clustering of potato varieties grouped into four distinct clusters of which 16.67 and 38.89% varieties included in Cluster III and I, respectively, while other two clusters (Cluster II and IV) contained each 22.22% varieties (Figure 4). The clustering was based on 153 pairs of Euclidean distances calculated from 51 quantitative traits. All the varieties released in 2005 and 2006 by different research centers except Gudanie released in 2006 by Holeta Agriculture Research Center were grouped in Cluster I while all the varieties released during 2009 to 2012 except Moti released in 2012 by Sinnana Agriculture Research Center were grouped in Cluster IV. Four (51.14%) out of seven varieties released during 1998 to 2003 were established separate Cluster II while one and two varieties were distributed under Cluster IV and I, respectively (Table 8).

Table 8. List of potato varieties in four clusters, year of release and recommendation areas.

Cluster	Common name	Year of release	Recommended for		Breeding Center
			Region	Altitude masl	
I (38.89%)	Araarsaa	2006	Bale	2400-3350	Sinnana
	Bulle	2005	Southern	1700-2700	Hwassa
Sub-group I	Chala	2005	Eastern	1700-2000	Haramaya
	Maracharre	2005	Southern	1700-2700	Hwassa
	Bedasa	2001	Eastern	2400-3350	Haramaya
Sub-group II	Gabbisa	2005	Eastern	1700-2000	Haramaya
	Gorebela	2002	Northeast	1700-2400	Sheno
II (22.22%)	Guasa	2002	Northwest	2000-2800	Adet
	Chirro	1998	Eastern	2700-3200	Haramaya
	Zemen	2001	Eastern	1700-2000	Haramaya
	Jalenie	2002	Central	1600-2800	Holeta
III (16.67%)	Batte		Eastern		
	Jarso		Eastern		
	Moti	2012	Bale	2400-3350	Sinnana
IV	Belete	2009	Central	1600-2800	Holeta
	Gera	2003	Northeast	2700-3200	Sheno

(22.22%)					
	Bubu	2011	Eastern	1700-2000	Haramaya
	Gudanie	2006	Central	1600-2800	Holeta

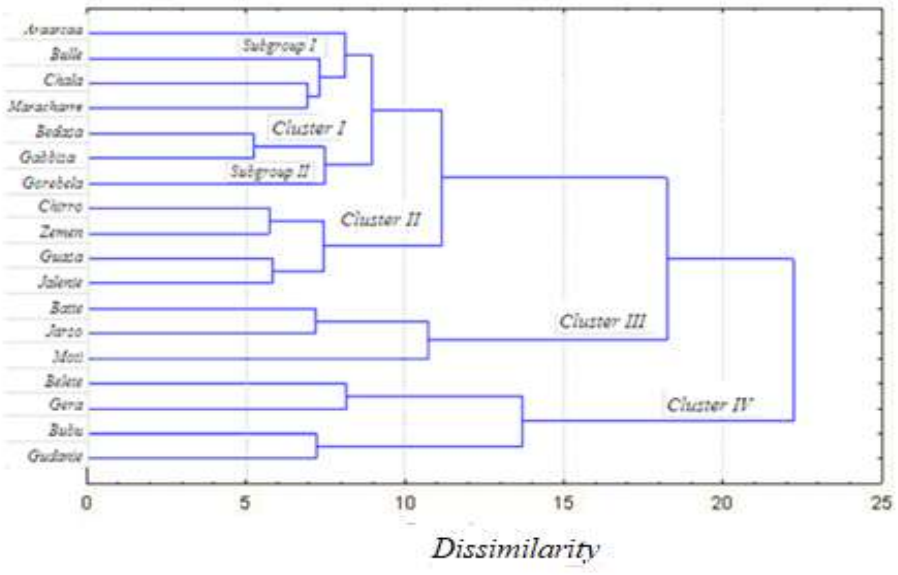

Figure 4. Dendrogram generated based on UPGMA clustering method depiciting genetic relationship among 18 potato varieties based on 51 agromorphology and tuber processing quality traits.

The highest Euclidean distance was computed between Batte and Gudanie (41.3) followed by between Jarso and Gudanie (40.3). The lowest Euclidean distance was calculated between Bedasa and Gabbisa (5.2) followed by between Chala and Zemen (5.7) as well as between Guasa and Jalenie (5.8). Gudanie was found the most distant variety to others with mean Euclidean distance of 25.77 followed by Bubu (22.51), Batte (21.55), Jarso (21.15) and Moti (20.01), all with >20 mean Euclidean distances where the overall mean Euclidean distance was 16.16 with standard deviation (SD) of 4.18 (Table 9). Other than the five distant varieties, only Belete (17.75) had mean Euclidean distance greater than overall mean Euclidean distance of varieties.

Cluster Characterization based on Mean Performances

The mean performances of varieties for 50 quantitative traits under each cluster were calculated and summarized in six tables of landscape format but it is difficult to present all data in this manuscript, therefore, the summary of the data included in six tables as distinguishing characters of each cluster is presented in Table 10. Generally, the varieties grouped under Cluster IV had highest tuber yield, resistant and moderately resistant to late blight disease, high mean values for growth, tuber physical characters and other traits. The tuber internal quality traits and chemical contents were better than varieties

grouped in other three clusters but the chips were turned to white and dry due to the high dry mater content of tubers of varieties grouped under this cluster. The other three clusters which consisted of 14 varieties susceptible and moderately susceptible to late blight disease, mean yield lower than overall mean values (Cluster II and III) or greater than overall mean values but with very low differences.

Table 9. Euclidean distances of 18 potato varieties estimated from mean performances of varieties for 50 quantitative traits

	Araarsaa	Batte	Bedasa	Belete	Bubu	Bulle	Chala	Chirro	Gabbisa	Gera	Gorebela	Guasa	Gudanie	Jalenie	Jarso	Maracharre	Moti
Batte	21.6																
Bedasa	9.0	17.3															
Belete	12.9	32.3	16.8														
Bubu	18.8	38.2	22.4	10.9													
Bulle	8.7	24.5	10.3	11.2	16.1												
Chala	7.8	24.8	10.0	10.0	14.7	7.1											
Chirro	10.5	15.7	7.6	19.5	25.7	13.8	12.6										
Gabbisa	7.7	19.3	5.2	15.0	20.4	9.3	8.6	8.8									
Gera	9.7	28.0	13.2	8.2	13.3	9.6	7.7	16.3	11.6								
Gorebela	8.9	20.5	8.3	14.9	21.1	9.9	10.3	9.4	6.7	12.9							
Guasa	12.2	14.5	8.5	20.8	27.4	14.3	14.3	6.0	9.2	17.8	9.8						
Gudanie	22.2	41.3	26.2	14.5	7.2	19.7	18.0	29.0	24.3	16.1	25.3	31.0					
Jalenie	11.8	14.5	8.5	20.6	27.5	13.7	14.2	7.7	9.6	17.2	9.3	5.8	30.9				
Jarso	20.6	7.2	17.2	31.3	37.2	23.8	23.7	15.2	19.0	27.6	20.1	14.3	40.3	14.3			
Maracharre	7.9	21.4	7.9	13.1	18.9	7.5	7.0	10.8	6.7	9.4	9.0	11.9	22.0	11.1	21.0		
Moti	19.1	10.3	16.0	28.9	36.0	22.8	23.0	13.3	17.8	25.9	17.7	11.7	39.7	12.8	11.2	20.4	
Zemen (14.2)	12.3	15.0	7.6	21.0	26.8	14.6	14.2	5.7	9.6	17.3	9.9	7.6	30.5	8.5	15.6	12.0	13.5
Mean	13.03	21.55	12.47	17.75	22.51	13.94	13.40	13.40	12.29	15.40	13.17	13.95	25.77	14.00	21.15	12.81	20.01

Number in parenthesis is mean Euclidean distance of the respective Zemen potato variety.

Table 10. Distinguishing characters of four clusters included 18 potato varieties.

Cluster	Distinguishing character
I	This cluster consisted of varieties with wide range of differences for most of the traits and also divided in to two subgroups. This cluster had better tuber bulking rate, plant height, and leaf area index, above and below ground biomass yield than the average mean values of varieties. It had highest number of tubers per hill and largest proportion of tubers with small size. The mean values for internal tuber quality were above the overall mean of cultivars, long tuber storage period with lower tuber weight loss. This cluster was characterized by having higher proportion of peel, tuber length, width, and tuber length to width ratio than overall mean values of varieties. The cluster had total and marketable tuber yield higher than overall mean of varieties with very low differences. Varieties under this cluster evaluated as having above overall mean for saltiness, sourness, texture and overall acceptance chips. The varieties of this cluster were categorized as susceptible and moderately susceptible to late blight. The cluster also had highest proportion of unmarketable tuber yield, low mean values for number of stem per hill, harvest index pH, total soluble solid, total and reducing sugar as well as for most of the chips quality parameters than overall mean values of varieties.
II	This cluster had higher mean values for plant height, leaf area index, above and underground biomass yield, early flowering and maturing than average of the cultivars tested. It had also higher mean values for tuber internal quality traits (specific gravity, dry matter and starch content), chips sweetness and overall acceptance. This cluster had lower mean values than overall mean values of cultivars for all other traits including for tuber yield and late blight susceptibility.
III	This cluster had lowest mean values for all other traits including chips overall acceptance. But it was characterized by early maturing, short tuber storage period with higher mean tuber weight loss, higher mean values for total, reducing sugar, disease severity parameters, all chips quality parameters except for two than cultivars average mean values.
IV	The varieties grouped under this cluster (Belete, Gera, Bubu and Gudanie) had highest mean values than varieties grouped in other three clusters for most of the traits. However, if earliness is considered as desirable trait, this cluster was characterized by late flowering and maturity. The cluster had highest average tuber weight, tuber length and width, tuber length to width ratio, higher proportion of tubers with large tuber size but lowest proportion of small and medium size tubers. The varieties under this cluster had also highest mean values for tuber internal quality parameters (specific gravity, dry matter and starch content). But the cluster had lower mean for tuber pH, total and reducing sugar as well as long tuber storage period with lower tuber weight loss. Moreover, the cluster consisted of three late blight resistant and one moderately resistant variety with highest total and marketable tuber yield. The varieties under this cluster were evaluated as having above the average for

	most of chips quality parameters except the chips color turned white and having dry chips.

Trends of Variety Development across Research Centers

The potato varieties released by Holeta Agriculture Research Center were grouped under Cluster IV except the oldest variety (Jalenie released in 2002) in which Cluster IV was characterized by highest yield, resistant and moderately resistant to late blight disease and with other desirable traits (Table 8 and 10). The two varieties released by this center were most distant and distant (Gudanie and Belete) to other varieties and even the third variety was more distant to others than the nine varieties released by other research centers (Table 9). Potato variety development at Holeta Agriculture Research Center was consistent in selection of genotypes with increased mean values of tuber yield, yield related traits, tuber quality traits, more resistant to late blight and low reducing sugar content than the old variety. In this Center, the number of tubers per hill was reduced from oldest to the recent but proportion of tubers with large size category and average tuber weight per hill were increased. The center developed varieties most distant genetically than the varieties developed by other centers.

The varieties developed by Haramaya University were grouped in Cluster I and II except one variety (Bubu grouped under Cluster IV) (Table 8) in which the two clusters were characterized as susceptible and moderately susceptible to late blight disease (Table 10). All varieties except Bubu were found closer to other varieties with mean Euclidean distances less than varieties overall mean Euclidean distance. The two pairs of varieties, Bedasa and Gabbisa (5.2) and Chala and Zemen (5.7) had the first and second lowest Euclidean distances among 153 pairs of Euclidean distances of varieties (Table 9). The overall mean values were increased for most of tuber yield, yield related traits and tuber quality traits in varieties released by Haramaya University (Table 7). However, selection of genotypes for increased mean values was not consistent in successive years of varieties released by Haramaya University. The breeders at Haramaya were selected varieties with delayed maturity, more number of tubers per hill, tubers with increased length and width, resistant to late blight and low reducing sugar content. The other centers had similar trend to Haramaya University except Sinana Agriculture Research Center that released variety recently with lower mean values for most of the traits than the variety released before six years.

3. Discussion

The observed significant differences among potato varieties for 50 agromorphology, reaction to late blight disease and processing quality traits indicated the presence of wide variations among the potato varieties under cultivation in Ethiopia. It was also observed significant influence of location, season, and interaction of these with genotype on most of the traits indicating the differential performance of varieties across locations and seasons. The presence of genetic variations among the released varieties for late blight resistance was reported (Wassu, 2014) and significant differences among the released varieties for tuber yield, yield related traits and tuber processing quality was reported

(Habtamu *et al*., 2016a&b). Other authors (Flis *et al*., 2014; Mulugeta, and Dessalegn, 2013; Mulema *et al*., 2008; Tekaliegn, 2011; Mateo *et al*., 2007) also reported the significant influence of environment and genotype x environment interactions on yield, yield related traits and late blight resistance of potato cultivars.

The annual relative tuber yields gain (RGG) >1.79 has been achieved for 25 years in the country and potato improvement was addressing agro-ecologies/regions considering all climate variables and product utilization. The reduction of disease susceptibility (AUDPC) through delayed late blight disease onset, increasing storage life of tubers and reduction of the reducing sugar of tubers in all centers except Sinnana Agriculture Research Center as compared to AL-624 were also a good achievement in the past 25 years potato varieties development. However, the annual relative genetic gain (RGG) for yield, resistance to late blight disease and other desirable traits was not consistent increase in successive years of variety release across centers except varieties released by Holeta Agriculture Research Center. This may result in differences of the average yield in each Agroecology or region where the varieties were recommended and thereby contributed the low average yield to be achieved in the country. The inconsistency of yield increase and resistance to late blight disease in successive years of variety release released by research centers and Haramaya University other than Holeta Agriculture Research Center might be due to the differences of access to receive genetically diverse potato genotypes from CIP breeding program in Peru. Potato germplasm for varieties development in Ethiopia is obtained mainly from International Potato Center (CIP) breeding program in the form of advanced clones, tuber families, and true potato seed (Gebremedhin, 2013).

Apart from differences of potato varieties released across research centers in the country for annual relative tuber yields gain and resistance to late blight disease, it was also observed yield differences i.e. the inferiority of new released varieties than the old variety within the same center and/or varieties released by other centers in same year or old varieties. This showed that the advantage of the new varieties over the existing commercial varieties was overlooked (not critically assessed) during the variety release. The annual relative genetic gain(RGG) for harvest index, average tuber weight and number stems per hill across centers except in few for some traits was not positive indicating these traits as basic criteria for variety selection did not considered uniformly across centers. The RGG for tuber length to width ratio, dry matter contents of tubers and overall chips quality across centers except in few varieties released by few centers for some traits was not positive indicating all centers were not in a position in a good progress towards developing varieties for processing quality chips. This might be the results of the major research focus in developing potato varieties for high yield and resistance to late blight (Baye and Gebremedhin, 2013; Gebremedhin, 2013) mainly for traditional meals and dishes not for other processed products (chips and French fries).The use of chips and French fries in cities is a recent phenomenon in the country but spread to small towns and it is available in super markets, restaurants, shops etc**.** (Habtamu *et al*., 2016a&b; Elfnesh *et al*., 2011). Breeders have been unable to forecast future cropping scenarios and the economics of production. The major task of the breeder is to develop high yielding varieties, resistant or tolerant to stress and varieties

that match the existing end use of the crop (Carter *et al.*, 2015). But this research results pinpointed the weakness of variety development to fit to quality chips processing which is an emerging industry either at small or at large scales in the country.

The differences of RGG for tuber yield and major yield components (harvest index, average tuber weight and number stems per hill) of potato varieties were not only the genetic differences of varieties released by different research centers in the country but it was also the significant influence of environment and genotype x environment interaction as many other authors indicated (Flis *et al.*, 2014; Mulugeta, and Dessalegn, 2013; Mulema *et al.*, 2008; Tekaliegn, 2011; Mateo *et al.*, 2007).The varieties developed would be grown under management situations for which the breeders did not develop and showed lack of adaptation (Pfeiffer *et al.*, 2000). But the differences among varieties released by different research centers for resistance to late blight disease might be mainly due to the differences of potato varieties for resistant gene(s) they carry as indicated by other authors (Wassu, 2014; Gebremedhin, 2013) in Ethiopia and from other countries (Stewart *et al.,* 2003; Wastie, 1991). This suggested the need to evaluate potato genotypes in areas favorable to the pathogen *Phytophthora infestans* (Mont.) de Bary before releasing varieties for different agroecologies/regions of the country as evaluated by different centers at different environments. This suggestion has given considering the exchange of seed tubers of varieties out of the intended region/environment to be cultivated and the nature of the pathogen which spreads like a wild fire under congenial weather conditions and destruct potato within a few days when the environment is conducive (Sundaresha *et al.*, 2014; Bekele and Hailu, 2001). Other scientists also recommended the evaluation of potato cultivars for susceptibility to the late blight in areas where the environment favors the pathogen (Lee *et al.*, 2001). Direct selection for stress conditions is more effective in the same environment than selection for the mean of both favorable and unfavorable environments (Kirigwi *et al.*, 2004; Cecarelli *et al.*, 1998; Calhoun *et al.*, 1994).

The clustering of potato varieties based on 153 pairs of Euclidean distances calculated from 51 quantitative traits showed that the four distinct clusters were constructed each by varieties released in same year or consecutive two or three years of variety release except admixture of few varieties. This indicated the varieties released at varied of years release were genetically distinict for varied traits. The varieties differences for resistance to late blight disease was reported that most of the potato varieties that have been released before 2008 possess genes for either vertical resistance or horizontal resistance to late blight in the presence of unknown resistance major R genes (Gebremedhin, 2013). The clustering of functional genes for qualitative and quantitative resistance to various pathogens suggests their evolution from common ancestors by local gene duplication, followed by functional diversification (Gebhardt and Valkonen, 2001; Oberhagemann *et al.*, 1999; Leister *et al.*, 1996; Leonards-Schippers *et al.*, 1994).The differences for resistance to late blight might also cause differences among potato varieties for yield and yield componentssince this disease is one of the major problems that cause an estimated potato tuberyield loss of up to 70% in the country (Mekonen *et al.*, 2011). The research results also revealed some of the varieties released by the same center in consecutive years of variety release (eg. Bedasa and Gabbisa & Chala and Zemen by Haramaya University) and different centers (eg.Guasa and Jalenie by Adet

and Holeta Agriculture Research Centers) were genetically very close each other. Moreover, all varieties except one released by Holeta Agriculture Research Center, only Bubu and Moti varieties released by Haramaya University and Sinnana Agriculture Research Center were found the most distant to other varieties. This indicated that all centers except Holeta were developing varieties from populations with similar genetic makeup and suggested the efforts of breeders at different centers for several years did not bring in developing genetically distant varieties.

Characterization of clusters for 50 traits revealed that varieties grouped under Cluster IV (Belete, Gera, Bubu and Gudanie) had highest tuber yield, resistant and moderately resistant to late blight disease, high mean values for growth, tuber physical characters and other traits. Of which Gudanie was moderately resistant to late blight disease that might not be recommended for cultivation without less frequent fungicides spray in eastern Ethiopia during main season where the late blight disease pressure. Similarly, Belete might not be recommended for quality chips processing that produced dry chips with color turned to white due to the high dry mater content of tubers of this variety. Gera had round tubers with low length to width ratio and the eyes of the tubers were very deep that produced high peel content during chips processing, therefore, this variety might not be preferred by chips processors. In general, from all varieties, Bubu, Belete and Gera could be recommended for cultivation in eastern Ethiopia during main season as all-purpose use including chips and French fries making except Belete not recommended for the two processed products. Potato cultivars producing tubers with dry matter content $\geq$20% and specific gravity $\geq$1.080 (Kabira and Berga, 2003) as well as starch content $\geq$13% (Kirkman, 2007) are the most preferred for processed products. Gudanie could be recommended for cultivation with less frequent fungicides spray during main season or in areas where the late blight disease pressure is very low or during dry season in the absence of late blight disease because even low infection levels, the crop may be unsuitable for storage (Fernández-Northcote *et al*., 2000).

The potato varieties (2002-2009) except the oldest variety (Jalenie released in 2002) released by Holeta Agriculture Research Center were distant to other varieties, showed consistent increased mean values in successive released potato varieties for all desirable traitswith highest RGG. Only one variety (Bubu) and Gera released by Haramaya University and Sheno Agriculture Research Center, respectively, were identified as high yielding, resistant to late blight disease and with other desirable traits. The results suggested that developing varieties for wider areas (wide adaptable varieties) had an advantage over the current approach, varieties development for different agroecologies/regions. There are two options, either to select varieties that perform well consistently in all environments or to identify specific varieties for each environment (Gauch, 2006). Of course, development of specific varieties that perform better in specific environment(s) (Vermeer, 1990) is important since it increased the progress that could be made by reducing effect of genotype x environment interaction. But this option requires the availability of all necessary resources which is one of the most limiting factors of research in developing countries, Therefore, the second option become more important viz. developing varieties that outperform consistently other competing genotypes and perform well over a range of environments (Lin *et al*., 1986) by

choosing superior genotypes with a low or minimal genotype x environment interaction (Cotes *et al*., 2002).

4. Summary and Conclusion

The potato varieties under cultivation in Ethiopia had significant variations for 51 quantitative traits though differential performance of varieties over locations and years was observed due to the significant effect of environment and genotype x environment interaction (GEI). The overall annual relative genetic gain (RGG) that has been achieved for 25 years in the country for tuber yield, resistance to late blight disease and other desirable traits was the strength of the potato improvement at national level. However, the annual relative genetic for yield and other desirable traits considerably varied within and between potato varieties released by same and different centers, respectively, in successive years of variety release. Only varieties released in successive years of variety release by Holeta Agriculture Research Center attained consistent increase of mean values and high annual relative genetic for yield and other desirable traits. Bubu, Belete and Gera could be recommended for cultivation during main cropping season in eastern Ethiopia for general purpose use and preferably Bubu as all-purpose use including quality chips and French fries processing. The research results allowed concluding that the advantage of developing wide adaptable varieties through nationally coordinated research as compared the existing varieties development for different agro-ecologies/regions by different research center and Haramaya University.

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