MORPHOLOGICAL VARIATION AMONG SOME WELLEGACOFFEE (*Coffea arabica* L.) ACCESSIONS AT HARU, WEST WELLEGA, ETHIOPIA

MSc Thesis

BY

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JUNE, 2016

JIMMA, ETHIOPIA

MORPHOLOGICAL VARIATION AMONG SOME WELLEGA COFFEE (*Coffea arabica* L.) ACCESSIONS AT HARU, WEST WELLEGA, ETHIOPIA

A Thesis

Submitted to School of Graduate Studies Jimma University College of Agriculture and Veterinary Medicine

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Plant Breeding

By

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June, 2016

Jimma, Ethiopia

Jimma University College of Agriculture and Veterinary Medicine

Thesis Submission for External Defense Request Form (F-07)

Name of Student: Solomon Admasu ID No. 06103/06 Program of study: MSc In plant breeding

Title: Morphological variation among Some Wellega Coffee *(Coffea arabica* L.*)* Accessions at Haru, West Wellega, Ethiopia

I have incorporated the suggestion and modifications given during the internal thesis defense and got the approval of my advisers. Hence, I hereby kindly request the Department to allow me to submit my thesis for external thesis defense.

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We, the thesis advisers have verified that the student has incorporated the suggestions and modifications given during the internal thesis defense and the thesis is ready to be submitted. Hence, we recommended the thesis to be submitted for external defense.

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Decision/suggestion of Department Graduate Council (DGC)

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Chairperson**,** CGS Signature Date

DEDICATION

This Thesis is dedicated to my beloved families Admasu Watiro,Tesfanesh Degsew,Girma Admasu, Hiwot Tibebu, Mulatwa Admasu, Musema Ali, Edgigu Admasu, Bereket Tesfaye; Tadeleh Admasu and Desta Anshebo for their due effort for the success of my life

STATEMENT OF AUTHOR

First, I declare that this thesis is my own work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for the Degree of Master of Science in Plant Breeding at Jimma University, College of Agriculture and Veterinary Medicine and is deposited at the University Library to be made available under rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate. Brief quotations from this thesis are allowable without special permission provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the Horticulture and Plant Science Department or the Dean of the School of Graduate Studies when in his judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

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BIOGRAPHICAL SKETCH

The author was born in April 1977 in Jimma town, Oromia Regional State Jimma Zone. He attended elementary, junior and secondary education at Kito Elementary School, and Jimma Comprehensive Secondary High School, respectively. He completed secondary education in 1994 after taking the Ethiopian School Leaving Certificate Examination.

He joined the then Jimma College of Agriculture, now Jimma University College of Agriculture and Veterinary Medicine in 1995 and earned a Diploma in General Agriculture in July 1996 Immediately after the graduation employed and have worked in Ethiopian Institute of Agricultural Research (EIAR) at Jimma (Haru) center as technical assistant.

For the second time he joined Jimma University College of Agriculture and Veterinary Medicine in 1997 and earned his Bachelor degree in Horticulture in July 2000 then joined Ethiopian Institute of Agricultural Research (EIAR) in June, 2002 and worked as researcher at Jimma (Haru) Agricultural Research Center. In 2006, he joined the school of graduate studies of Jimma University for his Master of Science study in the stream of Plant Breeding.

ACKNOWLEDGMENTS

I feel deeply indebted and express my sincere gratitude to my advisors Dr.Sentayehu Alamerew and Ato Yonas Belete for all the wealth of knowledge passed on to me during my thesis research work. I am also grateful for their useful comments and corrections on the thesis manuscript.

My gratefulness and thanks are going to EIAR for granting me financial support and provision of the necessary materials. Thanks are also due to the management and staff of JARC and JUCAVM for logistic support and encouragement meant a lot for me and my work.

My special gratitude goes to Dr.Taye Kufa, Dr Mandefro Nigusie, Ato Ashenafi Ayano, Ato Getachew Woldemariam, Ato Abrar Salihe, Ato Tarekegn Argaw, Ato Tewodros Mulalem and all lecturers in plant breeding for their encouragement and fruitful support from the execution of the study up to the final thesis write-up. The author also gratefully acknowledges all staffs of Haru and Jimma Research Center and his friends Abduletif Hassen, whose material and ideal support was always available to me throughout this thesis work.

I wish to express my appreciation to my families for their valuable assistance throughout the study period. Lastly, I am grateful to my friends and classmates for their moral support and encouragement in every aspect during the thesis preparation.

LIST OF ABBREVIATIONS AND ACRONYMS

CBD	Coffee Berry Disease
EIAR	Ethiopian Institute of Agricultural Research
GA	Genetic Advance
GAM	Genetic Advance as % of Mean
GCV	Genotypic Coefficient of Variation
GD	Genetic Distance
H^2	Heritability in Broad Sense
H'	Shannon-Weaver diversity index
IAR	Institute of Agricultural Research
IBC	Institute of Biodiversity Conservation
ICO	International Coffee Organization
IPGRI	International Plant Genetic Resources Institute
JARC	Jimma Agricultural Research Center
JATS	Jimma Agricultural Technical School
LSD	Least Significant Difference
PC	Principal Component
PCA	Principal Component Analysis
PCV	Phenotypic Coefficient of Variation
pH	Power of Hydrogen
PSF, PST^2	Pseudo F and Pseudo t^2
SAS	Statistical Analysis System
SPAD	Statistical Package for Augmented Design
UPGMA	Un-weighted Pair- Group Method of Arithmetic Average

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ABSTRACT

Arabica coffee (*Coffea arabica* L.) *plays vital role in the Ethiopian economy. Quarter of the people in the country in one way or the other derives their livelihood from coffee production, processing or its trading. Knowledge about extent of genetic diversity among coffee arabica genotypes is important in coffee breeding for various uses. So far, little or no information is generated in genetic diversity of East wellega coffee genotypes in Ethiopia. With the objective of evaluating the extent of genetic variation and association among bean yield and yield related traits. One hundred eleven arabica coffee accessions which were collected from different parts of Eastern wellega and four checks were tested in an augmented designs. The accessions showed significant variation for most traits and test versus control treatments. The variation among the test accessions was significant for most of the characters namely leaf length, leaf width, leaf area, petiole length, bean length, bean width, bean thickness, hundred bean weight, length of first primary branch, stem girth, fruit length, fruit width, fruit thickness and bean yield. Showing the fact that there is real difference among the accessions for these characters. Relatively the phenotypic coefficient of variation were higher than the genotypic coefficients of variation showing the fact that environment elevates the variations. Generally high PCV and GCV were recorded for bean width, hundred bean weight, length of first primary branch and bean yield per unit area. Relatively higher heritability value were observed for leaf length, leaf width, leaf area, bean width, hundred bean weight and fruit length. From the characters studied leaf area, petiole length, bean width, hundred bean weight and bean yield exhibited higher genetic advance showing the fact that the traits can be improved with ease. The* D^2 *analysis grouped the 115 coffee accessions in to twelve clusters. This shows that the accessions are divergent. Principal components (PC1 to PC6) considered eigen value greater than one accounted nearly 71% of the total variation. Bean yield showed positive and significant correlation with length of longest first primary branch (LFPB),stem girth (SG),fruit length (FL), fruit width (FW) and fruit thickness both at phenotypic and genotypic levels showing the fact that high emphasis need to be given for these characters to improve yield at trait basis. Path coefficient analysis showed that length of longest first primary branch which had positive and significant association with yield exert maximum direct effect on grain yield. The second and high direct effects was exerted by fruit width which had also positive and significant association with bean yield showing these two characters should be considered in selection. The Shannon weaver diversity index* (H') *analysis of the traits indicated diversity for fruit shape, mature fruit color, branching habit, angle insertion of primary branch, leaf shape and seed shape. This indicates the existence of variability based on their vegetative and bean characteristics. The present study indicated a considerable amount of variability for majority of the characters of interest in coffee Arabica for exploitation. Nevertheless, the need for characterization approach through advanced tools of molecular approaches is suggested.*

Key words: *Coffee Arabica, Morphology, Variability, Correlation, Path Analysis, Wellega*

1. INTRODUCTION

Coffea arabica L. belongs to the *Rubiacea*e family in the genus *Coffea*. It is the only tetraploid species from the genus with 11 basic chromosome numbers. It is predominantly self-pollinated crop with 7-10% out crossing (Clifford and Wilson, 1985; Anthony *et al.*, 2002). Arabica coffee plays a dominant role in the Ethiopian economy. Quarter of the people in the country directly or indirectly derives their livelihood from coffee production processing or its trading. The country used to fetch up to 65% of its foreign exchange earnings from coffee export alone until very recently (Bayetta, 2001; Yonas, 2005; ICO, 2014). Even currently with the increasing importance of many other commodities in export such as skin, hide, flower, and gold the share that comes from coffee still constitutes 25 to 40**%** of the total national export (Alemayew *et al.*, 2008; Nigussie *et al.*, 2008*;* Girma, 2011). Furthermore the land covered with coffee in Ethiopia currently is very substantial and is estimated to be 561,761.82 hectares, while the annual production of clean coffee is about 4,199,801.56 quintals (Abyot *et.al*, 2011; Yonas, 2014*;* CSA, 2015). Ethiopia is among the top ten countries in overall coffee production and it produces 6.4 million bags in 2012/13 (ICO, 2014).

Apart from being major producer and exporter of Arabica coffee, Ethiopia is also origin and center of diversity of the crop. The entire diversity of the species is confined mainly in the montane rainforest located in the West and East of Great Rift Valley (Tadesse *et al., 2008*; Kassahun *et al*, 2008; Taye and Jurgen, 2008). It has been reported in series of literature that there is wide varietal diversity of Arabica coffee in Ethiopia, whether the production system is forest, semi-forest or land races at farmers field (Mesfin, 2008; Seyoum *et al*, 2008; Kassahun *et al*, 2008) and presence of this diversity is highly prized for its potential value as a source of important gene for improvement of the crop in various aspects. The attributes in the diversity include quality, productivity, resistance to biotic and abiotic factors, and resistance for drought and other stresses. Some of the reason for the remarkable successes scored in coffee arabica research to improve some desirable coffee traits was attributed to the presence of the stated variability in the crop. This was first confirmed when the expedition of coffee collection to identify resistant varieties to the devastating coffee berry disease became successful

immediately after its outbreak (Vander graaf, 1981). Subsequently, improvement of coffee varieties in various aspects such as desired coffee tree configuration that determines planting density per unit area, coffee cup quality that determines coffee price in the international coffee trade, resistant to various diseases and insect pests was successful too. All these achievements became possible due to the presence of the stated variability in the populations of Arabica coffee types in Ethiopia.

Despite its importance as invaluable genetic resource nationally and internationally for the current as well as future genetic improvement work, the Ethiopian Arabica coffee gene pool is threatened of genetic erosion. The key challenge that causes losses to this gene pool is environmental degradation which is expressed in various forms such as land degradation, deforestation, habitat conversion and consequent losses of wild lands which harbor wild arabica coffees and replacement of land races and farmer varieties with narrow genetic base varieties released from research centers (Paulos, 2008; Yilma, 1999; Tadesse *et al*, 2008; Paulos and Demel, 1999).

The major factors associated to coffee genetic erosion in Ethiopia are mainly two. The first is deforestation which has been caused and is being caused by the conversion of forest lands (Coffee natural habitat) to agricultural food crops and other purposes. The second is replacement of the land races, farmer varieties and wild forest coffee types with the improved coffee varieties released from research centers. In this regard so far 34 pure line coffee varieties, which have been proved to be superior on research stations, for yield and coffee berry disease were released and planted extensively almost in all coffee growing areas replacing the existing broad genetic base populations even in areas where their performance was not confirmed to be better than the existing land races (Van der Graaf, 1981; Bayetta and Behailu 1999, Bayetta. and Gibramu, 1998; Yonas and Bayetta, 2008).

The released varieties were selected from huge coffee accessions made available by collection programs done in series of years starting from 1973. The attempt to develop additional varieties is under way as presence of multiple varieties in the production system is paramount important to minimize crop risk due to insects or diseases and also to counter adaptation problems that could result from climate changes.

A study conducted to see the potential performance of unimproved land race coffee types compared with the commercial varieties illustrated the possibility of identifying superior coffee types to improve the Ethiopian coffee industry in various aspects. This variability may include different aspects such as adaptation to prolonged drought environments, poor soil condition, inadequate rainfall amount and tolerance to biotic and abiotic environmental factors. Furthermore coffee types collected from farmers field was seen to exhibit equivalent yield potential as the latter showing their merit for direct improvement of arabica coffee to develop desirable varieties for the diverse agro ecologies of the country (Mesfin, 1980). Based on a molecular study carried out by Kassahun *et al* (2008) it was illustrated that the genetic diversity of Arabica coffee in Ethiopia is very enormous showing the emphasis that need to be given to conserve and characterize these gene pool before they are lost irreversibly by the alarming environmental degradations taking place these days. Indeed coffee collections have been undertaken for several years from the start of coffee research in Ethiopia. The program is also underway currently to collect and characterize the available Arabica coffee germplasm from uncovered areas.

Wellega is among the major regions in Ethiopia known for Arabica coffee production and which also exhibits high genetic variability for the crop (Ermias, 2005). Knowledge about extent of genetic diversity among coffee arabica genotypes is important in crop breeding for various uses. So far, little or no information is generated in genetic diversity of East wellega coffee genotypes in Ethiopia. Though the crop has huge area coverage in the region and its productivity is at low level too (Ermias, 2005; Kufa, 2010). One from the major factors owing to low productivity includes that the work done to collect and characterize the regions coffee is very limited. So far, a collection work was done at three phases from the region and the characterization works for the coffee accessions collected in batch one and two were done. Therefore the purpose of this study was designed to characterize arabica coffee accessions which have been collected from different parts of Eastern Wellega in 2005 and maintained at Haru with the objective to:

- ✓ Assess the extent of diversity of traits of Arabica coffee collected from different parts of Eastern Wellega
- ✓ Estimate the association among the different traits of Arabica coffee accessions

2. LITERATURE REVIEW

2.1. Botanical Description

Coffee belongs to the genus of *Coffea* in the *Rubiaceae* family that comprises 640 genera and 1000 species (Gichimu and Omoody, 2010). The biologically and morphologically diversified family gives it various live that ranged from tiny herbs, epiphytes, lianas, shrubs to tall trees (Bremer, 1996). Nearly 105 taxa of the genus Coffea are distinguished from a closely related genus, Psilanthus, based on flowering and flower characteristics (Bremer, 1996; Kumar *et al.,* 2008).

According to Bridson (1987) all *Coffea* species are native to the inter-tropical forest of Africa and Madagascar, whereas the genus Psilanthus species originated from either Asia or Africa. At genus level *Coffea arabica* L. has been categorized into two sub genera: *Coffea* and *Para Coffea* the cultivated economic species receive due attention and it consists of *Coffea arabica* L. and *Coffea canephora* Pierre (Kumer *et al*., 2008).

Coffee arabica is tetraploid (2n= 4x = 44) with 11 basic chromosomes and is self fertile, while the other *Coffea* species is diploid (2n = 2x = 22) and self incompatible. (Masumbuko *et al*., 2003; Hue, 2005). Many bisexual flowering plants avoid the deleterious effects of inbreeding by employing genetically controlled self-incompatibility (SI) mechanisms to ensure out crossing. SI mechanisms provide the biochemical machinery necessary for plants to recognize and reject their own pollen as well as non-self pollen with a genotype sufficiently similar to draw out activation of the SI mechanism. SI plants thus require a pollen donor with a divergent genotype for successful fertilization, a mating system known as “obligate out crossing” (Nowak *et al*, 2014). SI plays an important role in shaping the spatial and temporal distribution of genetic diversity in plant populations and is thought to influence patterns of lineage diversification in clades within which these mechanisms are utilized. The vast majority of *Coffea* species are known to exhibit a strong GSI response, but three African species (*C. arabica*, *C. anthonyi* and *C. heterocalyx* Stoff.) are exceptional for their ability to self-fertilize i.e. self-compatibility (Davis, *et al.,* 2006)

The narrow geographic origin and its self fertilizing nature have contributed to its low genetic diversity around the world (Chaparro *et al*., 2004). The glaciations phase of the quaternary period is another reason for the low level of arabica coffee variability (Lashermes *et al*., 1993)

The structural design of the coffee tree is a feature of tree growing in tropical forests. It has one main vertical trunk (orthotropic) with primary, secondary and tertiary horizontal branches. The growth has a typical form of monopodial branches and the primary branches remain subsidiary to the main stem growing indefinitely by the extension of the apical dominance (Wrigley, 1988; Witgens, 2004).

The root structure consists of a stout central root that extends 30 to 45 cm from the soil surface. The stem and leaf tissues all originate in the dome shoot apex, which measures 220 - 360µm in height. The leaves are born in opposite pairs on the side of branches. In the axils of each leaf on the primary branch there are three to six buds borne one above the other in a serial pattern, closely packed and covered with a gum like substance. As the buds grow, some become visible above the stipules. Each bud in an axial can develop in to a new branch, or an inflorescence with one or more flowers, or remains undifferentiated. When the flower buds are 4-5mm long, they remain dormant until stimulated in to flowering. The stigma of the flowers is receptive for 48 hours any one blossoming. The fruit of coffee tree is a drupe that normally contains two seeds but occasionally more. It is commonly referred to as a cherry or berry. Though the majority of coffee fruits contain two symmetrical normal beans, variations do occur due to genetic or environmental causes. The abnormalities could be triangle, elephant bean, pea berry, empty beans, and misshaped beans (Wrigley, 1988).

2.2. Coffee Production in Ethiopia

The broad genetic base population of arabica coffee in Ethiopia and the diverse types of the ecologies in the country offered opportunity to produce distinct types of coffee quality but, the productivity is still at low level. The national average coffee yield has not exceeded six quintals per hectare and this is much lower than the average productivity in other countries (Yonas *et al.,* 2014)

Though Coffee grows in various parts of Ethiopia, commercially coffee production is practiced at southwestern, Western, Southern and Eastern regions. Each of these regions is characterized by distinct coffee flavor. From all regions, Southwestern part of Ethiopia is the major coffee production area. This region includes the administration zones of Ilu - Ababora, Keffa Sheka, Jimma and Wellega, which are considered as the home of the crop (Paulos, 1994).

It is believed that Arabica coffee has been grown for long period in Western Wellega region. At Anfilo coffee grows as main cash source in the area since the time immemorial as wild even today. However; the production practice is still so traditional and productivity is low compared to the world standard. Among the major factors that contributes to low productivity for each distinct environment and poor management practices are the major ones (Melaku and Samuel, 2000).

Wellega stands the third largest coffee-producing zone in the Oromia region preceded by Jimma and Ilu- Ababora (Melaku and Samuel, 2000). Coffee from this zone is famous for its attractive flavor and fetches premium price in the world market. For this reason considerable attention has been given to improve and produce the land races of the region. In this regard to improve the wellega local landraces Haru Research Sub- Centre has been established on 1998.

Improved coffee lines require relatively high management input as compared to the local types that give considerable yield levels with minimum follow ups including slashing and hoeing as the survey report of Tsegaye and Taye (2002) conducted at Haru Woreda showed. In agreement to this report (Bayetta,1997) reported that indigenous coffee cultivars are location specific and management practices also vary slightly from region to region. The assessment by Tsegaye and Taye (2002) also signify that 70% to 80% of the local farmers depend on the production of the local coffee types. Similar to other areas in Ethiopia, Wellega coffee types exhibits a number of desirable attributes like disease resistance, high yield potential, long production without stumping, good vigor, good quality, attractive bean size, etc. in support of this idea indicated that land races are good source of genetic variation for qualitative traits and quantitative traits, and possesses good adaptation to specific environmental conditions (Tsegaye and Taye, 2002).

There is little research work done on Wellega coffee land races in this regard and the available genetic resources are not properly exploited. The land race development research program initiated by JARC in 1998 was aimed at making use of these enormous genetic potential and develop high yielding cultivars that possesses the typical quality of the specific production niches.

Production of coffee in Ethiopia is grouped in to four major systems: forest, semi forest, garden and modern coffee plantation system (Workafes and Kassu, 2000). The main activities conducted in semi forest coffee production system is through thinning of over story trees, exclusion of ground vegetation and enrichment of bare spaces in the forests by transplanting naturally regenerate or raised seedlings. This system represents about 24 percent of the total land covered by coffee, and contributes about 20 % of the total coffee production in the country and estimated average yield to be in the range of 400-500 kg/ha It is also less than 900 kg per hectare in all major coffee producing countries (Paulos and Demel, 2000; Weldemariam *et al.,* 2002; Yonas *et al.,* 2014).

From the total land covered with coffee about 33% constitutes forest coffee and contributing 25% of the total production while the garden coffee and modern plantation coffee production systems contribute 70 and 5 percent of the total coffee production in the country, respectively (Tadesse *et al.*,2008).

The system in plantation coffee is cultivation after land preparation with systematic soil preparation and seedling planting, and managed in order to maximize the volume of production and productivity. This division includes a few large private and state farms mainly located in the South-west, as well as many small scale farm spread all over the coffee growing areas. It shares 10% of national production (Labouisse *et al*., 2008).

The forest coffee ecosystem practiced by majority of local farmers through traditional practices to produce the coffee as the means of source of income (Weldemariam *et al.,* 2002). Thus, apart from its value as the world's most important gene pool, the existing coffee forests also contribute a lot to coffee production in Ethiopia (Kasahun *et al*., 2006).

2.3. Diversity of *Coffea arabica* L.

Among many species of the genus Coffea, *Coffee arabica* is one which has low caffeine, high lipid and sugars contents (Coste, 1992). It is the only tetraploid and self fertile species with approximately 90% self-pollination (Carvalho *et al.,* 1991). All the other coffee species are self-incompatible and diploid with 2n=22 chromosomes.

Highlands of South Western Ethiopia is native to *Coffee arabica* L. and suited to high altitude regions and produces good quality coffee with low caffeine content (Sylvain, 1955; Bethouly and Etienne, 2000). Formerly, *Coffee arabica* is believed to be characterized by narrow genetic diversity, which is attributed to its allotetraploid origin and mode of speciation.

However, at present, the genetic diversity within the Arabica coffee population in its homeland, Ethiopia, is so huge and this is believed to be mainly the result of mutation of major genes conditioning the plant and /or fruit and seed characteristics than of the residual heterogeneity (Van der Vossen, 1981).

Based on a study carried out by Carvalho *et al*. (1991); there are a number of varieties of *Coffee arabica* and more than 40 single gene mutants too. These mutants are extremely variable for a number of characters, for instance, caffeine content, leaf shape, color, growth and shape of the plant, type of the flower, blooming shape and color of fruits and seeds, as well as resistance to diseases. The study conducted by Lashemes *et al* (1995) on coffee germplasm, which were collected from Ilu - Ababora and Keffa area of Ethiopia, showed the presence of relatively large genetic variability among the germplasm.

The germplasm collected and conserved in different gene banks of the world by Guillaumet and Halle (1978) and FAO (1968) implies the existence of many characters of agronomic interest, such as incomplete resistance to orange leaf rust, resistance to nematodes and coffee berry disease (Van der Vossen, 1985). Using the same materials Anthony *et al.* (2001) showed that Ethiopian cultivars such as Anfilo revealed diversity comparable to that of wild coffee.

As discussed by Walyaro (1983) the existence of variability in morphology and quality aspects such as bean size and cup quality mainly attributed by genotype as well as environment.

Later on studies indicated in agreement with the earlier results that genotype environment interaction can be a major source of variation for most of the bean and morphological characters studied (Agwanda *et al.*, 1997). This finding supports the recent coffee improvement approach in the country. Among the verities of *Coffea arabica*, variety, typical and *Coffee arabica variety, bourbon* is the predominantly well-known verities in the world. The bourbon type is considered to be a recessive mutant, the tree is smaller than the typical variety, has compact plant with short internodes (Coste, 1992).

2.4. Arabica Coffee Ecology

Arabica coffee is a tropical plant and requires conducive environmental factors for successful growth and development such as the right balance of sunlight, rain fall, wind, soil quality and optimum temperature and is not good in frost tolerance and do not react well to frost (Leroy *et al.,* 2006). The ideal temperature for growth of coffee depends on the species of coffee for example; coffee Robusta can tolerate hotter temperature than coffee Arabica. Altitude also affects the success of coffee cultivation (Wrigley, 1988).

Rainfall is of primary importance for the cultivation of all species of coffee. The rainfall should be well distributed with a defined dry season, preferably in the cooler part of the year, with mists or low cloud frequent in the hotter part of the year. A rain fall of 1200mm to 1500 mm with optimum temperature of 15^0c to 23^0c during the year without long hot, sunny and dry season, is necessary for regular crop production (Wrigley, 1988).

Coffee is reported to tolerate annual precipitation of 4.8 to 42.9 dm annual temperature of 16.0 to 28.5°C and pH of 4.3 to 8.4 .Arabica coffee thrives from humid tropics to temperate climates from 5°N lat. to 34°S lat. where temperatures average 11-26.5°C, and from sea level to 2,500m altitude. The rainfall needs to be regular, abundant and well distributed that ranges from 800-2,500 mm. Ideal rainfall amount conditions at the equator are 1500-1800 mm. A short, relatively dry season may facilitate flowering and/or pollination. Native Ethiopian soils are deep red to brown-red lateritic loams or clay loams of volcanic origin of high to medium fertility with pH 5.3 - 6.6 (James, 1983).

2.5. Coffee Research in Ethiopia

Different coffee types were collected from Ethiopia by foreign experts for use abroad. The first extensive collections have been made by FAO in 1964 and 1966 G.C. (FAO, 1968). Jimma Agricultural Technical School (JATS) with the help of Sylvain and Food and Agriculture Organization (FAO) has launched a preliminary coffee improvement work in 1956 (Krug, 1958). A comprehensive research work on Arabica coffee was, however, started after the establishment of Jimma Agricultural Research Center (JARC) of the Institute of Agricultural Research (IAR) in late 1967. The major objective of JARC was (1) to collect and conserve germplasm (2) to develop cultivars that combine high yield, disease resistance and good quality and (3) to multiply and supply improved seed (IAR, 1969).

The initial coffee research by JARC was started in 1967, with the materials obtained from French collection mission (Bayetta, 1997). Later on, however, JARC had launched a long term national collection program which was effective since 1970. In this program efforts have been made to cover all the coffee growing areas and capture maximum genetic variability for selection, breeding work and conservation for future use. Since its establishment the center has released a number of CBD resistant selections and high yielding hybrids for high altitudes where the disease is the major production constraint. Subsequently, the center has also released high yielding and CBD resistant selections for the mid and low altitude areas (Bayetta and Behailu, 1998).

2.6. Breeding *Coffea arabica* L.

Coffee arabica L. is one of the very few examples of perennial plant to which breeding methods common to self-pollinated crops have been applied successfully (Sera, 2000). Successful breeding program in any crop depend on the exploitation of the available germplasm. Since Ethiopia is the center of origin and genetic diversity *of Coffee arabica*, there is an immense potential for the improvement of the crop through selection and hybrid development. The objective of all countries towards the improvement of arabica coffee is largely centered on the development of cultivars, which have the potential to yield optimum economic return

to the coffee growers. Similarly, in Ethiopia, the aim of breeding programs on *Coffee arabica* L. is focused on the development of high yielding and disease resistant cultivars with good quality (Yonas, 2014)

Four basic methods of breeding and selection in *Coffee arabica* L., distinguished Van der Vossen (2001) with increasing complexity from line to intra and interspecific hybridization. In *Coffea arabica* L., line selection is efficient because of its self pollinating nature. As indicated by Van der Graaf (1981) selection program from the natural source of population is effective in pure line selection. However, the application of these strategies could be varied depending on breeding objectives and expected output.

2.6.1. Selection in *Coffea arabica* L.

In selection, the ability to effect genetic improvement depends on judging whether a certain line is genetically superior to others or not. As described by Van der Vossen (2001), selection is one of the basic breeding strategies in *Coffee arabica* L. improvement program. According to Allard (1960) selection in breeding program has certain essential aspects of selection within a base population of genetically variable individuals and utilization of the selected material for the creation of new population to be employed either as potential newly coming varieties, or as an important parent for combination breeding.

The available information in earlier studies on coffee collection and selection in Ethiopia well confirmed the presence of high genetic variability within the arabica coffee population for yield, CBD resistance, growth and quality characters (Bayetta, 1997). A genetic advance of 2.2 kg fresh cherry per tree (at 20% selection intensity) has been reported in some studies. These results generally suggest the possibility to bringing improvement through selection. This also shows the possibility of selection to act when there is variation and the possibility to isolate lines with different value of traits. Van der Vossen (2001) indicated an overview to the selection criteria to be considered during coffee improvement program, which includes yield, plant vigor, plant arctecture, bean size, liquor quality and resistance to diseases and insect pests.

Biometrical genetic studies in *Arabica coffee* (Walyaro and Van der Vossen, 1979) have shown the selection efficiency for higher yield is increased considerably by taking into account various growth parameters and components of yield such as stem girth, canopy radius, percentage of bearing primaries, percentage of bearing nodes number of berry per node, Internodes length and angle of primary on main stem are important characters. In addition, arabica coffee selection was found to be more effective when cultivars are tested in their place of origin than when tested in other environment (Bayetta, 1997).

2.6.2. Early stage selection in coffee

In coffee, notably the species *Coffee arabica* L., it takes many years of observations to estimate productivity in genetic trials (Cilas *et al.,* 2002). However, premature evaluation system for yield (Walyaro and Van der Vossen, 1979) can bring fast progress in selection, resulting in new cultivars with larger genetic progress in shorter time.

This approach is commonly used for both autogamous and allogamous species, to select individual inbred lines or populations at early stages of endogeny (Sera, 2000). According to Medina *et al*. (1984) Selection in initial years is highly desirable in the genetic improvement of coffee plant. Understanding the components of yield and their correlation can aid in the indirect selection of promising genotypes for productivity (Gifford and Evans, 1981).

In addition, Walyaro (1983),Walyaro and Van der Vossen (1979) further added to the significance of early selection that indicated high genotypic correlation between 2-3 years yield records and 10-year yield totals. Sera (2000), indicated that early determination of yield and genetic advance based on the index comprising the first two years yield, stem girth, and percentage bearing primaries was 97% efficient compared to straight selection based on 10years yield total.

Moreover, research findings reported that, the expected genetic advance based on incorporating a few growth parameters (girth, canopy radius, percentage of bearing primaries) and the first 2-3 years yield data of the individual trees showed to be as large as that obtained by straight selection based on yield totals or plot means over several years (Sera, 2000). Further

study by Cilas *et al.* (2002) also indicated selection for high productivity can be achieved by using performance of the first year yield, stem diameter, tree height and number of primary branches.

2.7. Phenotypic and Genotypic Coefficients of Variation

Variation is the occurrence of differences among individuals due to differences in their genetic composition and/or the environment in which they are growing (Allard, 1999). Phenotypic variability is the observable variation present in a character in a population; it includes both genotypic and environmental components of variation and as a result its magnitude differs under different environmental conditions. Genotypic variations, on the other hand, is the component of variation which is due to the genetic differences among individuals within a population and is the main concern of plant breeding (Singh, 2003).

The geographic allocation of coffee within its homeland is another good indication for the existence of genetic variation within a population. And also the screening of selected coffee berry diseases resistant varieties and heterotic hybrid cultivars through crossing (Mesfin and Bayeta, 2001, 1987) and Van der Graaff (1987) are indicators of genetic variability.

2.8. Heritability (H^2b)

Heritability is a ratio of the total genotypic variance to phenotypic variance. The proportion of total variation caused by the genotype is heritable and can range from a value of one, where all variation is genetic, to zero, where all variations results from the environment (Sing, 2001; Acquaah, 2012 ;). The effectiveness of selection for a particular trait largely depends on the relative importance of genetic and non-genetic factors in the expression of phenotypic differences among genotypes in a population. Heritability indicates the relative importance of the genetic and environmental source of variation in the character and it is sometimes known as degree of genetic determination of the character. According to Fehr (1987) and Welsh (1981) heritability in the broad sense encompasses all types of gene actions including dominance, additive and epistasis.

Heritability of yield per se is generally reported to be low in most crop plants. While the report in coffee yield showed low to moderate heritability in coffee grown on toped single stem under shade. In other studies, it has been reported that internodes length show high heritability

followed by number of primaries and stem girth while yield had moderate heritability. On the other hand, Cilas *et al*. (1998) reported a high heritability estimates in characters such as yield, stem girth and tree height.

The knowledge of magnitude and type of genetic variability and their corresponding heritability of a trait help to determine the efficiency of selection strategy to use in breeding program. Because selection of superior genotypes is proportional to the genetic variability present and the extent to which the characters are inherited (Nechifor *et al.,* 2011).

Heritability indicates the effectiveness with which selection of genotypes can be based on phenotypic performance Walyaro and Van der Vossen (1979) obtained high heritability value for internodes length (90%) and number of primary branches (85%) whereas moderate values for stem diameter (43%) and nodes on the longest primaries (30%). On the other hand, Mesfin (1982) observed broad sense heritability for yield to be 55% and 44% for eight top selection of Arabica coffee. Similarly, Van der Vosen (1985) estimated from diallel crosses of 11 coffee cultivars that most of the growth and bean size characters such as girth of main stem (64%), tree height (70%), canopy radius (65%), internodes length (74%), angle of primary with main stem (60%), and 100 bean weight (74%) have high heritability.

In addition, Bayetta (2001) also reported high broad sense heritability for 15 of the 18 morphological characters studied on six elite parental lines and their 15 F1 crosses for characters like stem diameter, number of leaves, height, shoot fresh weight, root dry weight, number of nodes in the range of 71.43% to 97.32%, suggesting that effect of environment on the phenotypic expression of the characters is minimum which is good for improvement through selection.

Yigzaw (2005) obtained moderate broad sense heritability for seedling height (42.4%), internodes length (56.9%), total number of stem nodes (54.5%), leaf length (63.9%), leaf width (65.7%), stem diameter (40.1%), leaf area (55%). But on the contrary, broad sense heritability varied from 38% for bean thickness to 94% for bean weight and number of secondary branches per tree whereas all characters measured greater than 50% broad sense heritability except bean thickness (38%) and percentage of bearing (39%). Primary branch for eighteen

characters studied on coffee Arabica germplasm, indicating high heritability for most of the characters.

2.9. Expected Genetic Advance

According to Allard (1960), genetic advance measures the expected genetic progress that would result from selecting the best performing genotype for a given character. It indicates the improvement of the performance of the selected genotype over the original. Heritability value by itself does not indicate the amount of genetic progress that would result from selecting the best individuals. Thus the utility of estimates of heritability, therefore, increase when they are used in concurrence with selection differential, the amount that the mean of the selected lines exceeds the mean of the entire group (Johnson *et al.,* 1955). Yigzaw (2005) reported that larger genotypic coefficients of variation along with high heritability and high genetic advance provide better information than each parameter alone. Therefore, characters that exhibit a high genotypic coefficient of variation, heritability and genetic advance are useful as the base of selection. High heritability value could be obtained with accessions having small or large genotypic variance, but genotypic progress would be larger with larger genotypic variance (Allard, 1999).

Although, the available information about genetic advance for various yield related traits in *Coffea arabica* L. in Ethiopia is scanty some investigations carried out elsewhere exhibits higher genetic advance for primary branch (67%), total nodes per plant (87%) and internodes length of primary (26%) (Srinivasan, 1988). In Ethiopia, some reports indicated that genetic advance through selection for yield at 20% selection intensity was up to 2.2 kilogram of fresh cherry per tree, confirming the presence of high genetic variability within Arabica coffee population. Therefore, the opportunity to bring a reasonable improvement through selection is high (Bayetta, 1997). In addition, Mesfin (1980) obtained genetic advance for yield to be 1.4 kilogram fresh cherry/tree from indigenous coffee collections grown at Jimma.

This result indicates the genetic advance that can be made through selection directly for yield and /or indirectly by using yield components. It has been indicated that if the heritability of a trait is very high, then the phenotypic value will be a good indicator for its advancement through selection (Narain, 1990).

2.10. Correlation

According to (Acquaah, 2012) coefficient of correlation is the term used to explain the degree of amount of correlation between independent variables. If both traits are increased, the result is a positive correlation. If one is increased and the other decreased, there will be a negative correlation. The correlation coefficient always lies between -1 and +1. -1 indicates perfect linear negative relationship between two variables on the other hand +1indicates perfect positive linear relationship and zero indicates lack of any linear relationship (Steel *et al.*, 1997).

Charier (1998) obtained a high and positive correlation between height and stem diameter of arabica coffee, According to Berthaud and Charrier (1998), among the seven vegetative characters studied in thirty-four coffee arabica populations in Ivory Coast, number of nodes of the side branches and of the main stem and their basal diameter were found to have positive correlation.

Correlation at the genetic level may arise from different factors. Correlation arising from pleiotropy expresses the extent to which two characters are influenced by the same gene. But the correlation resulting from pleiotropy is the overall or net effect of all segregating genes that affect both characters in which some genes may increase both characters, while others increase one and reduce the other; the former tend to cause a positive correlation, the later a negative one (Welsh, 1981).

Yield in coffee has been shown to depend to some degree on the vegetative vigor of the tree (Walyaro, 1983). Because of their correlations of growth and yield characters are commonly considered in the evaluation of genotypes for productivity. Thus, it is essential to include such genetic estimation in selection and hybridization programs for improvement of yield particularly perennial crop like coffee (Mesfin, 1982). Therefore, correlation assessment may help as an aid to identify traits that are indicative of yield potential and be used for evaluation of genotypes at early bearing stage.

According to Srinivasan (1982) coffee morphological characters such as stem girth, width of canopy, number of primary branches and number of secondary branches have strong correlation with yield. In his research, Mesfin (1987) observed positive and significant correlation

between total growth and girth diameter growth and number of fruits (0.69) and growth and number of nodes on primary branches. Furthermore, Mesfin and Bayetta (1983) reported positive correlation of mean F1 yield with girth number of flowers and fruits length of the first primary branch number of nodes on primary branches (0.52), number of bearing nodes on primary branches and number of secondary branches (0.46). Yigezaw (2005) also reported correlation analysis performed among 18 agro – morphological characters indicated positive association between average green bean yield per tree with percentage of bearing primary branches per tree bean weight, canopy diameter trunk diameter, tree height, bean length, bean thickness (0.66), internodes lengths of orthotropic internodes lengths of primary branches fruit length and petiole lengths.

2.11. Genotypic Correlation Coefficients

Genotype correlation coefficients provide a measure of genetic association between traits and thus help in identifying the most important as well as the least important traits to be considered (Sylya and Carvalho, 1997). The association between two characters that directly observed is the phenotypic correlation, which is determined from the measurements of the two characters in number of individuals of the population (Singh, 1990).

In relation to coffee, Ermias (2005) reported that morphological characters, such as stem girth, canopy, fruit length, number of main stem nodes, canopy diameter and average internodes length of primary branch had positive and significant association with yield on coffee. Similar trends were reported by Seyoum (2001).

2.12 Genetic Distance

Genetic distance is a measure of the genetic divergence between species or between populations within a species (Nei, 1987). Populations with many similar genes have small genetic distances. This indicates that they are closely related and have a recent ancestor. The concept of genetic distance has been of vital importance in many contexts and more so in differentiating well defined populations (Van Hintum, 1995).

A systemic study and characterization of coffee germplasm is of great importance for current and future agronomic and genetic improvement of the crop. Mesfin and Bayetta (2008)

reported that morphological parameters have been widely used in the evaluation of *coffee arabica*. Exploration of such traits increases our knowledge of genetic diversity available and strongly facilitates breeding for wider geographic adaptability, with respect to biotic and abiotic stress. In addition, genetic diversity needs to be described and measured if it is to be effectively incorporated into breeding strategies and management of plant genetics resources (Agawanda, 2003).

2.13. Cluster Analysis

Cluster analysis is a multivariate analysis technique involving partitioning a set of objects into groups so that objects within group are more similar and objects in different groups are more dissimilar (Crossa *et al.* ,1995). One of the stages in clustering task is selecting a clustering strategy (Jain and Dubes, 1988).In this stage, a particular clustering algorithm is selected that is suitable for the data and the desired clustering type. Selecting a clustering algorism is not an easy task and requires the consideration of several issues such as data types, data set size and dimensionality, data noise level, type of shape of expected clusters, and overall expected clustering quality. Multivariate analysis of morphological quantitative characters and qualitative characters using cluster analysis has been used previously to measure genetic relationships within crop species Examples includes coffee (*Coffee arabica L*.) Mesfin and Bayetta (2005) and Getachew (2012) grouped 104 and 49 coffee accessions of 14 and 22 characters into 6 and 5 clusters respectively

2.14. Principal Component Analysis

Principal component analysis (PCA) is mathematically defined as an orthogonal linear transformation that transforms the data to a new coordinate system such that the greatest variance by some projection of the data comes to lie on the first coordinate (called the first principal component), the second greatest variance on the second coordinate, and so on.

It used as a method of data reduction to clarify the relationships between two or more characters and to divide the total variance of the original characters into a limited number of uncorrelated new variables (Katarzyna *et al*. 2013; Hammer *et al.,* 2001).

This will allow visualization of the differences among the individuals and identify possible groups. The reduction is achieved by linear transformation of the original variables into a new

set of uncorrelated variables known as principal components (PCs). The first step in PCA is to calculate eigen values, which define the amount of total variation that is displayed on the PC axes. The first PC summarizes most of the variability present in the original data relative to all remaining PCs. The second PC explains most of the variability not summarized by the first PC and uncorrelated with the first, and so on (Hammer *et al.*2001). Because PCs are orthogonal and independent of each other, each PC reveals different properties of the original data and may be interpreted independently. In this way, the total variation in the original data set may be broken down into components that are cumulative. The proportion of variation accounted by each PC is expressed as the eigen value divided by the sum of the eigen values. The eigenvector defines the relation of the PC axis to the original data axis. It also reflects the importance of the largest contributor to the total variation at each axis of differentiation (Sharma, 1998). A mathematical procedure uses an orthogonal transformation to convert a set of observations of possibly correlated variables into asset of values of linearly uncorrelated variables**.** The eigen values are often used to determine how many factors to retain. The sum of the eigen values is usually equal to the number of variables.

According to (Sharma, 1998), characters with largest absolute value closer to unity within the first principal component influence the clustering more than those with lower absolute value closer to zero. The differentiation of the 49 Arabica coffee accessions studied by (Getachew *et al.*, 2013; Olika *et al.*, 2011) into different clusters was because of relatively high contribution of few characters rather than small contribution from each character. Accordingly, the first principal component had high positive component loading from traits such as internodes length of main stem, primary branches, leaf length and hundred bean weights. The positive and negative loading shows the presence of positive and negative correlation trends between the components and the variables. The characters, which load high positively or negatively, contributed more to the diversity and they were the ones that most discriminated the cluster.

2.15. Path Analysis

Path coefficient analysis, which is simply a standardized partial regression coefficient, partitions the correlation in to direct and indirect effect (Dewey and Lu, 1959). They also reported the use of this method requires cause and effect relationship among the variables, and the experimenter must assign direction in the casual system based up on priori grounds of experi-

mental evidence. Partitioning the correlation coefficient into direct and indirect effects can be done through path analysis technique (Dewey and Lu, 1959). Path coefficients have been used to develop selection criteria for complex traits in several crop species of economic importance such as coffee (Ermias, 2005), cotton (Tariq *et al.*, 1992).

Although estimates of correlation coefficients are helpful in determining the components of a complex trait yield they do not provide an exact picture of the relative importance or direct and indirect influences of each of the component characters on yield (Bhatt 1973). Path coefficient analysis allows a more precise elucidation of the pattern of interaction of other known factors. It permits identification of direct and indirect causes of association and measures the relative importance of each character (Ariyo *et al.*, 1987). It is obvious that yield is the result of yield correlated characters and some other undefined factors.

Therefore, the use of this method requires a cause and effect relation among the variables (Dewey and Lu, 1959). Yield in coffee is commercially an important trait, which is considered in most, if not all, breeding goals of coffee improvement. Therefore, it is desirable to know the direct and indirect effect of yield related traits in coffee yield. These traits could be useful indicators in breeding programs to select coffee genotype for yield. The work by Seyoum (2001) showed that out turn ratio had the highest positive direct effect (0.729) on yield followed by angle of primaries (0.555) and number of bearing primaries (0.371). Studies in Kenya suggested that, yield components such as plant height, numbers of primaries, and stem girth are important parameters to use in selection for yield potential (Walyaro and Van der Vossen, 1979).

Olika *et al.* (2011) reported that yield per plant showed significant and positive direct effect on bean width, fruit length, leaf length and hundred bean weight and plant height. Therefore, indirect selection for these traits may be effective in developing high yielding coffee variety and the findings of this result emphasized the role of bean width upon ultimate increase of grain yield

3. MATERIALS AND METHODS

3.1. The Study Area

The experiment was conducted at Haru sub center of Jimma Agricultural Research Center. The sub center is 468 km far from Addis Ababa and located at $8^0$58' N latitude and 35^0 48' E longitudes and at an altitude of 1750 meters above sea level. The mean annual rainfall of the area is 1727 mm per annum with an average maximum and minimum air temperatures of 27^0C and16^0C, respectively. The major soil type of the area is dark reddish brown, with p^H of 4.8-5.6 (Tsegaye and Taye, 2000).

3.2. Experimental Material and Design

One hundred eleven *C. arabica L*. accessions which have been collected in the year 2009 from the Dega and Sasiga woreda of East Wellega zone and four standard checks namely: Menesibu (78/84); Haru1 (W66/98); Chala (W76/98) and Sende (W92/98) were used for the study (Table 1). The experiment was superimposed during the 2014/15 cropping seasons on six years old coffee trees.

The seedlings were field planted on July, 2009 in augmented design and mulched immediately after planted. Each seedling was protected from direct sunlight by grass hut and
The huts were removed when the dry months ends. Shade trees were planted with a spacing of 4m by 4m. Each plot consisted of ten trees in single row. Spacing between rows and plant were 2m by 2m, respectively. The plots received uniform application of fertilizer (120g DAP & 81g urea per tree) in three split and other recommended cultural practices were performed throughout the period of data collection as per EIAR/JARC coffee production manual recommendation.

3.3. Data Collected

For data collection IPGRI (1996) descriptor was used

I.Quantitative data

The sample taken is random for all variables

a) Leaf characteristics/average of five one year leave (IPGRI, 1996)

- ❖ Leaf length (cm) – average of five one year leaves were measured from petiole end to leaf apex and mean of five leaves were used for statistical analysis.
- ❖ Leaf width (cm) - five one year leaves were measured at the widest part and the mean of five leaves were used for statistical analysis.
- ❖ Leaf area (cm^2) - average length and width of five leaves were measured and the mean of the five leaves were used for statistical analysis.
- ❖ Leaf petiole length (cm) – average of five leave petiole length was measured from the base to insertion of the blade and the mean of the leaves were used for statistical analysis.

b) Stem characteristics

- Plant height (cm) – the height from the ground level to the tip of the tree was measured for five trees and mean of five trees heights were used for analysis.
- Number of nodes on main stem- nodes on main stem were counted on five tree and mean of five trees were used for analysis
- Internodes length (cm) – from total height, the height from ground up to first primary branch is deducted and divided by one less number of node and the mean of five trees were used for statistical analysis.
- Girth (cm) – main stem of five trees was measured at five cm above the ground and the mean of five trees were used for statistical analysis.
- Height up to first primary branch (cm): The height from ground level up to first primary branch was measured for five trees and the mean was used for statistical analysis.

c). Branch character

- o Length of longest first primary branch (cm): The average length of first primary branches was taken on five trees and the mean was used for analysis.
- o Canopy diameter (cm): The diameter of the bush of a tree was measured in East-West and added to the South North diameter and divided by two. Finally the mean of five trees canopy diameters were used for the analysis
- o Number of primary branch –all primary branches were counted on five representative trees and mean of the five trees were used for statistical analysis

d). Fruit character –five normal and matured fruits were measured (IPGRI, 1996)

- Fruit length (mm) - five normal matured fruits were measured at the longest part and the mean of the five fruits were used for statistical analysis
- Fruit width (mm) - five normal matured fruits were measured at widest part and mean of the five fruits were used for statistical analysis
- Fruit thickness (mm) - five normal matured fruits were measured at thickest part and the mean of the five fruits were used for statistical analysis.

e) Bean character – Average of five normal matured fruits were measured (IPGRI, 1996)

- Bean lengths (mm) – length of five normal matured beans were measured at maximum longest part using caliper and the mean of five beans were used for statistical analysis.
- Bean widths (mm) – width of five normal matured beans were measured at widest part and mean of the five beans were used for statistical analysis.
- Bean thickness (mm) – thickest part of five normal matured beans was measured at thickest part and mean of the five beans were used for analysis.
- 100-coffee beans weight: The weight of 100 coffee beans was weighed using sensitive balance at a standard moisture level of 11%.
- Yield of fresh cherry (g): Total fresh cherry yield harvested from all the 10 trees in a plot was measured in grams and used to compute mean yield per tree

Table 1. List of Arabica coffee accessions those used for morphological variation study

Accession	Collection altitude(masl)	Peasant assosa-tion	Specific site	Woreda	Total no collected
EW1/09,EW106-108/09	1706 -1732	Tokuma Tsige	Tsige	Sasiga	4
EW2 - 3/09	1700		Legagorba	Sasiga	2
EW4 – 5/09	1660	Ambelta	Migna	Sasiga	2
EW6 – 9/09	1891 -1940	Harogudina	Babuserte	Sasiga	4
EW10 -13/09	1882 – 1900	Feyneterano	Gabajimata	Sasiga	4
EW14/09	1724	Walkituma	Tufisa	Sasiga	1
EW15 -17/09	1711		Werasayo	Sasiga	3
EW24-35/09	1518 -1695	Lomicha	Gidugalesa	Sasiga	12
EW36 -40/09	1579 -1599		Weligalte	Sasiga	5
EW18 -20/09	1695		Lelistu	Sasiga	3
EW21 – 23/09	1600 -1630		Gidu	Sasiga	3
EW41 – 51/09	1921 -1968	Galojanja	Ayeru	Sasiga	11
EW52 – 61/09	1866 -1871		Arya	Sasiga	10
EW62 – 74/09	1782 – 1832	NanoSenbetadure	Hadiya	Sasiga	13
EW75 -80/09	1715 -1735	Megalagallo	Gallo	Sasiga	6
EW81 – 82/09	1670		Kumburo	Sasiga	2
EW104/09	1750		Senbetadure	Sasiga	1
EW83 – 90/09	1664 -1708	Gemene	Ayra	Sasiga	8
EW91 – 96/09	1683 – 1688		Bata	Sasiga	6
EW97 – 102/09	1635 – 1649	Oda	Bosoka	Sasiga	6
EW103/09&EW105/09	2100	7	Sasiga	Sasiga	2
EW109 – 110/09	1615 – 1630	Bedasa Jarso	Mender misreta	Dega	2
EW111/09	1888	Harofeysa	Haro	Dega	1
Total number of accessions collected					111

ii. Qualitative Data

Qualitative data of 14 characters, namely overall appearance, branching habit, angle insertion of primary branch, young leaf color, leaf shape, leaf apex shape, leaf petiole color, young shoot color, mature fruit color, fruit shape, absence or presence of fruit ribs, calyx limb persis-

tence, seed color and seed shape were evaluated according to a descriptor of coffee developed by international plant genetic resource institute (IPGRI, 1996) (Table 2)

Table 2. Lists of morphological and agronomic characters considered in the study

Character	Description and code
Overall appearance	1 = Elongated conical 2 = Pyramidal 3 = Bushy
Branching habit	1= Very few primary branches 2= Many primary with few secondary branches 3= Many primary with many secondary branches 4= Many primary with many secondary and tertiary branches
Angle of insertion of primary branches	1= Drooping 2= Horizontal /spreading 3= Semi- erect
Young leaf color	1= Greenish 2 = Green 3= Brownish 4 = Reddish brown 5= Bronze 6 =Other
Leaf shape	1= Obovate 2= Ovate 3= Elliptic 4= Lanceolate 5= Other
Leaf apex shape	1= Round 2= Obtuse 3= Acute 4= Acuminate 5=Apiculate 6 = Spatulate 7= Other
Leaf petiole color	1= Green 2= Dark brown 3= Other
Young shoot color	1= Green 2= Dark brown 3= Other
Mature fruits color	1= Yellow 2 =Yellow-orange 3 = Orange 4 = Orange-red 5= RED 6 =.Red-purple 7 = Purple 8 = Purple- violet 9 = Violet 10 = Black 11= Others
Fruit shape	1= Roundish 2= Obovate 3= Ovate 4 = Elliptic 5= Oblong 6 =.Other
Absence or presence of fruit ribs	0 = Absent 1= Present
Calyx limb persistence	0 = No 1 =Yes
Seed color (At 11% humidity)	1= Yellow 2 = Brown-purple 3= Other
Seed shape	1= Round 2= Obovate 3= Ovate 4 = Elliptic 5= Oblong 6.Other

3.4. Statistical Analysis

3.4.1 Analysis of variance (ANOVA)

Data were subjected to analysis of variance (ANOVA) using SPAD (Statistical Package for Augmented Design) software based on randomized complete block augmented design (Table 3). Least Significant Difference (LSD at P = 0.05) was employed to identify accessions that are significantly different from each other. The analysis was carried out according to the following model (Federer, 1956).

$$Y_{ij} = \mu + g_i + c_j + \beta_j + \varepsilon_{ij}$$

Where: yij is the observation of treatment i in j^{th} block μ is the general mean, g is the effect of test treatment, cj is the effect of control treatments in j^{th} block, βj is the block effects, (ε) is the error term

Table 3.Analysis of variance (ANOVA) of augmented design

Source of variation	Df	SS	MS	F-value
Block(adj)	(b-1)	SSb	MSb	MSb/MSe
Trt (adj)	(c+g) -1	SSt	MSt	MSt/MSe
Among-controls	(c-1)	SSc	MSc	MSc/MSe
Among-test	(g-1)	SSg	MSg	MSg/MSe
Test-v- Control	1		SSe/(c-1)(b-1)	
Error	(b-1) (c-1)			

Where: b = number of block, C = check varieties, g = genotype, df= degree of freedom, SS = sum square, MS = mean square, SSb and MSb are sum square and mean square of blocks, respectively; SSg and MS_g are sums squares of genotypes and mean square of genotype, respectively; SSc and MSc are sum square and mean square of check variety, respectively; SSt and MSt are sum square and mean square of treatment, respectively.

3.4.2. Estimation of genetic parameter

The phenotypic and genotypic coefficients of variation were calculated according to the form ula suggested by Burtons and Devane (1953) as follows

Phenotypic variance ($\sigma^2 p$) = $\sigma^2 g + \sigma^2 e$

Genotypic variance ($\sigma^2 g$) = Msg - Mse

Phenotypic coefficient of variation (PCV) = $\frac{\sqrt{\sigma^2 p}}{\bar{x}}$ X 100

Genotypic coefficient of variation (GCV) = $\frac{\sqrt{\sigma^2 g}}{\bar{x}}$ X 100

Where:

MSg = mean square due to genotypes

MSe = mean square due to environmental variance (error mean square)

$\sigma^2 g$ = genotypic variance

$\sigma^2 e$ = environmental variance

$\sigma^2_g = \sigma^2_p - \sigma^2 e$

Where, $\sigma^2 p$ = phenotypic variance

$\sigma^2 e$ = environmental variance

$\bar{X}$ = Grand mean

3.4.3. Heritability ($h^2 b$)

Broad sense heritability for all characters were estimated as the ratio of genotypic variance to the phenotypic variance and expressed in percentage according to the methods suggested by Falconer (1989)

Heritability ($h^2 b$) = $\frac{\sigma^2 g}{\sigma^2 p}$ X 100

Where, $h^2 b$ = heritability in broad sense.

3.4.4. Genetic advance under selection (GA)

The expected genetic advance expressed under selection in broad sense, assuming selection intensity of 5% of the superior progeny were estimated in accordance with the method described by Johnson *et al*. (1955) as: $GA = K.\sigma P.h^2b$

Where:

h^2b = Heritability in broad sense; σp = Phenotypic standard deviation on mean basis; GA= Expected genetic advance

k = the standardized selection differential at 5% selection intensity (K = 2.063) constant. Genetic advance as percent of mean were calculated to compare the extent of predicted advance of different traits under selection, using the following formula:

$$GAM = \frac{GA}{\bar{X}} x100$$

Where: GAM = genetic advance as percent of mean; GA= genetic advance under selection and $\bar{x}$ = grand mean of the population

3.5. Cluster analysis

Cluster analysis was employed for both quantitative and qualitative characters to identify accessions that are significantly different from each other. Hierarchical clustering was employed using the similarity coefficients among the 115 coffee accessions. Clustering was performed using the proc cluster procedure of SAS version 9.2 (SAS, 2008) by employing the method of average linkage clustering strategy of the observation. The numbers of clusters were determined by following the approach suggested by Copper and Milligan (1988) by looking into three statics namely Pseudo F, Pseudo T^2 clustering criteria. Genetic divergences between clusters were determined using the generalized Mahalanobis D^2 statistics Mahalanobis (1936) using the equation: $D^2p = (X_i - X_jS^{-1} (X_i - X_j)$

Where: D^2p = the distance between any two groups i and j;

Xi and Xj = the p mean vectors of accessions j and i.

S^{-1} = the inverse of the pooled covariance matrix.

The D^2 values obtained for pairs of clusters were tested for significance at 5% level of significance against the tabulated values of p degrees of freedom, where p is the number of variables considered (Singh and Chaudhary, 1987).

3.6. Principal Component Analysis (PCA)

The principal component analysis for quantitative and qualitative characters was carried out using Statistical Analysis System Version 9.2 (SAS Institute, 2008). Number of factors retained was decided by looking at the Eigen values. The principal components that had Eigen values >1 were selected (Costello and Osborne, 2005) were considered as relevant scores for the PCA and were 0.40 (ignoring the sign) flagged with an asterisk (*) which has been considered as meaningful loadings and significant contributor to distinguish genotypes (Costello and Osborne, 2005; Biabani and Pakniyat, 2008)

3.7 Correlation Coefficient(r)

The genotypic and phenotypic correlation coefficients were computed using the formula

$$r_g = \frac{\text{Covg (X.Y)}}{\sqrt{\text{VargX}} \cdot \sqrt{\text{VargY}}}$$

Where, $C_{ov}g$ (XY) = genotypic covariance between characters X and Y;

$V_{ar}g$ X = genotypic variance of character X;

$V_{ar}g$Y = genotypic variance of character Y

$$r_P = \frac{\text{Covp (X.Y)}}{\sqrt{\text{VarpX}} \cdot \sqrt{\text{VarpY}}}$$

Where: CovP (XY) = phenotypic covariance between characters X and Y

$VarP_X$ = phenotypic variance of character X

$Varp_Y$ is phenotypic variance of character Y

Estimates of genotypic and phenotypic correlation coefficients were compared against r-values given in Fisher and Yates (1963) table at n-2 degrees of freedom, at the probability levels of 0.05 to test their significance, where n is the number of genotypes. To test the significance of correlation coefficients, the following formula adopted (Sharma, 1998):

$$t = \frac{r}{SE(r)}$$

Where $SE(r) = \frac{1 - r^2}{\sqrt{n-2}}$

Where, r is correlation coefficient and n is number of genotypes. To test the significance of correlation coefficient, the calculated t-value can be compared with tabulated t-value at (n-2) degree of freedom at 0.05 levels of probability (Snedecor and Cochran, 1989).

3.8. Path Coefficient Analysis

The path coefficient was estimated with the formula given by Dewey and Lu (1959).

$r_{iy} = r_{1i}P_1 + r_{2i}P_2 + \ldots + r_{Ii}P_i + \ldots + r_{ni}P_n$

Where: r_{iy} = correlation of i^{th} character with bean yield;

$r_{1i}P_1$ = indirect effects of i^{th} character on bean yield through first character;

r_{ni} = correlation between n^{th} character and i^{th} character

n = number of independent variable

P_i = direct effect of i^{th} character on bean yield

P_n = direct effects of n^{th} character on bean yield

Direct effect of different component characters on grain yield were obtained by solving the following equations: (riy) = (Pi) (rij); and (Pi) = (rij) - 1 (r1iPi)

Where: (Pi) = matrix of direct effect

(rij) = matrix of correlation coefficients among all the n^{th} component characters;

(riy) = matrix of correlation of all component characters with bean yield;

(r1iPi) = indirect effect of i^{th} character on bean yield through first character

The residual factor can be calculated as described in Dewey and Lu (1959**).**

$1 = p^2 R + \varepsilon pkj\ rik$

3.9. Shannon - Weaver Diversity Index (H′)

The qualitative data were subjected to analysis of the Shannon-Weaver diversity index (H′) (Shannon and Weaver, 1949) .The Shannon-Weaver diversity index (H′) was computed using the phenotypic frequencies to assess the overall phenotypic diversity for each character. The Shannon-Weaver diversity index as described by Hutchinson (1970) was used to calculate phenotypic diversity for j^{th} trait with n sub classes:

$$h_{sj} = \sum_{i=1}^{n} pilnpi$$

Where pi is the relative frequency in the i^{th} category of the j^{th} trait. To keep Shannon-Weaver diversity index between 0 and 1 the formula suggested by Hennink and Zeven (1991) was used as:

$$H' = -\frac{\sum pi \ln pi}{\ln n}$$

Where: H′= Shannon Weaver diversity index

Pi = is the relative abundance (frequency) of each traits

ln (pi) = the natural logarithm of abundance

piln(pi) = relative abundance of trait, multiplied by the natural logarithm of the abundance

$\sum pi \ln pi =$ is the sum of p*i*ln (*pi*) product.

The negative sign of the sum that was calculated to keep Shannon - Diversity index between 0 and 1 or normalized divided by the maximum value ln(n) in each case the formula suggested by Hennink and Zeven (1991).

H′of 0 indicates that is monomorphic i.e. all individual belong to one and the same category whereas H′ of 1 indicates maximum diversity i.e. individuals are equally dispersed among the n class.

4. RESULTS AND DISCUSSION

4.1. Analysis of Variance (ANOVA)

Mean squares of the 20 characters from analysis of variance (ANOVA) are presented in Table 4. Significant differences among genotypes ($p < 0.05$) were observed for all characters except six characters. Among tests, significant differences were observed for all characters. This indicating the presence of significant difference among the traits considered in this study. Similarly, the work of Olika (2011) showed significant differences among forty nine coffee genotypes of twenty two quantitative characters. The variations observed for measured quantitative characters in this study were also in agreement with the earlier findings of Kebede and Belachew (2005) who reported the significant difference among the genotypes in 100 Hararge coffee accession germplasm using 14 quantitative characters namely: stem girth, leaf area, plant height, number of primary branch, length of longest primary branch.

Table 4. Mean squares of variance of the different characters considered in the study

Characters	Block (DF =3)	Error (DF =12)	A.trt (DF =114)	A cont (DF =3)	A. Test (DF =110)	Test v Con (DF =1)	CV (%)
Leaf length(cm)	0.22ns	0.56	2.26**	1.24ns	1.45*	96.02**	4.77
Leaf width(cm)	1.03*	0.09	0.40**	0.13ns	0.40**	0.40**	4.02
Leaf area(cm^2)	119.52*	31.76	381.17**	172.21*	314.40**	8577.63**	4.71
Petiole length(cm)	0.01ns	0.02	0.04*	0.01ns	0.001*	0.22**	15.34
Bean length(mm)	0.34ns	0.37	1.23*	0.33ns	1.23*	4.51**	6.63
Plant height(cm)	369.98	22.27	346.89ns	184.52ns	347.27ns	735.09ns	11.26
No. of primary branch	45.57	6.15	28.91ns	6.98ns	29.77ns	0.01ns	13.55
Height up to 1^{st} pr.br(cm)	31.81	8.63	61.50ns	164.83ns	57.33ns	223.92ns	26.45
No of nodes on stem	18.3	8.87	10.04ns	5.75ns	10.23ns	2.72ns	11.38
Bean width(mm)	0.33ns	0.16	4.59**	0.71ns	0.72*	0.33ns	5.81
Bean thickness (mm)	0.05ns	0.10	0.26*	0.08ns	0.26*	0.57*	7.72
Hundred bean weight(g)	4.05*	13.24	67.76**	3.29ns	3.66**	4.77*	21.15
Length of 1^{st} pr.Br(cm)	19.36ns	39.46	95.48*	54.87ns	88.54*	1008.62**	7.80
Stem girth(mm)	9.92ns	3.80	12.35 *	0.31ns	12.53*	3.75ns	4.92
Fruit length(cm)	0.39ns	0.18	0.87*	0.25ns	0.86**	3.64**	2.78
Fruit width(cm)	0.16ns	0.40	1.45*	2.66**	0.93*	53.01**	3.89
Fruit thickness(cm)	4.83*	0.31	0.87*	2.60*	0.78*	6.64**	3.79
Canopy diameter(cm)	488.03	175.68	159.7ns	71.1ns	162.2ns	152.77ns	10.57
Average int. length (cm)	0.76	0.71	0.69ns	2.56ns	0.6ns	0.63ns	12.7
Yield(g)	139527.88	167705.18	437264.10	136368.5	435599.67	1383294.90*	28.22

DF = degrees of freedom, ns = non-significant;* and** = significant and highly significant at 5% and 1% probability level respectively; CV= Coefficient of Variation

4.2. Range and Mean Values

The mean performances of all treatments and checks evaluated are presented in table 5. The mean values of leaf length ranged from 13.4 (Sende) to 20.0 (EW65), leaf width ranged from 5.49 (E58) to 9.32 (EW92). Leaf area is an important trait that affects overall bean yield. It was ranged from 77.54 (EW58) to 173.74 (EW 13) with a mean value of 119.6. Petiole length varied from 0.6 (EW79 & EW80) to 2.4 (EW16), bean length, width and thickness ranged from 7.09, 5.63,3.46 (EW3,EW57,EW69) to 11.26,8.4 and 5.21 (EW71, EW7, EW52).Hundred bean weight ranged from 3.17 (EW5) to 39.4 (EW35), length of first primary branch varied from 57.43 (EW50) to 108.56 (EW96).Whereas stem girth ranged from 28.91(EW99) to 48.16 (EW16).Fruit length, width, thickness and yield per plot ranged from 11.23 (EW105) to 17.01 (EW29); 12.25 (EW10) to 18.55 (EW77); 11.27 (EW10) to 17.52 (EW29) and 120.95 (EW10) to 5381.73 (EW71) respectively.

From the result it was observed that those characters with the higher range of values were also had higher mean values and vice versa. Such considerable range of variations provided a good opportunity for yield improvement. The presence of significant variation for the different characters indicates that genetic variation among the accessions was wide for all characters studied. This high range and mean value for each trait of interest suggests that great opportunity to improve the various desirable traits through selection as short term strategy and through hybridization as long term strategy. This finding is in agreement with what was reported by (Yigzaw, 2005; Olika *et al*., 2011)

4.3 . Phenotypic and Genotypic Coefficient of Variation

The PCV ranged from 6.91 for fruit length to 54 for bean yield whereas GCV ranged from 5.07 for fruit thickness to 43.5 for hundred bean weight (Table 5). Phenotypic coefficients of variation are generally higher than genotypic coefficients of variation for all the traits studied indicating that the influence of growing environment on the traits was high.

Burton and Devane **(**1953) classified PCV and GCV values as high (>20%), medium (10-20%) and low (<10%). Accordingly, high PCV and GCV were observed in bean width, hundred bean weight and bean yield per unit area. Medium PCV and GCV values were recorded for leaf area

and bean length. For petiole length PCV was high but GCV was medium whereas, medium PCV and low GCV were recorded for bean thickness, length of longest primary branch and stem girth. Low PCV and low GCV were recorded for fruit length, fruit width, leaf width and fruit thickness. The high and medium PCV and GCV indicate that selection of these characters could be of potential importance to the improvement of East wellega coffee population through selection and hybridization. This result is in agreement with the findings of Yigzaw (2005); Kebede and Bellachew (2008) who reported high and medium phenotypic and genotypic coefficient of variances for the characters, length of the longest primary branch, length of primary branches, stem girth and hundred bean weight of *coffee arabica.* The result is disagreeing with that of Gichimu and Omondi (2010) who showed low genetic variability among *coffee arabica.*

4.4. Estimates of Heritability (h^2b)

Broad sense heritability ranges from 0 to1 A high heritability means that most of the variation is genetic and the influence of the environment were minimum. In this study, the heritability estimates ranged from 33.3 for petiole length to 93.2% for bean width (Table 5). Robinson *et al.* (1949) classified heritability values as high (> 60%), moderate (30 - 60%) and low (< 10 %.). Based on these, characters which showed high heritability values were leaf length (60.28%), leaf width (63.26%), leaf area (84.62%), bean width (93.2%), hundred bean weight (67.3%) and fruit length (63.89%). Medium heritability values were recorded for petiole length (33.3%), bean length (54.4%), length of first primary branch (41.5%), stem girth (53.0%), bean thickness (44 %,) fruit width (56.76 %), fruit thickness (47.46 %.) and bean yield (46%). According to Singh (2001), if heritability of a character is very high selection for such characters could be fairly easy. This is because there would be a close correspondence between the genotype and the phenotype due to the relative small contribution of the environment to the phenotype. Although, for characters with low heritability selection may be considerably difficult or virtually impractical due to the masking effect of environment.

The high heritability suggest that most of the variation among individuals is caused by genetic variation among those individuals and effect of environment on the phenotypic expression of these characters is minimum which is good for improvement through selection. Knowing the he-

ritability can be of value because when the breeder selects for a phenotype the genes of that plant will be passed on but not the environment the plant grew in.

The result is in agreement with Walyaro and Vossen (1979); Yonas (2014) who reported medium heritability values of quantitative characters like stem girth in coffee. The obtained results were also in agreement with results of Kebede and Belachew (2005); Yigzaw (2005) who reported high broad sense heritability estimates for quantitative characters in *coffee arabica*.

4.5. Estimates of Expected Genetic Advance (GAM %)

Genetic advance expressed as a percentage of the mean ranged from 7.17% for fruit thickness to 73.6% for hundred-bean weight (Table 5). Falconer and Mackay (1996) classified genetic advance as percent of mean as low (0-10%), medium (10 - 20%) and high (20% and above). Accordingly, genetic advance as percentage of mean was high for leaf area, petiole length, bean width, hundred bean weight and bean yield, whereas medium for leaf length, leaf width; bean length, bean thickness, longest first primary branch and stem girth but low for fruit length, fruit width and fruit thickness of characters considered in this study.

The estimates of genetic advance help in understanding the type of gene action involved in the expression of various polygenic characters. High values of genetic advance are indicative of additive gene action whereas low values are indicative of non-additive gene action (Singh and Narayanan, 1993). Accordingly; heritability and genetic advance are important selection parameters. The estimate of genetic advance is more useful as a selection tool when considered jointly with heritability estimates (Johnson *et al.,* 1955). High heritability associated with high genetic advance was observed for leaf area, bean width, and hundred bean weights indicating their relevance for selection. Whereas medium heritability and high genetic advance was recorded for bean yield and petiole length. These results are in agreement with the findings of Yigzaw (2005) in coffee Arabica whereas high heritability with moderate genetic advance as percent of mean was recorded for leaf length, leaf width, bean length, bean thickness, girth and fruit width. Further more moderate heritability with high genetic advance as percent of mean were recorded for petiole length and moderate heritability with moderate genetic advance as per cent of mean was recorded for longest first primary branch character. These are simply inherited traits and they indi-

cate that most likely the heritability is due to additive gene effects and selection may be effective in early generations for these traits. In this study bean width and hundred bean weight shows high genotypic coefficient variation, heritability and genetic advance .This indicate that environment expression on these characters are minimum and indicative of additive gene action involved in the expression of the characters. This is good opportunity for the improvement of these characters through selection.

Table 5. Estimate of ranges, mean, phenotypic and genotypic coefficient of variation, broad sense heritability and genetic advance as percent of mean for the different characters

Character	Mean	Range		σ^2p	σ^2g	PCV (%)	GCV (%)	h^2b (%)	GA (k=2.06)	GAM (k =2.063)
		Min.	Max.							
LL	15.69	13.4	20	2.82	1.7	10.70	8.31	60.28	2.09	13.32
LW	7.57	5.49	9.32	0.49	0.31	9.25	7.36	63.26	0.91	12.02
LA	119.61	77.54	173.74	412.93	349.41	16.99	15.6	84.62	35.47	29.64
PL	0.85	0.60	2.40	0. 06	0.02	42.42	16.5	33.33	0.17	20.0
BL	9.19	7.09	11.26	1.58	0.86	13.76	10.1	54.4	1.41	15.34
BW	6.83	5.63	8.40	4.75	4.43	31.91	30.9	93.2	4.19	61.34
BT	4.18	3.46	5.21	0.36	0.16	14.35	9.6	44.4	0.55	13.16
HBW	16.97	3.17	39.14	81	54.52	53.04	43.5	67.3	12.49	73.60
LFPB	80.54	57.43	108.56	134.94	56.02	14.42	9.29	41.5	9.95	14.7
SG	39.57	28.91	48.16	16.15	8.56	10.16	7.4	53.0	4.39	12.31
FL	15.05	11.23	17.01	1.08	0.69	6.91	5.5	63.89	1.37	9.10
FW	16.23	12.25	18.55	1.85	1.05	8.38	6.3	56.76	1.59	9.80
FT	14.78	11.27	17.52	1.18	0.56	7.35	5.07	47.46	1.06	7.17
BY	1450.9	120.9	5381.7	604969.3	269559	54	36	46	738.1	50.87

σ^2p = Phenotypic variation, σ^2g = Genotypic variation, PCV= Phenotypic coefficient of variation, GCV= Genotypic Coefficient of variation, H^2b = Broad sense heritability, GA = genetic advance, GAM = Genetic advance as percent of mean , LL = leaf length, LW = leaf width, LA= leaf area, PL= petiole length, BL = bean length, BW = bean width, BT = bean thickness, HBW=hundred bean weight, LFPB = longest first primary branch, SG = stem girth, FL= fruit length, FW= fruit width, FT= fruit thickness, BY= bean yield

4.6. Genetic Divergence

Genetic divergence analysis quantifies the genetic distance among the selected accession and reflects the relative contribution of specific traits towards the total divergence. Divergence analysis is a technique used to categorize germplasm that are as similar as possible into one group and others into a different. D-square (D^2) statistics developed by Mahalanobis (1936) has been used to classify the divergent genotypes into different groups. The extent of diversity present between germplasm determines the extent of improvement gained through selection and hybridization. The more divergent the two germplasm are the more will be the probability of improving through selection and hybridization.

4.6.1. Clustering of germplasm

The D^2 values based on the pooled mean of accessions resulted in classifying the 115 coffee accessions in to twelve groups (Table 6). This indicated that the tested coffee arabica germplasm were divergent. The germplasm were clustered in such a way that fourteen germplasm (12.17%) were grouped into cluster I, twenty one germplasm (18.26%) in to cluster II, thirty three germplasm (28.7%) into cluster III, fifteen germplasm (13.04%) into clusters IV, eleven germplasm (9.56%) in to cluster V, eight germplasm (6.96%) in to cluster VI, five germplasm (4.35%) in to cluster VII, three germplasm (2.61%) in to cluster IX, two germplasm (1.74%) in to cluster X, cluster VIII ,XI and XII consist one accessions (0.87%) each respectively). Similarly, Kebede and Bellachew (2005); Getachew (2012) grouped 104 and 49 coffee accessions of 14 and 22 characters into 6 and 5 clusters respectively.

In the present study, accessions collected from different kebeles clustered together, for instance, accessions collected from eight kebeles clustered together in cluster I. In support of this Bayetta (2001) reported that morphological variation is more important than variation in geographic origin as indicator of genetic diversity in coffee. Seyoum (2003) has also reported that accessions collected from Gambella, Kullo, Keffa, Ilu Ababora, Wello, Wellega, Maji, Harar, and Sidamo were clustered together, despite the fact that they were collected from different geographic origins. In addition, in the present study, accessions collected from the same kebeles were clustered into different clusters, suggesting the existence of high genetic diversity within each collection

sites. So, this diversity could be exploited further in order to increase the genetic base of coffee varieties.

Table 6. Clusters of the 115 coffee accessions based on D^2 analysis

Cluster number	No. of Germplasm	Percent	Accession Number
I	14	12.17	6,16,18,19,20,43,46,50,64,71,78,85,89,114
II	21	18.26	1,2, 9, 22, 23,30,32,36,40,44,58,63,73,77,80,88 ,95,97,101,106,113,
III	33	28.70	51,34,115,11,54,87,76,47,65,3,68,7,67,27,66,86,79,42,41 ,96,70,15,4,110,108,82,25,102,48,107,17,52,103
IV	15	13.04	57,10,94,60,83,56,29,92,55,31,26,49,105,37,91
V	11	9.56	45,24,111,98,62,84,112,53,90,61,69
VI	8	6.96	74,21,5,104,109,33,81,100
VII	5	4.35	8,28,12,99,39
VIII	1	0.87	14
IX	3	2.61	35,93,59
X	2	1.74	38,72
XI	1	0.87	13
XII	1	0.87	75

Remark: detail description of accessions number and name is found in Table - 1

4.6.2. Cluster mean analysis

The mean values of the 14 traits in each cluster are presented in (Appendix Table 3). Cluster I exhibited the highest petiole length and fruit thickness. Cluster II could be characterized the highest hundred bean weights with the lowest leaf width. Cluster V revealed the lowest bean thickness and lowest stem girth. Cluster VI revealed the highest leaf length and leaf width. Cluster VII revealed the highest leaf area. Cluster X revealed the highest bean thickness and the lowest length of first primary branch, bean length, bean width, fruit length, and bean yield. Cluster XI revealed the highest stem girth, length of first Primary branch, fruit length and the lowest leaf

length, leaf area, petiole length, hundred-bean weight. Cluster XII revealed the highest bean length, bean width, fruit width, and bean yield.

Therefore, the highest and the lowest mean values are recorded between clusters I and cluster XI for petiole length and fruit thickness. Cluster II with cluster XI for hundred bean weight; cluster V with X and XI for bean thickness and girth. Cluster VI with cluster VII, X and XI for leaf length; cluster VII with XI for leaf area; cluster X with XI and XII for bean length, bean width, fruit width, bean yield, length of first primary branch and fruit length, respectively (Table 7). This shows that the traits considered have large genetic distance among them and the tested accessions were divergent. The result is in agreement with Getachew (2012) and Olika (2011) who classified Arabica coffee germplasm accessions into five and six clusters respectively and found that the highest and lowest mean value of traits among clusters.

4.6.3. Average intra and inter cluster distance

The average intra and inter cluster distance D^2 values are presented in Table 8. Maximum intra cluster distance was shown by cluster II (157.8) followed by cluster IV (135.4**)** and VII (130.3)**.**The lowest intra cluster distance D^2 was recorded in clusters VIII, XI and XII (0.00),which shows the absence of genetic variability within this cluster. The inter cluster distance was range from 173.3 to 5381(Table 7). Cluster XI and XII showed maximum inter cluster distance of 5381.7 followed by that between clusters VI and XI (4745.9) which had shown they were genetically more divergent from each other than any other clusters. The lowest inter cluster distance was noticed between clusters V and III (173.3) followed by that between clusters III and IV (228.1). The chi- square test for the 12 clusters indicated that there were statistically accepted differences between all clusters (Table 7). This result agreed with the findings of Kebede and Bellachew (2005); Wasu *et al*. (2008) who reported the magnitude of heterosis largely depends upon the degree of genetic diversity among the parental lines, the germplasm accessions belonging to the pairs of distant clusters could be very useful in hybridization program to obtain a wide spectrum of variation among the segregates and to maximize heterosis. In light of the above finding, it is possible to conclude that the germplasm accessions from cluster XI and cluster XII could offer potential parental lines for maximizing heterotic value.

Based on Mahalanobis distance (D^2) significant genetic dissimilarity was detected within clusters except VIII, IX, XI and XII that showed no significant 0.00, 30.8, 0.00 and 0.00 values respectively (Table 7). The significant value of genetic distances within clusters I, II, III, IV, V, VI, VII and X was an indication of heterogeneity of the germplasm present within these clusters (Table 8). Considering the inter-cluster distances, cluster XI showed the maximum and significant genetic distance (5381.73) from cluster XII. This indicates that the crossing between superior germplasm of above diverse cluster pairs might provide desirable recombinants for developing high yielding coffee arabica varieties (Table 7). The result is in agreement with Bayetta *et al*. (2008); Wasu *et al*. (2008) who reported the requirement of genetic divergence among parents with respect to geographic origin and/or morphological traits for maximum heterosis to occur to certain hybrid character like yield and stem diameter

Table 7. Average intra and interclusters distance of the 115 coffee accessions based on D^2 analysis

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
I	**90.6**	279.3*	362.9**	589.2**	189.9**	776.6**	520.2**	2713.6**	1555.1**	1202.7**	3969.4*	1091.13*
II		**157.8**	640.6**	867.7**	468.4**	497.7**	241.1**	2992.5**	1834.04**	1481.6**	4248.3*	812.6**
III			**64.7**	228.1**	173.3**	1138.1*	881.2**	2352.7**	1194.2**	841.9**	3608.3*	1452.8**
IV				**130.3**	399.5**	1365.3*	1108.4*	2125.3**	966.6**	614.3**	3380.9*	1679.8**
V					**80.4**	966.0**	709.3**	2524.2**	966.6**	1013.2**	3779.9*	1280.6**
VI						**128.3**	257.1**	3490.1**	2331.6**	1979.1**	4745.9*	315.9**
VII							**135.4**	3233.4**	2074.9**	1722.3**	4745.9*	572.0**
VIII								**0.000**ns	1158.8**	1511.3**	1256.9*	3804.2**
IX									**30.8**ns	352.9**	2414.4*	2645.9**
X										**112.9**	2767.0*	2645.9**
XI											**0.000**ns	5381**
XII												**0.000** ns

** = Significant at p < 0.05 (X^2=31.41), ** = Significant at p < 0.01 (X^2= 37.57), ns = non significant*

4.6.4. Cluster characterization for qualitative traits

Cluster analysis based on qualitative traits classified accessions using distance between cluster and UPGMA clustering which gave nine major clusters. The number of accessions belonging to each cluster varied from one in clusters VII, VIII and IX to 37 in cluster I (Table 8). Cluster I was the largest and consisted of 37 accessions (35%) (Table 8). 3 from Tokuma tsigie, 2 from Ambelta, 1 from Haro gudina, 2 from Feyene terano, 7 from Lomicha, 9 from Galojanja, 3 from Magala gallo, 4 from Gemene, 2 from Oda and 1 from Jarso. Of the total accessions grouped under this clusters have predominantly roundish fruit shape, red fruit color, many primary branches with few secondary and many primary and many secondary branches; horizontal branching habit; lanceolate and ovate leaf shape; acuminate and apiculate leaf apex shape and round seed shape.

Cluster II had 20 Accessions (17.39%) 1 from Haro Gudina, 4 from Lomich, 4 Gallo janja, 3 from Nanno senbeta, 1 from Magala gallo, 4 from Gemene, 2 from Oda and 1 from Bedhaso jarso. Accessions clustered under II had oblong and elliptic fruit shape; red fruit color, many primary branch and few secondary branch and consecutively many primary branch and many secondary branches; horizontal and semi erect branching ;ovate and lanceolate leaf shape; apiculate leaf apex shape and oblong seed shape

Cluster III had consisted of 19 accessions (16.52%) 1 from Feyinetrano, 1 from Welkituma, 4 from Lomicha, 4 from Gallo janja, 2 from Nanno senbeta, 2 from Megala gallo, 2 from Gemene, 1 from Oda and 1 from Bedhaso. Accessions clustered in this group had elliptic and oblong leaf shape; red fruit color; many primary branch with few secondary branches; horizontal branching, lanceolate leaf shape; apiculate leaf apex shape and round seed shape

Likewise cluster IV consisted of twenty nine accessions (25.22%) 1 from Ambelta feyera,2 from Horo gudina, 1 Feyene Terano, 1 from Wolkituma, 4 from Lomicha,6 from Gallo Janja, 4 from Nanno senbeta dure,2 from Megala gallo, 2 from Gemene, 1 from Oda, 2 from 07, 1 from Haro feyissa. Accessions clustered in this group had round and obovate leaf shape; red fruit color; many primary branch with few secondary branches; horizontal branching, lanceolate leaf shape; apiculate leaf apex shape and oblong seed shape.

Cluster V consists of four accessions (3.48%) 1 from Lomicha, 1 from Gallo Janja, 1 from Nanno Senbeta dure and 1 from Gemene. Accessions clustered in this group had roundish leaf shape; red fruit color; many primary branch with few secondary branches; horizontal branching, lanceolate leaf shape; apiculate and acuminate leaf apex shape and oblong seed shape

Cluster VI consists of three accessions (2.61%) 2 from Lomica and one from Gemene. Accessions clustered in this group had round leaf shape; yellow orange fruit color; many primary branch with few secondary branches; horizontal branching, lanceolate leaf shape; apiculate leaf apex shape and round seed shape

Cluster VII, contribute 0.87% of the variation via traits elliptic leaf shape; yellow orange fruit color; many primary branches with many secondary branches; horizontal branching, accuminate leaf apex shape and round seed shape

Accessions grouped under Cluster VIII express 0.87% of the variation via oblong leaf shape; red fruit color; many primary branch with many secondary branches; horizontal branching, elliptic leaf shape; obtuse leaf apex shape and oblong seed shape. The ninth cluster comprises only one accession (0.87%) entry and from tokuma tsigie accessions clustered in this group had elliptic leaf shape; yellow fruit color; many primary branch with many secondary branches; horizontal and spreading branching, lanceolate leaf shape; apiculate leaf apex shape and elliptic seed shape (Table 8).

Clustering values between qualitative and quantitative characters did not show similarity in grouping of genotype. For instance, accessions clustered in quantitative cluster I compared to Cluster I of qualitative traits only four accessions have in common. This may be due to seed exchange among farmers or the influence of environment on the character under study. The result is in agreement with the work of Tewodros (2008) who grouped 17 qualitative characters of areal Yam into six distinct groups and Woyessa, 2006 who grouped 10 accessions of *Plectranthus edulis* in to four Clusters.

Table 8: Clusters of the 115 coffee accessions based on D^2 analysis for qualitative characters at Haru

Cluster number	No. of Germplm	percent	Accession Number
1	37	32.17	4,51,110,89,92,20,1,55,77,114,13,76,95,108,27,30,66,81,26,34,68,39,97,32,12,41,8,18,115,42,25,85,48,59,100,74,2
2	20	17.39	98,70,101,91,15,109,82,50,57,84,58,46,21,64,16,90,73,37,9,87
3	19	16.52	40,80,29,19,44,83,53,23,14,107,56,78,61,99,86,63,65,22,10
4	29	25.22	47,105,33,5,113,112,17,54,7,62,6,102,31,69,52,104,11,103,60,24,111,71, 79,49,36,67,43,96,94
5	4	3.48	38,93,72,45
6	3	2.61	35,28,88
7	1	0.87	75
8	1	0.87	3
9	1	0.87	106

Remark: detail description of accessions number and name is found in Table - 1

4.7. Association of characters

4.7.1. Correlation of bean yield with other traits

Bean yield exhibited significant and positive association with stem girth, fruit length, fruit width, fruit thickness and length of longest first primary branch at phenotypic level (Table 9). Yield also exhibited significant and positive association with, bean length, bean thickness, fruit length, fruit width and fruit thickness at genotypic level. Characters are often correlated, that is, the phenotypic value of one character in an individual is correlated with the phenotypic value of another character on that individual. These correlations can also be due to environmental effects or genetic effects. The genetic causes of correlation are pleiotropy (that genes affect more than one character) and linkage disequilibrium. This need not be constant across genes: some genes can cause positive pleiotropy and others negative pleiotropy; the balance determines the genetic correlation of the two characters. (http://www.zoology.ubc.ca/~whitlock/QGPG/QG5/).

Therefore, the positive and significant association of these traits with bean yield may be used for indirect selection of accession for yield potential. This result is in agreement with the report of various researchers (Walyaro,1981;Van der Vossen,1982; Mesin,1986, Ermias, 2005; Olika et al., 2011; Getachew *et al*.,2013) indicated the existence of associations between growth characters that were responsible for vigor, such as stem girth and yield.

4.7.2. Correlation among other traits

4.7.2.1. Phenotypic correlation

Estimates of phenotypic correlations among the characters are presented in Table 9. The magnitude of the estimates of phenotypic correlation coefficients, in most cases, was slightly lower than that of genotypic correlations this may indicate that the effects due to the environmental variance were lower than genetic variance for the characters considered in this study.

Leaf length had positive and significant phenotypic correlation with leaf area, leaf width and petiole length. Length of longest first primary branches had positive and significant phenotypic correlation with stem girth, fruit thickness, leaf width and bean yield. Bean length revealed positive and significant phenotypic correlation with bean width, bean thickness, fruit length, fruit width and fruit thickness. Bean width had significant and positive correlation with bean thickness, fruit length and fruit width.

The positive associations imply that increasing of the associated characters could be achieved if the selection is based on characters positively and significantly correlated each other (Table 9). For instance increasing of bean length could be achieved if the selection is based on characters positively and significantly correlated with bean length namely: bean width, bean thickness, fruit length, fruit width and fruit thickness. Moreover, the indirect selection for these characters will also affect the bean yield if, similar trends of association are exhibited in genotypic correlation. Ermias (2005); Olika (2011) also reported the positive association of fruit width with bean yield earlier.

4.7.2.2. Genotypic correlation

The magnitude of the estimates of the genotypic correlation coefficients, in most cases, was higher than that of phenotypic correlations (Table 9). This may indicate that the effects due to the

environmental variance were lower than genetic variance for the characters studied. This result agrees with that of Ermias (2005), Getachew *et al*. (2013) who reported that phenotypic correlations were in most cases lower than the corresponding genotypic values.

Generally, there was association among growth characters considered. Length of longest first primary branch showed positive and significant association with stem girth and bean length. The correlation between length of first primary branch, stem girth and bean length were positive and significant at genotypic level. Suggesting that an increase in length of first primary branch could result from simultaneously increase stem girth and bean length. This result indicated that there is a positive and mutual association among the traits and selection based on these traits are crucial for developing coffee varieties and it may be effective traits to select better yielding accessions. Stem girth also exhibited significant associations with bean length and bean thickness considered in the present study.

These results are in line with Mesfin, 1986; Olika *et al.* (2011). Bean width showed positive and significant association with bean thickness and length of longest first primary branch. Therefore, indirect selection for these traits may be effective in developing yielder coffee variety. Similarly, Mesfin, 1986; Olika *et al.* (2011) reported, yield per plant positively and significantly correlated with bean width, fruit length, leaf length.

Table 9. Estimates of genotypic (above diagonal) and phenotypic correlation coefficient among the different characters of arabica coffee accessions

	LL	LW	LA	PL	LFPB	SG	BL	BW	BT	HBW	FL	FW	FT	YLD
LL	**1**	0.61*	0.73**	0.24*	0.04	0.08	0.08	0.05	0.02	0.04	0.14	0.09	-0.03	- 0.02
LW	0.60**	**1**	0.85**	0.26**	0.18*****	0.06	0.25**	- 0.12	0.28**	0.18*	0.24*	- 0.001	0.11	- 0.1
LA	0.71*	0.81*	**1**	0.26**	0.11	0.003	0.16	- 0.1	0.14	0.13	0.15	0.06	0.04	0.05
PL	0.22*	0.24*	0.27**	**1**	- 0.02	0.06	0.02	- 0.02	0.14	0.08	- 0.08	- 0.06	0.11	0.01
LFPB	0.08	0.18*	0.14	0.01	**1**	0.3**	0.3**	- 0.13	- 0.01	0.13	- 0.02	- 0.05	0.07	0.36**
SG	0.003	0.04	0.03	0.06	**0.3	**1**	0.19*	- 0.04	0.23	- 0.09	- 0.08	- 0.01	- 0.04	0.33**
BL	- 0.01	0.20*	0.07	- 0.02	0.08	- 0.18*	**1**	- 0.01	0.19*	0.22*	0.58**	0.05	- 0.01	0.22*
BW	0.02	0.02	0.001	- 0.22*	0.09	-0.14	0.53**	**1**	-0.08	0.13	0.05	0.02	- 0.01	0.10
BT	- 0.01	0.27*	0.13	0.15	0.07	0.19*	0.31**	0.34**	**1**	0.19*	0.14	0.09	0.08	0.19*
HBW	0.06	019*	0.14	0.12	0.12	- 0.09	0.05	0.03	0.18*	**1**	- 0.09	- 0.01	0.03	0.13
FL	0.09	0.22*	0.16	-0.06	0.07	- 0.05	0.57**	0.28**	0.15	- 0.08	**1**	0.42**	0.06	0.34**
FW	0.17	0.06	0.13	-0.10	- 0.02	- 0.05	0.27**	0.41**	0.08	- 0.09	0.65**	**1**	0.002	0.34**
FT	0.07	0.43*	0.25**	0.08	0.22*	0.11	0.26**	0.06	0.35**	0.17	0.54**	0.41**	1	0.35**
BY	- 0.01	0.06	0.03	- 0.01	0.19*	0.24**	0.12	0.07	0.10	0.08	0.21*	0.19*	0.33**	**1**

t = 0.174 (P < 0.05) and t = 0.228 (P < 0.01) for DF= n- 2, where n is the number of genotypes (sample size) Where, LL= leaf length; LW = leaf width; LA= leaf area; PL= petiole length; HBW = hundred bean weight; BL= bean length ;BW = bean width ;BT = bean thickness , SG = stem girth; LFPB = length of first primary branch; FL= fruit length ; FW = fruit width; FT = fruit thickness ;BY = bean yield

4.7.3. Path Coefficient Analysis

4.7.3.1. Direct effect

Although estimates of correlation coefficients are helpful in determining the components of a complex trait, such as yield, they do not provide an exact picture of the relative importance or direct and indirect influences of each of the component characters on yield (Bhatt, 1973). Results in (Table 10) showed path coefficient analysis of some traits on bean yield per plot. The length of first primary branch, which had positive and significant association with bean yield, exerted maximum direct effect (0.241) on bean yield. The second and high direct effect was exerted by fruit width (0.176) which also had positive and significant association with bean yield. These indicate the true relationship between these traits and bean yield. As a result, these traits could be considered as important traits for selection in a breeding program for better bean yield of the coffee arabica accessions considered in this study. This result agrees with that of Seyoum (2001), who reported, that the number of primary branches and length of primary branch had significant association with yield.

Bean length which had strong association with yield (0.25) exhibited high direct effect (0.1328). Bean thickness which had positive and significant correlation with bean yield (0.19) show low direct effect (0.077). Fruit lengths which had a strong and positive association with bean yield (0.34) exhibited weak and negative direct effect (-0.093). Fruit thickness which had a strong and positive association with bean yield (0.35) exhibited low direct effect (0.121) its strong association with yield may be largely due to the relatively high indirect effect via bean width (0.171). The other traits namely leaf length, leaf width, hundred bean weights, bean width, leaf area, petiole length, and stem girth which have weak and non significant correlation with bean yield exhibit low direct effect (0.107), (0.333), (- 0.175), (0.152), (- 0.026), (- 0.035) and (0.087) respectively.

4.7.3.2. Indirect effect

Leaf length shows positive indirect effect through leaf width, bean length, bean width, petiole length, length of first primary branch, fruit length, fruit thickness and stem girth whereas nega-

tive indirect effect through hundred bean weight and leaf area. Leaf width shows positive indirect effect via bean length, bean width, bean thickness, petiole length, length of fist primary branch, fruit length, fruit width and stems girth but shows negative indirect effect via hundred bean weight, leaf area and fruit thickness. Hundred bean weights shows positive indirect effect via bean length, bean width, bean thickness, length of first primary branch, fruit length &fruit thickness but negative indirect effect via leaf area, petiole length, Fruit width and stem girth. Bean width shows positive indirect effect through bean thickness, length of first primary branch, fruit width, fruit thickness but negative indirect effect through leaf area, petiole length, &stem girth. Leaf area show positive indirect effect via petiole length, length of first primary branch, fruit width, fruit thickness and stem girth but negative indirect effect via fruit length. Petiole length shows positive indirect effect via fruit length, fruit width, fruit thickness and stem girth but negative indirect effect via length of first primary branch.

Bean length shows weak indirect effect via bean thickness and fruit width and negative indirect effect through stem girth, length of first primary branch, fruit length and fruit thickness. Bean thickness s had positive indirect effect through length of longest first primary branch, fruit length, fruit width but negative indirect effect through stem girth and fruit thickness. Bean thickness had positive indirect effect through length of longest first primary branch, fruit length, fruit width but negative indirect effect through stem girth and fruit thickness. Stem girth had a positive indirect effect through length of first primary branch, fruit length, fruit width and fruit thickness but a negative indirect effect via bean length and bean thickness. Length of first primary branch had a positive indirect effect via bean thickness and a negative indirect effect through bean length, fruit length, width and thickness. Fruit length had a positive indirect effect via bean length, length of first primary branch, fruit width, fruit thickness but a negative direct effect via bean thickness and stem girth. Fruit width had a positive indirect effect via bean length, bean thickness and fruit length but negative indirect effect via stem girth, length of first primary branch and fruit thickness (Table 10). Fruit thickness had a positive indirect effect via bean length, bean thickness, and length of first primary branch, fruit length, and width. In general it could be eminent that the characters which showed greater direct effect such as length of first

primary branch and fruit width can be used as yield component and could be very useful traits for indirect selection for yield.

The estimated value of residual was 0.41 that shows 59% of the variation of yield was explained by the characters considered in the present study. This might suggest that the characters other than the one considered in the present study might be attributed to the remaining 41 % of the variation observed in yield.

Table 10. Direct (bold) and indirect path coefficient analysis of the different Arabica coffee characters towards yield

Variable	LL	LW	HBW	BL	BW	BT	LA	PL	LFPB	FL	FW	FT	SG	rg
LL	**0.107**	0.027	-0.004	0.002	0.01	0.002	-0.009	0.007	0.028	0.005	-0.002	0.01	0.004	- 0.02
LW	0.088	**0.033**	-0.001	0.01	0.018	0.006	-0.014	0.004	0.038	0.005	0.002	-0.013	0.006	- 0.1
HBW	-0.003	0.0001	**- 0.175**	0.004	0.021	0.013	-0.045	-0.003	0.014	0.015	-0.013	0.003	-0.007	0.13
BL	-0.001	0.003	- 0.005	**0.132**	0.079	0.02	0.002	-0.07	-0.0001	-0.045	0.065	0.029	-0.028	0.26
BW	0.007	0.004	- 0.024	0.068	**0.152**	0.04	-0.009	-0.002	0.042	-0.018	0.077	0.002	-0.002	0.10
BT	0.003	0.003	- 0.03	0.035	0.079	**0.077**	-0.003	0.002	0.017	-0.006	0.009	0.024	-0.004	0.22
LA	0.005	0.002	- 0.039	-0.001	0.007	0.001	**- 0.026**	0.001	0.069	-0.034	-0.018	0.027	0.004	0.05
PL	0.021	- 0.004	- 0.014	0.027	0.007	-0.005	0.004	**- 0.035**	-0.051	0.029	0.008	0.007	0.09	0.01
LFPB	0.013	0.005	- 0.01	-0.001	0.026	0.005	-0.059	0.007	**0.241**	-0.034	-0.011	-0.004	0.073	0.38
FL	- 0.05	- 0.0002	0.028	0.064	0.029	-0.007	-0.041	0.003	0.025	**- 0.093**	0.09	0.007	-0.004	0.33
FW	-0.001	0.001	0.014	0.053	0.171	0.011	-0.035	-0.002	-0.006	-0.051	**0.176**	0.016	-0.015	0.37
FT	-0.002	- 0.0001	0.001	0.022	0.018	-0.028	-0.021	-0.001	0.004	0.01	-0.021	**0.1219**	-0.0024	0.32
SG	0.003	0.04	- 0.09	0.19*	- 0.04	0.23	0.03	0.06	0.19	- 0.08	- 0.01	- 0.04	**0.0873**	0.34

Residual = 0.415602

Where: LL= leaf length, LW = leaf width, HBW = hundred bean weight, BL = bean length, BW= bean width, BT = bean thickness, LFPB =length of fist primary branch, SG = stem girth, FL, FW and FT = length, width and thickness of fruit respectively

4.8. Principal Component Analysis (PCA) for quantitative characters

Principal component analysis reflects the importance of the largest contributor to the total variation at each axis for differentiation (Sharma, 1998).The data matrix of 14*115 was prepared for principal component analysis and correlation matrix was used for principal component analysis. It was obvious from the analysis that six PCs out of twenty were selected having >1 Eigen values and contributed 71% of the total variation among 115 *coffee arabica* accessions for all parameters (Table 11). It was noted that principal component first contributed 16% of the variability among coffee accessions is mainly through traits such as bean length, bean width, fruit length, fruit width and fruit thickness. Principal component second 15%, principal component third 13% and principal component fourth, fifth and sixth contributes 12%, 8% and 7% respectively of the total genetic variability for all the accessions.

In the second principal component the variation was mainly due to leaf length, leaf width and leaf area whereas, in principal component three variations were chiefly originated from leaf length, leaf width, leaf area and stem girth in principal component four variations was obtained from bean length, bean width and longest first primary branch. In principal component five variations was chiefly attributed due to hundred bean weight, bean width, bean thickness and fruit length. In principal component six variations was originated from hundred bean weight and yield. Sign in principal component is arbitrary; substantive (significant) meaning logically depends on the sign. You may always change the sign of any factor labeled "X" to the opposite sign, and label it then "opposite X". It is true for loadings, for principal component scores. Other implementations do nothing and leave the decision whether to reverse the sign on if you need it. Statistical meaning such as effect strength does not change apart from its direction gets reversed regardless, the interpretation remains the same.

The result implies that these traits take the lion share for the observed variation among coffee accessions and should be considered in selecting diverse parents in crossing program. Similarly Kebede and Bellachew (2005) grouped 104 Hararge coffee accessions of 14 characters into the first four principal components with Eigen values greater than unity explained 78.5 % of the total variation among 104 accessions for the 14 quantitative characters measured. In addition Getachew (2012) also reported the first six principal components with Eigen values greater than one accounted for 70 % of the total variation among the accessions for 22 quantitative traits. This finding is partly in agreement with the finding

of Olika *et al.* (2011) who reported bean length, hundred bean weight, leaf length and leaf width contributed to the variation among Limmu coffee accessions.

Table 11. Eigen values, variance, cumulative variance and component scores of the first six principal components for quantitative traits in 115 coffee Arabica genotypes

Variable	PC1	PC2	PC3	PC4	PC5	PC6
Leaf length	0.06	- 0.41	0.3	0.19	-0.06	-0.05
Leaf width	0.08	- 0.41	0.32	0.15	-0.03	-0.01
Leaf area	0.08	- 0.43	0.33	0.18	-0.04	-0.03
Petiole length	-0.06	- 0.11	0.04	0.12	0.28	-0.28
Hundred bean weight	0.01	- 0.05	-0.08	0.07	0.37	0.53
Bean length	0.33	0.08	0.17	-0.21	0.1	0.05
Bean width	0.31	- 0.02	0.18	-0.26	0.32	0.14
Bean thickness	0.16	- 0.07	0.05	-0.17	0.55	0.04
Stem girth	0.1	- 0.21	-0.32	-0.05	0.02	-0.21
Longest first primary branch	0.06	- 0.29	-0.17	-0.21	0.01	0.04
Fruit length	0.34	0.03	-0.02	-0.18	-0.43	0.03
Fruit width	0.44	0.08	0.06	-0.13	-0.15	0.05
Fruit thickness	0.42	0.08	-0.01	-0.11	-0.16	-0.09
Bean yield	0.15	0.01	-0.06	-0.18	0.25	0.47
Eigen value	3.38	3.16	2.78	2.41	1.57	1.43
Proportion	0.16	0.15	0.13	0.12	0.08	0.07
Cumulative variance	0.16	0.31	0.44	0.56	0.63	0.7

4.9.2. Principal component analysis (PCA) for qualitative characters

The results of principal component analysis based on 14 qualitative traits also revealed the existence of diversity among the coffee accessions used in this study. Ordination among accessions showed that the first five principal components (PCs) had Eigen values greater than one and cumulatively accounted for 75.3% of variation (Table 12).

The first component alone explain 39.8% of the total variation and was mainly associated with characters, such as overall appearance (OA), young leaf color (YLC), seed color (SC) and branching habit (BH). The second principal component (PCs) explained 10.9% of variation and were associated with leaf shape (LS) and leaf petiole color (LPC). The third principal component (PCs) explained 9.3% of the variation and was associated with calyx limb, petiole color, and seed shape. The forth principal component (PCs) explained 7.9% of variation and was associated with fruit shape (FS), persistence calyx and angle insertion of primary branch (AIPB) and young shoot color (YSC). The fifth principal component (PCs) explained 7.4% of variation and was associated with branching habit and young shoot color (YSC).

Table 12.Eigen values, variance, cumulative variance and component scores of the first five principal components for qualitative traits in 115 Coffee Arabica genotypes

Variable	PC1	PC2	PC 3	PC4	PC5
Fruit shape	0.041	-0.297	0.254	0.592	-0.375
Fruit Color	-0.011	-0.268	-0.088	-0.157	-0.720
Overall Appearance	0.421	-0.013	-0.017	0.001	-0.006
Branching habit	0.034	-0.391	0.096	-0.587	0.226
Angle insertion of primary branch	0.004	-0.465	-0.448	0.256	0.166
Young leaf color	0.421	-0.013	-0.017	0.001	-0.006
Leaf shape	-0.036	0.472	-0.224	0.075	-0.180
Leaf apex shape	-0.038	-0.248	-0.126	-0.377	-0.334
Leaf petiole color	-0.421	0.013	0.017	-0.001	0.006
Young shoot color	0.003	-0.155	-0.676	0.158	0.183
Seed shape	0.041	-0.333	0.439	0.184	0.284
Seed color	0.421	-0.013	0.017	-0.001	-0.006
Persistence calyx	-0.324	-0.225	0.019	0.088	0.063
Calyx limb	-0.421	0.013	0.017	-0.001	0.006
Eigen value	5.578	1.5298	1.299	1.106	1.034
Variance (%)	0.398	0.109	0.093	0.079	0.074
Cumulative (%)	0.074	0.508	0.600	0.679	0.753

4.10. Qualitative Trait Analysis

4.10.1. Shannon -Weaver diversity index and frequency distribution for qualitative traits

Analysis of Shannon Weaver diversity index (H′) as the measure of phenotypic diversity for 14 qualitative for morphological character revealed moderate diversity in Coffee qualitative morphological traits (Table 13). Relatively the minimum and the maximum diversity index were recorded for fruit shape (0.14) and angle insertions of primary (0.52), respectively. Jamago (2000) as cited by Islam *et al.* (2012) the Shannon-Weaver diversity index (H′) classified as high (H′ > 0.75), moderate (H′ = 0.5 - 0.75) and low (H′ < 0.5). A moderate (0.52 for fruit shape) to low (0.12 for seed shape) range of variation was observed among the 115 coffee accessions investigated with regard to qualitative morphological character. However, in some characters such as overall appearance, young leaf color, leaf petiole color, young shoot color, seed color, fruit ribs and calyx limb persistence no variation for all accessions (Table 13). The result implies that there are variations among traits regarding qualitative characters considered in this study

a. Leaf characteristics: Out of the three phenotypic classes of this character, ovate, elliptic and lanceolate was found predominant leaf shape of coffee accessions. Of the tested cultivars, 26.96% exhibited ovate leaf shape; 37.39% elliptic and 55.65 % lanceolate leaf shape. Four dominant leaf apex shapes were observed among coffee accessions, which are 0.87%, 1.74% 37.39% and 60% of the accessions exhibited by obtuse, acute, acuminate and apiculate respectively The result indicates that there is variability in leaf character among *coffee arabica* accessions considered in this study.

b. Fruit characteristics: A variation among coffee accessions based on fruit shape was observed. In this study, 34.8%, 26.1%, 26.1% 12.17% and 0.87%, of accessions express roundish, obovate, ovate, elliptic and oblong fruit shape respectively. Similarly, 85.21% 6.09%, 6.09% and 2.61%, of accessions had red, yellow-orange, red purple and yellow fruit color. This also indicated that there is a wide range of variation in fruit character of *Coffea arabica* in the collected area of East wellega. (Table13). The result is in agreement with Yada *et al.* (2010) who found diversity index ranged from 0.1 to 0.99 in sweet potato using 40 morphological traits.

c. seed characteristics: out of four phenotypic classes of this character round, ovate, elliptic and oblong was found predominant seed shape of coffee accessions. Of the tested cultivars, 0.51 % exhibited round seed shape; 6.96% ovate; 13.04% elliptic and28.7% oblong comprise seed shape (Table 13).

d. Branch characteristics: Out of the 3 phenotypic class of branching habit many primary with few secondary branches exhibited 53.9 % and followed by many primary with many secondary with a cumulative diversity index of (0.28). Similarly, out of two phenotypic classes 88.7% and 11.3% showed horizontal and semi erect orientation respectively with a Shannon diversity index of (0.14) (Table 13). The result indicate that the presence of low to moderate variability within coffee accessions regarding qualitative characters of branches which is a good opportunity to undertake as a supplementary selection tool during rest or non bearing period coffee.

Table13: Frequency distribution and Shannon – Weaver diversity indices (H') of 14 qualitative traits of arabica coffee grown at Haru

	Qualitative character	Index and description adopted	Freq (%)	H'
1	Fruit shape	1.Roundish 2. Obovate 3. Ovate 4. Elliptic 5. Oblong	34.8 26.1 0.87 12.17 26.1	0.52
2	Mature Fruit color	1= Yellow 2 =Yellow-orange 5=RED 6.Red-purple	2.61 6.09 85.21 6.09	0.22
3	Overall appearance	2 = Pyramidal	100	0.0
4	Branching habit	1= Very few branches primary 2= Many (primary) with few secondary 3= Many primary with many second-ary	0.87 53.91 45.22	0.28
5	Angle of insertion of primary branch	2=Horizontal 3= Semi-erect	88.7 11.3	0.14
6	Young leaf color	2 =Green	100	0.0
7	Leaf shape	2=Ovate 3= Elliptic 4= Lanceolate	26.96 17.39 55.65	0.37
8	Leaf apex shape	2= Obtuse 3= Acute 4= Acuminate 5=Apiculate	0.87 1.74 37.39 60	0.30
9	Leaf petiole color	1= Green	100	0.0
10	Young shoot color	1= Green	100	0.0
11	Seed color	3= Other(grayish)	100	0.0
12	Seed shape	1 =Round 3= Ovate 4= Elliptic 5= Oblong	0.51 6.96 13.04 28.7	0.12
13	Absence or presence of fruit ribs	0 = Absent	100	0.0
14	Calyx limb persistence	0 = Absent	100	0.0

6. SUMMARY AND CONCLUSION

The present study comprises 115 coffee Arabica genotypes that were evaluated at Haru Agricultural Research Sub Center (HARSC) with the objective of assessing the genetic variability and character association for 20 quantitative traits and diversity for qualitative traits.

Analysis of variance revealed that significant differences were obtained among the genotypes for fourteen quantitative characters but non significant for the rest of the traits.

The ranges of mean values for most of the characters were large showing the existence of variation among *coffee arabica* accessions. Bean width, hundred-bean weight and bean yield per plot showed high PCV and GCV values. While leaf area and bean length showed medium PCV and GCV. The high to medium PCV and GCV values of characters suggest that the possibility of improving the desired traits through selection**.** The lowest PCV values were observed for the rest of the traits which implies that the limitation of selection. The values of heritability for six quantitative characters were high and moderate for the rest eight characters. Genetic advance expressed as a percentage of the mean ranged from 7.17% for fruit thickness to 73.6% for hundred-bean weight.

Leaf area, petiole length, bean width, hundred bean weight and bean yield characters show high genetic advance as a percent of mean which allow the improvement of the characters through selection.

The cluster analysis based on D^2 analysis on pooled mean of accessions using 14 quantitative traits classified the one hundred fifteen accessions in to 12 clusters. Based on 14 qualitative traits the accessions were classified into 9 clusters. These make them divergent. There was a statistically approved difference between all the clusters.

In principal component analysis of 115 coffee accessions for fourteen quantitative traits measured the first five PCs with Eigen values greater than one explained 70% of the total variation. The first three PCs accounted for about 44% of the total variability among accessions.

Bean yield per plot had positive and significant phenotypic and genotypic association with stem girth, fruit length, fruit width, fruit thickness and length of longest first primary branch. By se-

lecting for those traits, showing positive and significant correlation coefficient with bean yield there is a possibility of increase bean yield of coffee arabica.

Path analysis revealed that maximum positive direct effect on bean yield was exerted by length of first primary branch followed by fruit width. Since length of first primary branch and fruit width had positive correlation with bean yield indicating these two characters are the most important characters in this studies and in the process of selection much attention should be given to them.

The following conclusion can be drawn from this study

There is an opportunity to bring about improvement of the bean yield through direct selection using the accessions collected from East wellega. Length of first primary branch and fruit width showing positive and significant correlation and positive direct effect, these will be useful trait for indirect selection to increase bean yield.

Leaf area, bean width and hundred-bean weight showed high heritability with high genetic advance as percent of mean and these traits may be included as components of indirect selection.

The results of principal component analysis based on 14 qualitative traits also revealed the existence of diversity among the coffee accessions used in the study. A moderate range of variation was observed among the germplasm accessions for these qualitative characters, which provide good scope for selection among genotypes to make further breeding program to increase the desired traits.

The present experiment was carried out at single location and season. It is possible that the trends could vary across location and need for ascertaining genotypic-environment interaction is highlighted through appropriate studies. The present study indicated a considerable amount of variability for majority of the characters of interest in coffee Arabica for exploitation. Nevertheless, the need for characterization approach through advanced tools of molecular approaches is suggested.

6. REFERENCES

Abyot, T., Sentayhu A., Taye, K. and Woyessa, G., 2011.Variablity and association of quality and biochemical attributes in some promising coffee arabica germplasm collection in Southwestern Ethiopia. *International Journal of Plant Breeding and Genetics, **5**: 302-316.*

Acquaah, G., 2000. Principles of plant genetics and breeding UK: Blackwell publishing Ltd.UK.pp.89.

Aga, E., Bryngelsson, T., Bekele, E. and Salomon, B., 2003. Genetic diversity of forest arabica coffee (*Coffea arabica L.*) in Ethiopia as revealed by random amplified polymorphic DNA (RAPD) analysis. Hereditas **138:**36 – 46

Agwanda, CO., Lashemes, P., Anthony, F., MC. Trouslot, P. and Charrier, A., 1997. Molecular marker- Assisted selection: A powerful approach for coffee improvement. ASIC 17th Nairobi, Kenya. Pp 474 - 480, July, 20 -25, 1997.

Agwanda, CO., Baradat, P., Eskes, A.B.,Cilas, C. and Charier, A., 2003.Selection for bean and liquor qualities within related hybrids of Arabica coffee in multi-local field trials. Euphytica, **131**: 1-3.

Allard, R.W., 1960. Principles of Plant Breeding. John Willey and Sons.Inc. New York.430p

Allard, R.W., 1999. Principles of Plant Breeding (second edition). John Wiley and Sons.Inc., New York, USA

Amsalu, A. and Endashaw, B. 1999. Multivariate analysis of morphological variation in sorghum (*Sorghum bicolor* L. Moench) germplasm from Ethiopia and Eritrea. *Genetic Resources and Crop Evolution.***46**: 273-284.and quality.

Anthony, F., Bertrand, B.,Quiros, O., Wilches, A., Lashermes, P.,Berthaud,J.,and Charrier, A., 2001a.Genetic diversity of wild coffee (*Coffea arabica L.*) using molecular markers. Euphytica. **118:**53–65.

Anthony, F., Combes, MC. Astorga, C., Bertrand, B., Graziosi G. and Lashermes, P., 2002. The origin of cultivated *Coffea arabica* L.varieties revealed by AFLP and SSR markers. Theory of Applied Genetics **104**:894 – 900.

Ariyo, O.J., Akeriova, M.E. and Fatokun, C.A., 1987. Plant character correlation and path analysis of pod yield in Okra (*Abelmoschus esculentus*). Euphytica **36**:677-686

Bayetta, B. and Behailu, A., 1998. Description and production recommendation for new cultivar of arabica coffee. Research Report no 34 IAR 32

Bayetta, B., 2001. Arabica Coffee Breeding for yield and resistance to CBD (Colletotrichum Kahawae Sp.nov). PhD thesis university of London, Department of Agricultural Science. Imperial College at Wye University of London UK.

Bayetta, B., 1997. Arabica coffee breeding in Ethiopia: A review. ASIC 1997 Nairobi, Kenya **17**:406-41.

Bello, O.B., S.Y.Abdulmaliq, M.S.A folabi, S.A. Ige, 2010.Correlation and path coefficient analysis of yield and agronomic characters among open pollinated maize verities and their F1 hybrids in a diallel cross. *African journal of Biotechnology*, **9** (18), pp.2633 - 2639.

Bermer, B., 1996.Combined and separate analysis of morphological and molecular data in the plant family Rubiaceae .Cladistics **12**:21 - 40

Berthaud, J. and Charrier, A., 1998. Genetic Resources of *Coffea*. Pp.1-42. In Clarke RJ and Marcrae R (eds). Coffee Vol.4 Agronomy

Bethouly, M. and Etienne, H., 2000. Somatic Embryogenesis of Coffee, biotechnology Significance of path coefficient analysis in determining the nature of character association. Euphytica **22:**338-343.

Biabani, A.R., Packniyat H., 2008. Evaluation of seed yield related characters in sesame (Sesamum indicum L.)Using Factor and path analysis. Pakistan *Journal of Biological Scienc*es **11**:1157 -1159

Bridson, D., 1987. Nomenclature notes on Psilnthus, including Coffea sect, Paracoffea (*Rubiaceae* tribe *Coffea).*Kew Bulletin. 453 - 460.

Burton, GW. and Devane, EH. 1953. Estimating heritability in tall fescue (*Festuca arundinacea*) from replicated clonal material. *Agronomy Journal*. **45**:478-481.

Carneiro, M.F., Elsevier, M.F., 1999. Applied Science, London and New York. Advances in coffee biotechnology Agricultural Biotech Net **1**:1-8.

Carvalho, V.P., 1988. Principles and practices of coffee plant breeding for productivity and quality factors: *Coffea arabica*. Pp.1-42. In RJ. Clarke and R Marcrae (eds.). Coffee Vol.**4** Agronomy. Elsevier Applied Science, London and New York.CBD (Colletotrichum Kahawae Sp.nov). PhD thesis university of London, Depatment of Agriculture.

Carvalho, A., Medina, F.H., Fazuoli, L.C., Guerreiro, O.and.Limma, M.M.A., 1991.Genetic aspect of the coffee tree in Brasil.Genetic.135-183

Chaparro, A. P., Christancho, M.A., Cortina, H.A. and Gaitan, A.L. 2004. Genetic variability of *Coffea arabica* L. accessions from Ethiopian evaluated with RAPDs. *Genetic. Resource. Crop.Evolution*. **51**:291-297

Cilas C., Bouharmont, P., Boccara, M., Eskes A. B. and Boradat P.H., 1998. Prediction of genetic value for coffee production in Coffea arabica from a half diallel with lines and hybrids. *Euphytica*, **104**:49-59

Cliford, M.N. and Wilson, K.L, 1985. Coffee: Botany, Biochemistry, and Production of Beans and Beverage. Croom Helm. London

Copper, M.C. and Milligan, G.W., 1988. The effect of error on determining the number of clusters. Proceeding of International Workshop on Data Analysis, Decision Support and Expert Knowledge Representation in Marketing and Related Areas of Research, pp: 319-328.

Cristancho, MA., Chaparro, AP., Cortina, HA., and Gaitan, AL., 2004a. Genetic variability of *Coffea arabica L*. accessions from Ethiopia evaluated with RAPDs. ASIC 20th. Bangalore, India.12 February, 2004.

Cros, J., Lashermes, P., Combes, MC. Trouslot, P., Anthony F. And Charrier, A., 1995. Origin and genetic diversity of *Coffea arabica* L. based on DNA molecular markers. ASIC, 16th.Kyoto. 20 January, 1995

Crossa, J.P.L., Corneius, K., Sayre K.and Ortiz – Monasterion, J.I., 1995. A shifted Multiplicative Model Fusion Method for Grouping Environments without Cultivar rank change .Crop Science **35**:54 -62

CSA (The Federal Democratic Republic of Ethiopia Central, Statistical Agency), 2014a. Agricultural sample survey report on crop and livestock product utilization. Volume VII Addis Abeba, Ethiopia.pp.11 - 97

Dar, R.A. and Sharma, J.P., 2011.Genetic variability studies of yield and quality traits in tomato (*Solanum lycopersicum L.*). *International. Journal. Plant Breeding*. Genetics. **5**: 168-174.

Davis, AP, Govaerts, R., Bridson, DM. Stoffelen, P. An annotated taxonomic conspectus of the genus Coffea (Rubiaceae). Bot Journal Linn Soc. 2006; **152**:465–512

Dewey, D.R. and Lu, K.H., 1959. A correlation and path coefficient analysis of components of crested wheat grass seed production. *Agronomy Journal*, **51:515**-518

Ermias, H., 2005. Evaluation of Wellega coffee germplasm for yield, yield component and resistant to coffee berry disease at early bearing stage. An MSc thesis submitted to school of graduate studies of Alemaya University Ethiopia. P 69.

Falconer, D.S. and. Mackay, T.F.C, 1996.Introduction to Quantitative Genetics. Longman, Harlow, UK. *Genetic. Research. **38:** 25–46*

Falconer, D.S., 1989. Introduction to Quantitative Genetics. (3rded). Logman Scientific and Technical, Logman House, Burnt Mill, Harlow, Essex England**.** *Genetics **133:** 137–142*

FAO, 1968. FAO Coffee Mission to Ethiopia 1964-1965. Report, FAO of the United Nations, Rome Italy.200p.

Federer, W. T., 1956. Augmented designs. Hawaii. Plant. Rec.**55**, 191–208.

Fehr, W.R., 1987. Principles of Cultivar Development. Theory and technique. Volume IMc Graw Hill. New York

Fisher, R. A., Yates, F., 1963.Statistical tables for biological, agricultural and medical research. Oliver and Boyd, London.

GENRES statistical software, 1994.Data entry module for Pascal intl soft ware solution.

Gessese, MK., Bellachew, B., Jarso, M., 2015. Multivariate Analysis of Phenotypic Diversity in the South Ethiopian Coffee (*Coffea arabica* L.) for Quantitative Traits. Adv Crop Sci Tech S1:003.doi: 10.4172/2329-8863.1000S1-003

Getachew, W., Sentayehu, A., Taye, K., and Tadesse, B., 2013. Genetic Diversity Analysis of Some Ethiopian Specialty Coffee (Coffea arabica L.) Germplasm Accessions Based on Morphological Traits Benti *Time Journals of Agriculture and Veterinary Sciences* Vol. **1** (4): 47-54.

Getu, B., 2009. Genotype x environment interaction of arabica coffee (*Coffea arabica*) for bean biochemical composition and organoleptic quality characteristics. MSc. Thesis papper submitted to Graduate studies of Alemaya University of Agriculture: Alemaya, Ethiopia

Gichimu, B.M. and Omoodi, C.O., 2010.Morphological characterization of five newly developed lines of arabica coffee as compared to commercial cultivars in Kenya. *International. Journal of. Plant Breeding. Genetics.* **4:238**-246.

Girma, N.K., 2011.Marketing information operation in Ethiopia with special reference to the Ethiopian commodity exchange (ECX) coffee trading Msc thesis. Swedish university of Agricultural Science Uppsala, Sweden. Department of Urban and Rural development.xx, pp75.

Guillumet, J.L. and Halle, F., 1978. Echantiillonnage du mateeriel recolte en Ethiopie.Bulletine Fcc**14**:13-18

Hammer, O., D.A.T. Harper and P.D.Ryan, 2001.PAST (paleontological Statistics Soft ware Package) for education and data analysis .palaeontologia Electronica, **4**:1 -9

Hennink, S.and A.C. Zeven, 1991. The interpretation of Nei and Shannon- Weaver within population variation indices. Euphytica **51**: 235-240.

https://www.ndsu.edu / pub web/~mcclean/ plsc731/ Linkage %20 Disequilibrium %20% 20 Associaton % 20 Mapping % 20 in% 20 Plants-lecture - overheads .pdf.

Hue, T.T.M., 2005. Genetic variation in cultivated coffee (*Coffea arabica* L.) accessions in Northern New South Wales, Australia. Master's Thesis, Southern Cross University, Australia

Hutchinson, K., 1970. A test for comparing diversities based on the Shannon formula. *J. Theoretical. Biology*.**29:** 151-154.

ICO, 2014. Ethiopian coffee Intellectual property Rights and geographical Indication protection perspective. Available from http://wwweuropa.cu/Agricultural events /2011/ gi-africa2011 / Senayhu_ en. Pdf. ICO, 2014.

Dubes, R. C., and Jain, A. K. 1988.*Algorithms for Clustering Data*. Prentice-Hall advanced

Johnson H.W., H.F. Robinson and R.E. Comstock, 1955. Estimates of Genetic and Environmental variability in soya beans .*Agronomy Journal* **47**:314-318.

Kassahun, T.2006. Genetic diversity of wild Coffea arabica populations in Ethiopia as a contribution to conservation and use planning, Ecology and Development Series NO. 44 Cuvillier verlang, Gottingen.pp147 - 168

Katarzyna, B., Jack, W. and Silverstein, M., 2013. Separation of the largest eigen values in eigen analysis of genotype data from district sub population

Krug, C.A., 1958. The genetics of Coffea.advan.in Genet.**4:**127-158

Kufa, T., 2010.Environmental sustainability and coffee diversity in Africa. Paper presented in ICO world coffee conference, 26-28 February, 2010, Guatemala City.

Kumar, S.A., Sudisha, J. and Screenath, H.L. 2008.Genetic relation of Coffea and Indian psilanthus species as revealed through RAPD and ISSR markers.IJBI, **3**:2-2.

Labouisse, J.P. and Bayetta, B., 2008. Arabica coffee (*Coffea arabica L*.) local landrace development strategy in its centre of origin and diversity. Proceedings of the 21st International Conference on Coffee Science (ASIC) Colloquium, Sept. 11-15, Montpellier, France, pp: 818-826.

Lashermes, P., Trouslot, P., Anthony, F., Combes, M-C. and Charrier, A., 1996 Genetic diversity for RAPD markers between cultivated and wild accessions of Coffea arabica. Euphytica **87:**59 –64

Lashermes, P., Cros, J., Marmey, P.and Charrier, A., 1995. Use of random amplified DNA markers to analyzer genetic variability and relationships of *Coffea* species.Genet. Resour. *Crop Evol*, **40**: 91-99

Leroy, T., Ribeyre, F., Bertrand, B., Charmetant P.and Dufour, M., 2006.Genetics of coffee quality. Braz. *J. Plant Physiol*., **18:** 229-242

Mahalanobis, P.C., 1936. On the generalized distance in statistics. Proc. Natl. Inst. Sci., 2: 49-55.

MCTD, 1986. Report on coffee improvement project activities. Ministry of tea and coffee symposium, Aug. 20-23, 1986. IAR, Addis Ababa.

Melaku, W., 1982. Coffee genetic resources in Ethiopia, conservation utilization with particular reference to CBD resistance .In proceedings of 1st regional work shop of coffee diseases. Addis Ababa, 19 – 23, July Ethiopia pp 203 -211

Melaku, J.and Samuel, A., 2000. The status of Coffee Berry Disease in Oromia. pp. 9 - 17.Procedding of the work shop on Control of Coffee Berry Disease (CBD) in Ethiopia. Addis Ababa, Ethiopia, .13-15 August 1999. Ethiopian Agricultural research Organization

Mesfen, A., 1982. Hetrosis in crosses of indigenous coffee (*Coffea Arabica L.*) selected for yield and resistance to coffee berry disease: I. first bearing stage. *Ethiopian .Jornal Agricultural.Science*, IV: 33-43

Mesfen, A.and Bayetta, B., 1987. Genotype - Environmental interactions in coffee (*Coffea arabica L.*). ASIC 12th.pp.476 - 481\Montreux.

Mesfen, K. and Bayeta, B., 2005. Genetic Divergence of Hararge Coffee (*Coffea arabica* L) Germplasm Accessions at Pre-Bearing Stage

Mesfen, K., 2008. Multivariate analysis phenotypic diversity of (*Coffea Arabica L*). In: Girma, A.Bayetta, B., Tesfaye, S., Endale, T. and Taye, K. (eds.). Coffee Diversity and Knowledge. Proceedings of a National Workshop Four Decades of Coffee Research and Development in Ethiopia, 14-17 August 2007, Addis Ababa, Ethiopia. pp. 58-63.

Mesfen, A., 1980.Yield assessment of indigenous coffee grown at Jimma research station.Eth.Jr.Agr.Sci, II: 69-71.

Meyer, FG. 1965. Notes on wild *Coffea arabica* from southwestern Ethiopia, with some historical considerations. Econ Bot **19**(2):136–151

Narain, P., 1990. Statistical Genetics Wiley Eastern Ltd., New Delhi**.**

Nei, M., 1987.*Molecular Evolutionary Genetics*. (Chapter 9).New York: Columbia University Press

Nowak, M. D. Haller, B. C. and Yoder. A. D. (2014). The founding of Mauritian endemic coffee trees by a synchronous long-distance dispersal event. *Journal of Evolutionary Biology*

Olika, K, Sentayehu, A., Taye, K., Woyesa, G., 2011.Variability of quantitative Traits in Limu Coffee (*Coffea arabica*.) in Ethiopia. Int. *J. Agric. Res.* **6:** 482-493.

Orozco-Castillo, C., Chalmers, K.J., Waugh, R. and Powell, W., 1994.Detection of genetic diversity and selective gene introgression in coffee using RAPD markers. Theory of Applied Genetics **87**:934-940.

Paulos, D., 1994. Mineral fertilization of coffee in Ethiopia Institute of Agricultural Research, Addis Ababa. Pp 3-17.

Paulos.D, and Teketay, D., 2000. The need for forest coffee germplasm conservation in Ethiopia and its significance in the control of coffee diseases. In: the proceedings of the workshop on control of coffee berry disease in Ethiopia, pp.125-135. Ethiopian Agricultural Research Organization (EARO), Addis Abab

Rene, C., 1992. Coffee the Plant and the Product. Phil Brodatz, Dover Publications Inc. p 328.

Robinson, H F, Comstock, R E, and Harvey, P H. 1949. Estimates of heritability and the degree of dominance in corn. Agricultural Journal, **41**: 353–359

SAS, 2008. Statistical analysis system (version 9.2), SAS Institute, Cary, NC.USA

Sera, T., Raus, PM., Rampim, L. and Carvalho, VP., 2003. Genetic relationship in *Coffea* species and parentage determination of interspecific hybrids using ISSR (Inter- Simple Sequence Repeat) markers. Genetics and Molecular Biology **26(3)**:319-327.

Seyoum, S., 2003. Genetic divergence for seedling parameters and associations among agronomic traits in the Ethiopian coffee (*Coffea arabica L*.) germplasm. An MSc thesis submitted to the School of graduate studies of Alemaya University.

Shannon CE and Weaver W.1949.The mathematical theory of communication. Urbana, Illiois, USA; University of Illiniois press.

Sharma, P.K., Gupta P.K. and Balayn, H.S., 1998. Genetic diversity in a large collection of wheats (*Triticum* spp.).*Indian Journal of Genetics and Plant Breeding*, **58**(3): 271-278.

Singh, BD., 2001. Plant Breeding: Principles and methods. Kalyani Publishers, New Delhi. pp. 896.

Singh, RK., Chaudhary, BD., 1990. Biometrical methods in quantitative genetic analysis. Kalyani publishers, New Delhi-Ludhiana, India's 318.

Singh, Narayanan, SS., 1993. Biometrical techniques in plant breeding.1st ed. Kalayani Publishers, New Delhi, India.

Snedecor, GW. and. Cochran, WG. 1989. Statistical Methods. 8th ed. Ames: Iowa State Press.

Sondahl, M. R., Van der Vossen, H. A. M, Piccin, A. M. and Anzueto, F. (2005). The Plant. In Viani, R. (ed.) Espresso Coffee: the Chemistry of Quality, 2nd edition. Academic Press Ltd, London.

Srinivasan, C.S., 1982 Pre selection for yield in coffee.*Indian Journal of Genetics and plant breeding.***42 (1):**15-19.

Srinivasan, C.S., 1988. Association of some vegetative characters with initial fruit yields in coffee. *Journal of Coffee Research* **10 (2):** 21-27

Steel, R., James, G.D., Torrie, G.and David**,** D., 1997. Principles and procedures of statistics, a biometrical approach. 3rd ed. Mc Graw-Hill Book Co., New York, NY

Steiger, DL., Nagai, C., Moore, PH., Mordents, CW., Osgoog, RV.and Ming, R. 2002. AFLP analysis of genetic diversity within and among *Coffea arabica* cultivars. Theory of Applied Genetics **185**:189-215.

Sylvain, PG., 1955. Some observations on *Coffea arabica* L. in Ethiopian.Turrialba **5** (1–2):37–53

Tadesse, M., Nigatu, L., 1996.An ecological ethno botanical study of wild spontaneous coffee *Coffea arabica* L.in Ethiopia. In: The Biodiversity of African Plants. Proceedings of 14th AETFAT Congress, 22–27 August 1994,Wageningen. Kluwer Academic Publisher, Wageningen, pp 277–294

Tariq, M., Khan, M.A. and Idress, G. 1992. Correlation and Path coefficient analysis in upland cotton. Sarhad J. Agri., 8: 341 - 51.

Tesfaye, GK., Govers, K., Oljira, T., Bekele, E. and Borsch, T., 2007. Genetic diversity of wild *Coffea arabica* in Ethiopia: analyses based on plastid, ISSR and microsatellite markers. In: 21st International Coffee Science Conference, Montpellier, 11–15 September 2006, pp 802–810

Tewodros, M., 2008.Morphological characterization of preliminary evaluation of areal Yam (*Dioscorea bulbifera*L.) accessions collected from south and southwest Ethiopia Msc.Thesis presented in Hawasa university pp120.

Tsegaye, Y. and Taye, K., 2002. Characterization of the farming Systems of Haru Woreda.West Wellega zone, Oromia region. Research Report **(44)** EARO. 38p

Van der Graaf, N.A., 1981. Selection of arabica coffee types resistance to CBD in Ethiopia.

Van der Vossen, H.A.M., 1985. Coffee Selection and Breeding. In: Coffee Botany, Biochemistry and Production of Beans and Beverage, Clifford, M.N. and K.C.Willson (Eds.). Croom Helm, London, pp: 49-96.

Vander Vossen, H.A.M, 1997. Quality aspects in arabica coffee breeding programs in Africa. In: Asic 17e international scientific colloquium on coffee, Nairobi, Kenya. Verma, M.M., K.S

Vander Vossen, H.A.M., 2001. Coffee breeding and selection review achievements and challenges: 18th international colloquium on coffee (**1)**2001, Italy. 401-408.

Van Hintum, Th.J.L. ,1995. Hierarchical approaches to the analysis of genetic diversity in crop plants Pp23 -24 *in* core collections of plant Genetic resources (T.Hodgkin A.H.D. Brown Th.J.L Van Hintum and E.A.V.Morales, Eds.).John Wiley and Sons, UK.

Walyaro, D.J.and Van der Vossen, H.A.M, 1979. Early determination of yield potential in arabica coffee by applying index selection. *Euphytica*.**28**: 465-472

Walyaro, D.J.A., 1983.Considerations in breeding for improved yield and quality in arabica coffee (*Coffea arabica* L.) A PhD thesis, Wageningen 234p Agricultural University. Available at (http://library.wur.nl/wda/abstracts/ab961.html)

Wassu M , Bayetta B , Harjit S (2008). Heterosis and combining ability for yield and yield related traits in Arabica coffee (*Coffea arabica* L.). In: Girma A, Bayetta B, Tesfaye S, Endale T and Taye K (eds.). Coffee Diversity and Knowledge. Proceedings of a National Workshop Four Decades of Coffee Research and Development in Ethiopia, 14-17 August 2007, Addis Ababa, Ethiopia. pp.79 - 87.

Woldemariam,T.,Denich,M.Teketay,D. and Vlek,P.L.G.2002.Human impacts on the *Coffea arabica L*. genetic pools in Ethiopia and the need for its in situ conservation .In: Engels,J.M.M. Rao,V.R. Brown ,A.H.D. and Jackson, M.T.(Eds.),Managing plant Genetic Diversity,pp.237 - 247.IPGRI,Rome.

Workafes, W. and Kassu, K., 2000.Coffee Production Status of Ethiopia.pp.99-106.Procedding of the workshop on Control of Coffee Berry Disease (CBD) in Ethiopia. Addis Ababa, Ethiopia, 13-15 august 1999. Ethiopian Agricultural research Organization

Wrigley, G., 1988. Coffee. Tropical Agriculture Series. Longman Scientific and Technical, Longman group UK Limited, England 639 .PP

Yigzaw, D., 2005. Assessment of genetic diversity of Ethiopian arabica coffee genotypes using morphological, biochemical and molecular markers. PhD Dissertation, University of the Free State, South Africa. P197.

Yonas B, Tarekegn A, 2014. Genetic Variation and Extent of Heritability of the Various Agronomic Traits of Arabica Coffee (*Coffea Arabica* L.). Genotypes Grown across different Environments in Ethiopia. Greener Journal of Agronomy, Forestry and Horticulture, **3(1**): 001-010

APPENDICES

Appendix Table 1. Mean performances of the different accessions for different morphological characters

Acc. No	LL	LW	LA	PL	TH	HUFPB	LFPB	NPB	NNMS	GIRTH
Menesibu	13.54	7.28	98.42	0.72	204.12	40.74	69.92	46.12	26.52	39.84
Hru-1	13.4	7.22	100.6	0.8	194.72	35.26	76.66	45.18	26.88	40.18
Chala	14.38	7.52	108.6	0.72	205.5	39.28	76.74	46.4	25.72	39.72
Sende	13.28	7.14	94.72	0.76	208.92	27.92	72.7	43.78	24.46	37.29
EW70/09	15.4	8.52	132.61	1.1	208.67	24.33	88.46	49.17	28.5	38.16
EW8/09	14.5	6.84	100.54	0.7	183.8	35.13	84.21	43.8	24.47	35.41
EW37/09	14.98	6.64	100.49	0.84	171.84	16.75	66.73	47.85	27.07	38.36
EW67/09	17.98	9.32	167.71	0.9	185.27	28.93	86.06	43.57	24.8	45.96
EW94/09	15.95	6.59	107.24	0.8	177.89	37.5	82.06	45.25	22.9	39.07
EW15/09	16.45	7.39	124.34	0.8	186.59	34.8	83.76	44.95	18.6	42.17
EW79/09	16.05	7.74	125.59	0.83	213.84	46.05	78.43	40.55	25.37	40.96
EW47/09	16.38	8.32	136.61	0.8	212.27	29.63	90.06	48.17	28.8	45.16
EW88/09	14.13	7.12	96.34	0.68	222.12	37.1	93.26	53.85	28.07	46.41
EW105/09	15	6.14	93.84	0.7	187.79	38.43	71.81	39	21.47	38.81
EW36/09	14.55	6.79	100.24	0.8	190.89	30.8	102.06	45.55	24.9	42.07
EW106/09	14.85	7.44	111.69	0.73	201.24	28.05	57.43	49.55	29.77	40.86
EW85/09	17.4	7.74	136.84	1	250.79	29.43	95.21	56.5	33.17	40.11
EW82/09	16.5	7.44	124.64	0.9	190.19	35.13	75.21	44	22.77	40.81
EW16/09	16.78	8.22	138.11	0.7	195.97	23.33	88.06	46.57	26.2	45.66
EW27/09	15.78	7.72	122.11	2.4	208.67	26.93	82.06	54.87	33.2	48.16
EW43/09	16.95	7.94	136.09	0.93	183.84	22.35	76.73	45.25	19.77	45.56
EW66/09	18.33	8.82	153.94	0.88	203.72	33.4	75.26	50.55	26.77	39.21
EW76/09	16.35	7.09	118.34	0.7	219.59	34.1	83.36	45.95	24.6	45.37
EW51/09	14.25	6.59	95.14	1	205.89	24.1	81.36	52.95	31.6	42.27
EW52/09	17.15	8.74	151.39	1.03	225.54	22.05	95.13	49.55	27.07	45.96
EW25/09	16.85	7.14	121.69	0.83	192.24	23.35	91.73	48.55	28.77	39.66
EW29/09	16.8	7.34	125.34	0.8	194.49	23.83	93.81	42.8	26.17	43.21
EW101/09	17.23	9.42	155.24	0.68	198.12	37.7	76.26	44.55	26.07	40.21
EW1/09	17.38	7.92	137.51	0.92	211.97	35.33	87.46	49.87	31.8	44.16
EW73/09	13.8	6.24	87.34	0.8	207.79	30.13	99.21	51.8	25.47	37.61
EW4/0	15.08	7.52	113.91	1.1	170.97	28.33	73.76	30.87	22.2	37.26
EW18/09	16.75	7.84	132.79	0.93	183.84	35.35	77.13	42.55	23.07	42.26
EW110/09	17.38	8.12	141.11	1	191.97	32.63	86.46	44.57	30.5	42.76
EW39/09	16.05	7.54	122.39	0.83	201.54	31.35	70.13	45.55	26.37	39.16
EW74/09	16.53	8.62	136.14	0.88	175.42	35.7	83.26	45.25	24.07	41.71
EW75/09	17.5	7.44	132.44	0.9	189.79	22.43	81.21	42.8	24.17	41.21
EW95/09	14.05	6.89	98.04	0.9	211.29	35.2	82.86	50.85	29	41.57
EW9/09	15.23	8.22	119.34	0.78	218.72	35.7	86.26	49.25	27.07	39.21

Appendix Table 1(*continued)*

EW34/09	15.45	6.94	108.49	0.63	195.24	49.75	86.73	40.55	25.07	37.56
EW31/09	15.18	7.82	119.31	0.8	202.97	40.63	78.06	43.87	24.8	36.76
EW55/09	16.28	8.62	140.81	1.8	176.97	29.63	72.06	44.17	24.2	39.26
EW60/09	14.35	6.84	99.29	0.73	219.84	20.35	75.13	50.85	31.77	39.76
EW71/09	17.03	7.82	126.64	0.88	193.42	23.1	82.56	47.25	27.37	34.11
EW68/09	16.5	7.24	121.44	0.9	179.19	26.13	96.81	40.5	22.47	35.01
EW89/09	16.15	7.44	121.59	0.83	198.54	29.75	72.13	47.85	27.37	40.26
EW24/09	16.8	7.34	125.34	0.7	211.19	39.13	82.81	51.1	30.47	39.11
EW96/09	17.08	7.92	135.21	0.9	218.67	32.33	81.76	42.17	29.2	39.16
EW99/09	17.07	7.54	130.29	0.93	168.84	47.05	71.73	35.25	21.77	32.16
EW92/09	13.45	6.09	82.74	0.6	210.29	42.5	80.06	51.55	29.9	39.47
EW72/09	17.55	7.09	127.44	0.8	197.29	33.1	91.06	40.25	21.6	40.77
EW91/09	15.98	8.32	133.41	0.7	226.97	32.93	89.06	46.17	26.8	38.76
EW59/09	18.01	7.74	141.74	0.8	202.19	35.73	79.71	44.4	27.07	37.41
EW90/09	16.75	7.09	121.34	0.9	219.29	39.8	89.06	50.95	28.2	43.27
EW40/09	16.05	8.04	130.39	0.93	202.24	20.35	71.43	37.85	25.37	32.86
EW10/09	16.58	8.72	145.01	0.84	220.27	29.93	91.46	37.87	26.2	41.26
EW14/09	16.58	8.62	143.31	1.08	197.27	25.33	97.76	42.87	27.2	36.76
EW2/09	16.15	6.89	113.54	0.9	196.59	36.5	78.36	39.25	23.6	41.57
EW93/09	14.25	6.79	98.04	0.8	166.59	36.5	81.36	43.25	21.6	38.97
EW98/09	14.43	7.22	99.64	0.78	198.72	30.7	86.56	53.25	28.37	43.41
EW77/09	16.15	7.44	121.59	0.73	205.84	37.35	72.43	46.55	28.77	41.36
EW104/09	17.6	8.04	143.74	0.9	239.49	37.83	68.81	50.1	28.47	41.41
EW42/09	13.95	5.49	77.54	0.7	239.29	26.8	76.36	53.55	29.6	37.37
EW32/09	16.93	8.82	142.54	0.98	184.72	33.4	84.56	38.55	23.07	36.71
EW23/09	16.33	8.22	128.14	0.98	182.12	26.4	77.26	40.55	25.07	39.21
EW111/09	15.95	8.04	129.59	0.83	182.84	33.75	75.73	42.55	26.37	38.76
EW65/09	17.3	8.04	141.14	0.8	208.79	30.13	89.51	41.1	25.17	37.41
EW57/09	14.45	7.19	105.34	0.9	190.89	45.1	68.76	38.25	27.9	41.07
EW26/09	14.05	6.34	90.19	0.73	205.54	18.75	70.73	53.55	30.77	36.26
EW13/09	20	8.54	173.74	0.8	181.79	30.83	66.21	41.5	22.17	32.81
EW62/09	17.98	8.72	156.01	1	183.67	29.33	89.06	47.87	30.5	40.76
EW109/09	16.28	7.12	115.91	0.8	179.66	25.93	78.06	46.57	27.5	39.76
EW108/09	15.93	7.92	120.34	0.88	184.72	40.4	89.96	46.85	25.07	39.11
EW48/09	16.05	7.09	116.04	1	180.29	48.1	68.36	43.55	25.2	37.17
EW17/09	16.28	7.62	124.21	0.9	183.67	15.63	85.76	50.87	27.8	47.96
EW50/09	15.73	8.12	122.04	0.78	186.42	28.6	82.46	49.15	26.57	40.31
EW100/09	15.83	8.52	129.04	0.98	198.12	29.4	80.96	51.55	26.37	40.21
EW38/09	14.4	7.62	111.01	0.9	199.97	33.63	72.06	42.87	27.8	36.76
EW64/09	14.43	6.82	93.94	0.88	197.42	33.4	84.26	48.85	28.37	38.41

Appendix Table 1(*continued)*

EW21/09	18.23	8.62	149.54	0.98	178.72	26.7	80.96	43.25	24.37	36.61
EW81/09	14.07	7.41	105.21	0.8	185.27	29.33	89.46	39.17	26.5	41.16
EW78/09	16.6	8.04	135.34	0.8	201.49	28.83	95.21	44.1	25.77	37.81
EW44/09	17.75	7.84	140.79	0.73	153.24	25.35	57.43	47.55	26.07	39.56
EW97/09	16.1	8.22	133.41	0.6	183.27	27.33	98.76	38.87	24.2	38.26
EW7/09	14.35	6.39	93.04	0.6	192.59	27.5	86.76	45.55	23.6	47.27
EW12/09	17.95	8.04	145.99	1.03	228.24	23.75	101.73	45.25	26.37	39.06
EW102/09	16.48	7.82	129.01	1	197.27	28.63	83.06	40.87	22.8	41.96
EW22/09	15.85	6.69	108.14	0.8	211.59	27.5	76.06	57.55	33.2	44.97
EW30/09	14.05	6.59	93.74	0.8	161.59	48.1	69.06	34.55	22.2	36.57
EW35/09	15.38	7.92	122.31	0.9	180.97	36.93	86.46	37.87	21.2	34.46
EW3/09	15.55	7.19	113.84	0.9	173.89	24.1	74.36	37.95	24.6	31.27
EW61/09	15.85	7.59	122.54	0.8	173.59	38.5	75.76	52.95	27.2	42.27
EW56/09	14.48	7.72	112.51	0.8	216.97	29.33	106.06	48.87	26.5	40.66
EW28/09	14.63	7.52	105.24	0.68	219.72	33.7	94.56	56.85	31.07	43.41
EW41/09	16.5	7.74	129.54	0.7	178.19	29.83	78.81	41.8	20.47	43.51
EW49/09	16.33	8.62	134.54	0.78	224.12	37.1	70.96	53.25	29.07	39.91
EW87/09	18.03	9.62	165.74	1.08	202.42	45.4	82.56	45.85	25.37	41.21
EW46/09	14.8	6.74	101.24	0.7	216.79	41.13	78.81	44.8	26.17	43.71
EW45/09	15.48	7.62	118.31	0.7	166.67	30.33	73.4	34.87	25.8	35.46
EW20/09	13.53	7.22	93.84	0.88	175.42	35.7	73.2	48.55	26.07	37.11
EW58/09	17.13	9.62	157.74	0.88	226.72	29.4	108.56	56.85	30.07	44.11
EW86/09	16.15	7.64	124.79	0.83	228.84	33.75	80.13	50.85	31.37	42.46
EW83/09	17.3	7.64	134.34	0.8	174.19	24.43	71.51	41.8	25.77	34.61
EW69/09	14.13	7.52	101.84	1.08	155.42	72.4	80.56	32.55	17.77	28.91
EW33/09	16.65	7.94	133.69	1.03	208.84	24.72	89.43	40.85	26.4	37.96
EW63/09	16.48	8.42	139.11	1.1	213.67	31.63	74.06	49.57	34.2	38.26
EW53/09	16.95	7.34	125.69	0.93	185.24	31.35	78.43	39.25	23.37	33.36
EW84/09	15.75	7.59	121.74	0.8	202.29	36.5	85.36	45.55	22.9	42.17
EW107/09	17.5	7.74	137.64	0.9	183.49	18.83	78.81	41.1	24.17	37.61
EW11/09	17.68	9.22	163.21	0.9	174.97	24.32	78.06	45.57	26.2	35.46
EW80/09	14.48	7.12	103.61	0.72	186.27	35.32	77.76	36.87	32.8	42.26
EW19/09	14.75	6.99	104.74	0.7	185.59	29.8	90.76	51.95	26.9	44.47
EW103/09	15	6.74	102.64	0.8	203.49	36.43	65.81	48.5	30.17	35.55
EW54/09	16.2	7.34	120.74	0.9	178.19	37.13	61.81	34.5	21.17	34.01
EW5/09	16.12	8.12	125.04	0.68	195.42	37.7	94.56	41.85	23.37	38.21
EW06/0	16.8	7.04	120.34	0.9	216.49	38.43	83.21	47.8	26.47	37.71
Grand mean	15.69	7.57	119.60	0.85	197.62	32.63	80.54	45.42	26.17	39.57
CV %	4.76	4.02	4.71	15.34	11.27	26.45	7.8	13.55	11.38	4.923
F- test	*	*	*	*	Ns	Ns	ns	ns	*	*
Lsd 0.05 same block	2.30	0.94	17.37	0.40	68.61	26.60	19.3	18.96	9.18	6.01
Lsd 0.05 b/n block	2.57	1.05	19.42	0.45	76.71	29.74	21.20	21.20	10.26	6.71

Appendix Table 1*(continued*)

Acc.no	CD	AIL	BL	BW	BT	HBW	FL	FW	FT	YLD
Menesibu	119.34	6.38	9.54	6.74	4.2	16.96	14.84	14.6	13.92	1446
Haru-1	123.26	6.22	9.48	6.76	4.36	14.76	14.36	13.78	13.64	1185.07
Chala	127.74	6.76	10.02	6.93	4.28	18.58	14.82	15.02	14.44	1104.24
Sende	120.32	7.81	9.5	7.28	4.5	12.46	14.7	15.5	15.28	1090.12
EW70/09	120.74	6.73	8.96	6.23	3.91	15.64	15.73	16.28	15.92	1995.83
EW8/09	123.54	6.43	7.88	6.54	3.99	10.77	13.43	16.15	15.07	1971.63
EW37/09	130.22	6.02	8.84	6.4	3.91	8.17	15.68	16.58	13.47	1026.03
EW67/09	122.44	6.63	8.46	6.53	3.91	14.54	14.91	15.18	16.02	1862.33
EW94/09	112.24	8.37	8.16	6.45	3.86	3.17	13.16	14.58	12.6	321.63
EW15/09	118.94	8.87	9.76	7.15	4.16	9.77	15.46	16.58	14.1	1760.53
EW79/09	105.22	7.12	10.94	8.4	4.71	22.07	14.78	15.98	13.87	561.63
EW47/09	144.04	6.53	8.76	6.73	4.41	26.74	15.31	17.08	16.32	1076.63
EW88/09	119.97	6.84	9.66	7.18	4.24	12.27	16.03	16.63	16.45	917.23
EW105/09	150.14	7.18	7.09	6.34	3.79	32.97	11.23	12.25	11.27	1666.63
EW36/09	133.94	6.67	10.16	6.75	4.26	4.77	15.06	14.17	15.2	1519.53
EW106/09	110.22	6.12	9.14	7.3	4.31	9.57	15.08	17.78	15.27	1150.92
EW85/09	123.54	7.06	9.09	7.14	3.99	25.77	14.93	16.35	14.17	1376.13
EW82/09	136.84	7.07	8.89	7.64	4.49	20.77	15.33	17.45	15.07	1043.83
EW16/09	139.04	6.93	9.16	6.63	4.11	15.64	15.81	16.38	16.12	1487.93
EW27/09	125.74	5.53	9.56	6.13	4.11	21.24	15.11	16.08	16.42	821.63
EW43/09	136.82	8.82	8.84	6.7	3.91	17.07	14.68	16.18	13.87	904.13
EW66/09	114.97	6.64	9.76	7.38	4.64	21.37	14.53	15.73	14.85	836.93
EW76/09	132.24	7.87	9.26	7.75	4.36	28.67	15.16	16.78	14.6	1358.33
EW51/09	127.24	5.77	9.36	7.25	4.16	10.77	14.86	16.58	14.3	749.13
EW52/09	136.82	7.92	8.54	6.4	5.11	17.07	14.28	16.28	14.27	680.52
EW25/09	150.22	6.12	7.84	6.3	3.81	22.07	13.78	15.78	13.07	704.93
EW29/09	128.54	6.85	8.59	7.14	3.89	10.77	14.63	16.55	14.67	1711.23
EW101/09	140.67	6.38	10.26	7.18	4.44	9.17	15.73	16.83	16.55	961.63
EW1/09	129.04	5.63	7.96	5.63	3.91	14.54	14.01	15.58	15.72	1915.63
EW73/09	131.84	7.26	8.39	6.94	3.89	25.77	14.13	16.55	14.17	1121.63
EW4/0	114.04	6.83	9.96	6.83	4.21	24.54	16.71	17.38	16.22	1841.63
EW18/09	121.82	6.92	9.04	6.7	4.21	19.27	15.78	17.78	14.97	804.73
EW110/09	139.04	5.33	10.06	7.33	4.71	15.64	17.01	17.28	17.52	1413.63
EW39/09	146.82	6.82	8.34	6.4	3.81	17.07	13.48	14.88	12.37	1261.73
EW74/09	113.37	6.04	9.56	7.08	4.14	23.37	14.93	15.83	14.35	1245.03
EW75/09	125.14	7.19	9.89	6.54	3.79	25.77	13.33	17.75	15.37	945.03
EW95/09	110.74	5.77	9.46	7.35	4.16	8.47	14.86	16.88	14.2	1726.17
EW9/09	123.37	7.04	9.86	6.58	4.04	11.17	16.03	17.53	15.95	4059.03
EW34/09	145.22	6.12	9.74	6.7	4.21	9.57	16.68	17.08	14.77	3096.13
EW31/09	135.74	7.03	8.56	6.73	4.31	29.54	14.71	15.78	16.22	2459.03
EW55/09	139.04	6.53	7.96	4.83	5.21	18.84	13.01	14.28	14.72	2186.33

Appendix Table 1*(continued)*

EW60/09	133.52	6.52	8.74	6.5	4.61	32.07	14.88	16.28	14.47	1580.73
EW71/09	123.37	6.24	8.76	6.78	4.44	17.87	14.33	16.33	15.65	5381.73
EW68/09	153.54	7.07	9.39	7.64	4.09	22.97	16.43	17.45	14.47	2796.43
EW89/09	140.22	6.52	7.84	6.3	4.11	11.37	14.08	16.48	14.47	3189.03
EW24/09	120.14	6.09	9.69	6.44	4.09	22.97	15.03	16.85	17.17	1885.03
EW96/09	119.04	6.63	9.26	7.03	4.31	17.04	15.83	16.88	16.82	2205.03
EW99/09	103.52	6.02	8.74	6.7	4.01	19.27	15.28	16.68	14.57	745.03
EW92/09	122.24	5.67	9.46	7.25	3.96	13.17	14.96	17.48	14.3	1410.03
EW72/09	138.94	8.07	9.46	7.25	4.26	8.97	14.46	16.38	13.3	1441.46
EW91/09	135.74	7.63	8.36	6.33	3.91	24.54	15.81	16.98	16.62	978.00
EW59/09	122.94	6.54	8.69	6.94	3.89	20.77	14.63	16.45	14.57	1265.03
EW90/09	127.24	6.47	9.36	6.65	4.26	6.47	14.76	15.38	12.3	1225.35
EW40/09	146.82	7.52	9.44	7.5	4.31	13.77	15.78	17.18	14.67	1553.95
EW10/09	135.74	7.63	8.46	6.43	3.91	29.54	14.61	16.08	15.32	120.95
EW14/09	107.44	6.63	9.96	7.13	4.51	24.54	16.31	16.58	16.22	2180.35
EW2/09	125.54	7.57	8.96	7.35	3.86	10.77	15.76	18.38	15.3	2375.95
EW93/09	117.24	6.27	9.86	7.56	4.46	18.67	15.76	16.98	14.7	1780.35
EW98/09	123.37	6.14	9.76	5.68	3.94	21.17	15.03	15.03	14.75	1343.75
EW77/09	135.22	7.02	8.64	6.5	4.11	8.47	15.08	17.68	14.97	1957.95
EW104/09	125.14	7.39	8.39	5.64	3.49	25.77	14.73	15.85	13.77	1379.25
EW42/09	123.94	7.37	9.26	6.85	4.06	8.97	14.96	16.58	14	2185.95
EW32/09	119.97	6.8	10.46	7.38	4.64	21.17	14.83	15.73	15.25	1942.05
EW23/09	103.37	6.44	9.66	7.01	4.34	12.26	15.73	17.13	16.35	1662.65
EW111/09	136.82	6.02	8.54	6.2	3.81	13.77	15.28	17.08	14.37	1855.95
EW65/09	121.84	7.34	9.09	6.84	3.89	14.07	15.23	16.18	13.57	755.95
EW57/09	102.24	5.27	9.66	6.65	3.76	10.77	15.96	16.78	13.7	613.45
EW26/09	123.52	7.22	8.24	6.8	4.41	30.07	14.18	16.78	13.97	1960.95
EW13/09	110.14	7.06	9.59	8.04	4.29	15.07	15.83	18.25	15.37	1455.95
EW62/09	125.74	5.13	8.86	6.83	4.41	24.54	15.01	16.18	15.92	1435.95
EW109/09	119.04	5.73	9.76	6.83	4.21	17.04	15.91	17.28	16.82	1704.25
EW108/09	130.37	5.96	9.56	7.08	4.04	12.27	14.93	15.73	15.45	1347.05
EW48/09	110.54	5.27	9.36	6.25	3.46	8.97	15.26	16.18	13.1	1473.75
EW17/09	136.44	6.23	8.16	6.43	4.81	26.75	14.11	15.08	15.52	2116.82
EW50/09	113.67	6.15	11.26	7.78	5.04	12.27	15.93	17.23	16.05	1375.73
EW100/09	135.97	6.63	9.46	6.68	4.04	13.67	15.53	16.72	16.25	1980.73
EW38/09	108.44	6.23	8.76	7.13	4.51	15.64	16.31	17.58	17.02	1226.08
EW64/09	129.97	6.04	9.46	7.28	4.24	21.17	15.83	18.03	16.45	1243.13
EW21/09	124.97	6.44	9.56	6.78	4.44	21.17	14.73	15.43	14.25	1117.43
EW81/09	110.74	6.13	8.16	6.83	4.31	12.84	15.11	16.38	16.32	1912.23
EW78/09	120.14	7.01	9.09	7.14	4.09	14.07	15.63	18.55	15.07	1865.33
EW44/09	116.82	5.22	9.035	6.3	4.21	8.17	16.88	18.08	16.27	1187.43
EW97/09	130.74	7.33	9.36	6.63	4.11	22.74	16.01	15.98	16.02	1986.42
EW7/09	132.24	7.37	7.86	6.45	4.16	7.57	12.76	14.68	13	982.43
EW12/09	153.52	8.12	8.64	6.9	3.91	17.07	15.98	16.88	13.97	1870.03

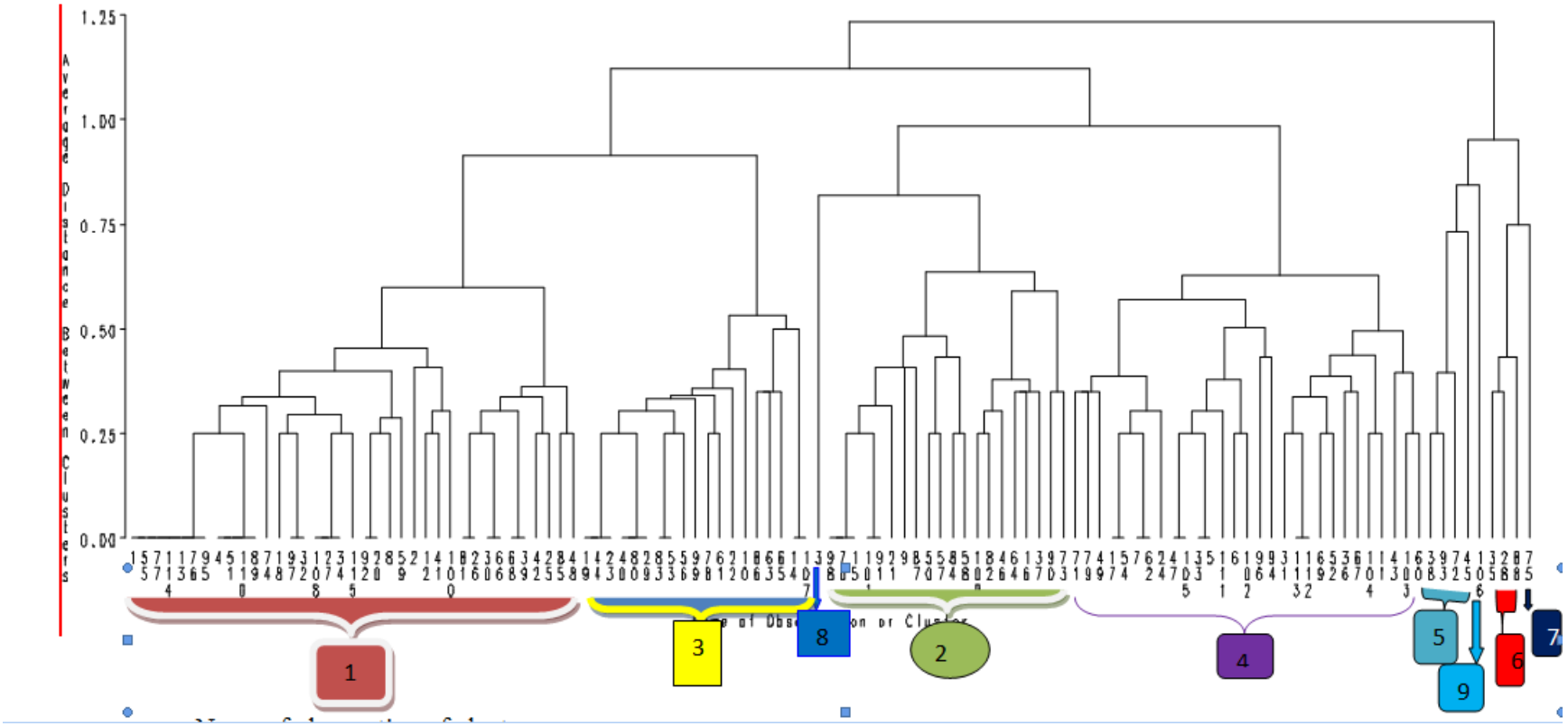
Appendix Table 1(*continued)*

EW102/09	127.44	7.93	9.36	6.43	4.91	15.94	16.21	15.98	16.62	1727.73
EW22/09	127.24	5.57	8.96	6.25	3.66	14.67	14.96	16.08	13.8	1153.52
EW30/09	97.24	5.17	9.36	7.45	4.16	16.47	15.36	17.28	14	1405.13
EW35/09	129.04	7.33	9.86	7.63	4.31	39.14	15.31	16.38	16.52	2219.53
EW3/09	93.94	6.27	9.36	6.35	3.46	8.47	14.76	14.58	12.8	1031.83
EW61/09	117.24	4.97	9.96	7.05	4.46	18.67	14.86	16.18	13.3	1002.13
EW56/09	127.44	7.43	9.86	7.33	4.51	24.54	16.21	17.08	17.12	867.43
EW28/09	147.67	6.21	9.96	6.48	3.94	15.47	15.83	16.63	15.85	1569.13
EW41/09	157.14	7.42	9.09	7.34	4.09	15.07	14.73	17.45	14.47	397.43
EW49/09	121.37	6.67	10.06	7.48	4.34	23.37	14.43	15.63	14.85	524.96
EW87/09	134.97	6.41	10.26	7.78	4.64	12.27	15.73	17.63	16.05	1986.42
EW46/09	126.84	7.03	10.09	7.44	4.59	17.47	15.73	17.85	14.47	1729.96
EW45/09	119.04	5.73	10.06	6.23	4.11	14.54	16.41	16.08	16.02	1127.16
EW20/09	103.37	5.24	8.66	6.48	4.94	23.37	15.33	16.93	16.05	1182.76
EW58/09	146.67	6.63	9.96	7.08	4.54	33.37	16.33	17.23	15.85	898.26
EW86/09	113.52	6.52	9.04	7.3	4.31	9.57	14.68	17.08	14.47	1604.96
EW83/09	123.54	6.2	8.79	7.54	4.19	17.47	15.03	16.15	13.87	1454.96
EW69/09	118.37	4.79	8.79	7.54	4.19	23.37	12.63	14.43	13.95	1607.16
EW33/09	150.22	7.32	8.74	7.4	4.31	11.37	14.68	17.38	14.07	985.56
EW63/09	109.04	5.33	8.96	6.03	3.81	18.84	15.3	16.38	15.52	1161.95
EW53/09	105.22	7.02	8.54	6.4	4.01	12.07	15.18	17.18	13.57	1233.56
EW84/09	135.54	7.67	10.76	8.15	4.86	18.67	16.46	17.18	14.9	1604.96
EW107/09	110.14	7.09	8.29	6.54	3.69	15.07	14.7	16.55	14.57	1094.93
EW11/09	122.44	5.93	9.56	6.23	4.21	24.54	15.21	15.28	15.32	1347.16
EW80/09	132.44	4.63	7.36	6.03	4.01	18.84	14.81	15.88	16.52	826.39
EW19/09	117.24	5.87	9.36	6.65	3.66	9.37	14.66	15.98	13.9	2251.66
EW103/09	126.84	6.14	10.29	6.84	3.99	29.37	16.33	16.85	14.17	1404.96
EW54/09	105.14	6.94	9.49	7.04	3.99	14.07	16.43	17.15	13.67	1469.96
W5/09	123.37	7.04	10.36	6.98	4.14	11.17	16.23	16.93	15.75	1729.26
EW06/0	123.54	7.04	9.59	7.54	4.19	22.97	16.03	18.15	14.97	1310.66
Grand mean	125.42	6.65	9.19	6.82	4.18	16.97	15.15	16.23	14.78	1450.94
CV%	10.57	12.71	6.63	5.81	7.72	19.35	2.78	3.89	3.79	28.22
F test	ns	ns	*	*	*	*	*	*	*	*
Lsd $_{0.05\ \text{same block}}$	40.84	44.72	2.60	1.88	1.22	0.99	10.12	1.29	1.94	917.5
Lsd $_{0.05\ \text{b/n block}}$	45.66	70.10	2.91	2.10	1.37	1.11	11.31	1.44	2.17	1025.86

Appendix Table 2. Haru agricultural research sub center meteorology data

Year	Month	Rain fall mm	soil temperature 5cm	10cm	20cm	50cm	sunshine hour
2013	January	0.00	25.6	23.7	24	23.4	18.5
	February	xx	xx	xx	xx	xx	xx
	March	xx	25.8	24.5	24.6	24.4	xx
	April	190.1	xx	xx	xx	xx	xx
	May	631.5	25.0	25.4	23.7	24.5	xx
	June	190.1	xx	xx	xx	xx	xx
	July	457.3	22.3	21.9	21.3	22.1	3.4
	August	414.4	22.1	21.6	21.4	21.9	2.7
	September	336.4	xx	xx	xx	xx	xx
	October	220.1	23.9	22.9	23	22.7	65.9
	November	44.2	25.4	23.7	23.8	23.4	7.9
	December	0.00	24.7	22.3	22.8	24.2	9.5
2014	January	0.00	25.6	23.7	24	23.4	7.9
	February	0.00	26.8	25.6	25	24.2	8.6
	March	xx	25.8	24.5	24.4	xx	6.7
	April	152.6	24.7	24.1	24.1	24.0	5.9
	May	148	24.6	23.8	23.6	23.3	xx
	June	252.7	22.9	22.9	23.1	23.1	xx
	July	425.4	21.8	22.6	22.1	23.6	3.4
	August	418.1	21.9	21.9	22.0	21.9	3.9
	September	xx	22.9	22.1	22.1	21.9	3.5
	October	507.9	23.0	23.0	22.7	22.6	6.7
	November	0.00	23.7	23.7	23.2	26.6	8.4
	December	10.0	24.6	23.1	23.2	26.6	8.4
2015	January	xx	24.4	24.3	25.1	23.1	8.9
	February	0.00	26.3	25.9	25.3	23.9	9.0
	March	237	26.2	26.5	26.5	25.0	6.6
	April	xx	26.2	26.7	26.7	25.5	8.3
	May	422.2	23.9	24.2	18.3	24.6	11.4
	June	358.2	22.9	22.8	23.4	23.4	5.2
	July	577.6	23.2	22.6	23.3	22.7	xx

(Source: JARC meteorology research process)



Appendix Fig. 1.Dendrogram showing relationships of 115 Coffee accessions based on Euclidean distance and UPGMA clustering using 14 qualitative traits

Appendix Table 3. Mean of clusters for the 115 coffee accessions based on D^2 analysis

Variable	CL1	CL2	CL3	CL4	CL5	CL6	CL7	CL8	CL9	CL10	CL11	CL12
LL	16.2	15.1	16.1	16.1	15.9	18.9	16.1	15.4	14.9	14.8	13.3	15.5
LW	7.4	7.2	7.7	7.7	7.5	9.3	7.9	7.4	7.1	6.5	6.4	7.4
LA	120.4	10.1	124.2	123.8	119.4	136.9	128.4	12.5	106.3	96.3	89	114.7
PL	1	0.8	0.9	0.8	0.8	0.9	0.8	0.9	0.8	0.7	0.7	0.8
HBW	16.9	19.1	17.7	17.1	15	18	15	10.6	18.8	12.2	11.1	11.1
BL	9.2	9.4	9.2	9.2	9.2	9.2	9.1	9.4	9.4	7.3	9.3	10.9
BW	7	7.1	6.9	6.9	6.4	7	6.9	7	6.5	6.2	7.3	7.9
BT	4.2	4.2	4.3	4.1	3.9	4.3	4.4	4	4	6.2	4.2	5
SG	39.7	38.9	39.3	39.4	38.7	40.8	41.1	40.3	43.9	39.9	47.5	41.4
LFPB	82.47	8.1	80.2	84.3	76.1	88.8	82.4	86.9	86.9	72.3	92.1	81.2
FL	15.3	15.5	15.4	15.4	15.7	15.4	15.2	15.5	15.2	11.3	16	15.9
FW	14.9	14.6	14.7	14.7	14.1	14.6	14.5	14.9	14.1	11.3	14.9	15.5
FT	14.9	12.8	12.9	12.7	12.61	2.7	13.1	13.1	12.3	10.1	13.8	13.4
BY	1739	1527.8	1218.1	698.1	757.2	1972.2	2053.7	25	2874	3241	4154	5381.7

LL = leaf length; LW =leaf width; LA = leaf area; PL = petiole length; HBW = hundred bean weight; BL = bean length; BW = bean width; BT= bean thickness; SG = stem girth; LFPB = length of first primary branch; FL = fruit length; FW = fruit width; FT= fruit thickness; BY= bean yield