MORPHOLOGICAL AND ORGANOLEPTIC CHARACTERIZATION OF LIMU COFFEE (*Coffea arabica* L.) GERMPLASM ACCESSION AT AGARO

M.SC. THESIS

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JANUARY, 2011
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MORPHOLOGICAL AND ORGANOLEPTIC CHARACTERIZATION OF LIMU COFFEE (*Coffea arabica* L.) GERMPLASM ACCESSION AT AGARO

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By

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As thesis research advisors, we hereby certify that we have read and evaluated this thesis prepared, under our guidance, by Olika Kitila, entitled: Morphological and Organoleptic Characterization of Limu Coffee (*Coffea arabica* L.) Germplasm at Agaro. We recommend that it be submitted as fulfilling the Thesis requirement.

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DEDICATION

I dedicate this thesis manuscript to my father Mr. Kitila Gonfa, my mother Mrs. Amuse Gelan and my brother Marga Kitila for their persistence and dedication paving long the way to realize my dream.

STATEMENT OF AUTHOR

I declare that this piece of work is my own and all sources of materials used for this thesis have been duly acknowledged. The thesis has been submitted in partial fulfillment of the requirements for the advanced MSc degree at Jimma University and is deposited at the University Library to be made available to borrowers under rules of library. I solemnly declare that this thesis is not submitted to anywhere institution any where for the award of any academic degree, diploma, or certificate.

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BIOGRAPHY

The author was born on September 1, 1970, Eastern Wollega Zone. He attended his Elementary and junior educations at Kiramu Elementary and Junior School. He attended his high School at Gida Ayana Senior Secondary School. After passing the Ethiopian School Leaving Certificate Examination (ESLCE) he joined Jimma College of Agriculture (now Jimma University, College of Agriculture and Veterinary Medicine) in1986 and awarded diploma in General Agriculture in 1987. Soon after graduation, the author was employed in Coffee Plantation Corporation, currently Coffee Plantation Development Project at Teppi in1989. He served as unit farm manager. Again he joined Jimma University, College of Agriculture and Veterinary medicine and graduated in 2006 with B.Sc degree in Horticulture. He has been working at Shabe District of Jimma Zone assigned as irrigation office manager till he rejoined the School of Graduate Studies at Jimma University in October 2009 to continue his studies for M.Sc degree in Horticulture; specializing in Coffee, Tea and Spices.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CBD	Coffee Berry Disease
CIRAD	Center de cooperation International e en Recherche Agronomique pourle Développent
CLR	Coffee Leaf Rust
CLUE	Coffee Liquoring Unit
FAO	Food and Agriculture Organization
GA	Genetic advance
GCV	Coefficient of genotypic variation
H^2	Broad Sense Heritability
IBPGR	International Board for Plant Germplasm Resources
IPGRI	International Plant Genetic Resource institute
ISO	International Standard Organization.
ITC	International Trade Center
JARC	Jimma Agricultural Research Center
LSD	List Significance Difference
PC	Principal Component
PCA	Principal Component Analysis
PCV	Coefficient of phenotypic Variation
RCBD	Randomized Complete Block Design
SAS	Statical software
WFP	World Food Program
CEC	Cation Exchange Capacity
SNNPRS	Southern, Nation, Nationality, Peoples and Regional state

MORPHOLOGICAL AND ORGANOLEPTIC CHARACTERIZATION OF LIMU COFFEE (*Coffea arabica* L.) GERMPLASM AT AGARO

By: Olika Kitila

Advisors: Sintayehu Alamerew (PhD) and Taye Kufa (PhD)

ABSTRACT

Arabica coffee (Coffea arabica L.) is an economically important crop, which is contributing the highest of all export revenues in Ethiopia. There has been no systematic diversity analysis carried out in Limu coffee germplasm accessions. Thus, the over all objective of this experiment was to characterize and estimate the extent of genetic variation and correlations between pairs of morphological and organoleptic characters. Forty nine Coffee arabica accessions from Limu Kossa Wereda (Jimma) were planted in simple lattice design. Analysis of variance indicated the presence of significant (P<0.05) variability of coffee accessions for most of quantitative traits. However, the results not indicated variation for characters such as stem diameter, canopy diameter, average internode length of stem, average length of primary branches, average internode length of primary branches, number of primary branches, and percentage of bearing primary branches. Principal component analysis grouped 22 quantitative characters in to ten uncorrelated components. About 85.74% of the variation present among accessions was explained by ten principal components. Clustering analysis grouped the accessions in to four genetically divergent classes based on the average similarity value for quantitative characters. Magnitude of genetic and environmental variations explaining a given trait was found different. Accordingly, high broad sense heritability value was obtained for most of quantitative characters. However, canopy diameter (1.51%), average internodes length of stem (0.09%), average length of primary branches (16.03%) and percentage bearing primary branches (10.3%) showed low. Mean square for organoleptic traits indicated the presence of significant (P<0.05) variations among coffee accessions for cup quality attributes studied except aromatic intensity, bitterness, astringency, and body. Cluster analysis based on coffee quality traits grouped 49 coffee accessions into three genetically divergent and three uncorrelated principal components. Shannon diversity values were variable among qualitative traits. Traits such as growth habit, leaf shape, stipule shape and fruit shape showed high level of diversity for most of collection sites. Over all, the study confirmed the presence of trait variation in Limu coffee accessions and this could be exploited in the genetic improvement of the crop through hybridization and selection.

Key words*:* Arabica coffee Genetic divergence, Cluster analysis and Principal component analysis

1. INTRODUCTION

Coffee arabica is the back bone of Ethiopia's economy and contributes largely to the national foreign currency income and accounts for more than 35% of the total major export commodities earnings (FAO/WFP, 2008). Furthermore, coffee plays a vital role both in the cultural and socio-economic life of people of the country (Workafes and Kassu, 2000). The estimated area of land covered by coffee is about 600,000 hectares whereas the estimated annual national production of clean coffee is about 1.7 tons/ha (Alemayehu *et al.,* 2008).

The Ethiopian coffee is also important source of coffee genetic resources for the world coffee industry. As a matter of fact, Ethiopia is the single known center of origin and genetic diversity for arabica coffee (*C. arabica*) (Sylvain, 1955; Wellman, 1961). It is cultivated in most parts of the tropics, accounting for 80 percent of the world's coffee market, about 70 percent of the production (Woldemariam *et al.,* 2002) and it is also important source of income and employment in developing countries like Latin America, Africa and Asia (Anthony *et al*., 2001).

In Ethiopia, coffee grows under different environmental conditions with an altitude ranging from 550 m to 2600 m above sea level and with annual rainfall of 1000-2000 mm, which makes fineable the existence of different agro-types of coffee and wide ecology in the country (Paulos and Tesfaye, 2000; Bayetta, 2001). The bulk of coffee is produced in the eastern, southern and western parts of the country, which have altitudes ranging from 1,300 to 1800 m above sea level. The phenotypic variation as well as adaptation under different environmental conditions show the presence of high arabica coffee genetic diversity in Ethiopia (Melaku, 1988). Presently coffee genetic resource is under threat mostly due to deforestation of its natural habitat for timber and food crop production, replacement of the farmers variety by a few high yielding and disease resistant varieties, establishment and expansion of modern plantation and illegal and legal settlements (Bayetta, 2001; Woldemariam *et al*., 2002 and Kassahun, 2006).

To reduce such threats, efforts to collect, conserve and utilize Ethiopian coffee germplasm was carried out since 1928 by individual researchers and international missions organized by FAO 1964-65 (French Institute of Scientific Research for Development and Cooperation) (Berthaud and Charrier, 1988) of which the collections were established in field gene banks in several African and Latin America countries (Anthony *et al*., 2001 and Yigzaw, 2005). After these missions, a national programme was set up to organize exploration and conservations of coffee genetic resources in Ethiopia (Berthaud and Charrier, 1988).

Consequently, about 5127 accessions were collected from different coffee growing areas of the country and were maintained at Jimma Agricultural Research Center and its six sub centers (Bayetta and Jean-Pierre, 2006). In addition, the Institute of Biodiversity Conservation (IBC) of Ethiopia preserved over 4000 accessions in *ex situ* coffee field gene bank at Chochie, Jimma Zone, and southwestern Ethiopia (Paulos and Demel, 2000).

Morphological and agronomical traits as well as resistance to biotic and abiotic stresses that are known to individual accessions increase the importance of the germplasm. The economic value of a population is related to plant morphology, agronomic performance, seed quality and nutritional qualities. Efficient utilization of indigenous germplasm required knowledge of biodiversity of economic interest (Beer *et al.,* 1993). Though the country is highly endowed with suitable environments, the productivity of coffee per unit area remains very low as compared to world average. One of the major factors contributing to low yield includes lack of adaptable cultivars for each ecological zone of the different regions for each of the very diverse environment (Bayetta 2001).

During the initial phase of coffee breeding in Ethiopia, the major emphasis was given to development of improved varities with wide ecological adaptation (Mesfin and Bayetta, 1987). The approach was not very successful due to adaptation problem together with distinct coffee quality variation within and between regions or localities (CTA, 1999) and

has necessitated the development of the local landrace development program preferably using the local land races of the respective region (Bayetta and Jean –Pierre, 2006). Local landrace development program through modified long term screening program and a crash program, has already been implemented for priority areas, viz., Hararge, Sidamo (Yirgacheffe), Wellega (Gimbi) and Limu, which do not have improved cultivars from the respective areas but very important coffee areas well recognized on international market for their best quality and fetch premium price (Fekadu., *et al.,* 2008). From 2 years evaluation of mother trees through a crash program, good number of CBD resistant mother trees were selected from Hararghe and Limu coffee areas between 2001 and 2005. On the other hand, through studies superimposed on already established field gene banks through modified long term approach, intensive evaluations have been made on several accessions collected from Hararghe (that were established at Jima), Sidamo and wellega coffees showed the existence of promising coffee types in the respective areas and the possibility to improve the production and productivity of coffee in these named areas (Fekadu., *etal,* 2008).

Efficient utilization of the genetic potential held in germplasm collections requires detailed knowledge about the collections (Beuselinck &Steiner, 1992), including characterization, evaluation and classification. However, apart from some observations based on the variety trials, there has been no systematic diversity analysis carried out in Limu coffee germplasm collection and this might have resulted in the handling of a large degree of duplicated germplasm collection. Similarly, there is no detailed information on the extent and nature of interrelationships among characters. Keeping this in view, the present study was carried out with the following specific objectives:

1. To characterize some Limu coffee germplasm accessions based on morphological traits and organoleptic quality attributes

2. To estimate the extent of phenotypic and genotypic variability, heritability (in the broad scene) and genetic advance expected under selection.

3. To estimate the extent of phenotypic and genotypic correlations between pairs of characters in the study coffee germplasm accessions
4. To estimate the genetic differences among the genotype and thereby cluster into different homogenous groups using quantitative trait and organoleptic quality attributes.

2. LITERATURE REVIEW

2.1 Botanical Description

Coffee belongs to the genus Coffea in the Rubiacea family, which contains some 640 genera and 10000 species (Gichimu and Omondi, 2010). It is a biologically and morphologically diverse family consisting of varied life form ranging from tiny herbs, epiphytes, lianas, shrubs to tall trees (Bremer, 1996). The genus *Coffea* consist of approximately 105 taxa and is distinguished from a closely related genus, Psilanthus, based on flowering and flower characteristics (Kumar *et al.,* 2008). All *Coffea* species are native to the inter-tropical forest of Africa and Madagascar, while species belonging to the genus Psilanthus originate from either Asia or Africa. The genus *Coffea* has been reorganized into two subgenera: *Coffea* and Para *Coffea* (Bridson, 1987). Particular attention has been paid to the subgenus Coffea which includes two cultivated species of economic importance, *Coffea arabica* L. and *Coffea canephora* a Pierre (Kumar *et al.,* 2008).

C. arabica is tetra ploid (2n = 4x = 44) and is self-fertile while other *Coffea* species are diploid 2n = 2x = 22) and generally self-incompatible (Masumbuko *et al*., 2003). *C. arabica* has two distinct botanical varieties *C. arabica* var. arabica (usually called Typica) and *C. arabica* bourbon (usually called Bourbon) (Hue, 2005). Historical data indicate that the Typica genetic base originated from a single plant from Indonesia which was subsequently cultivated in the Amsterdam botanical garden in the early 18th century, around 1715 (Gichimu and Omondi, 2010). The Bourbon genetic base originated from a few coffee trees introduced from Mocha (Yemen) to the Bourbon Island (now La Reunion) at about the same time (Hue, 2005). The narrow geographic origin of C. arabica, along with its self-fertilizing nature and the historical or selective bottlenecks in its agricultural adoption, have resulted in low genetic diversity of C. arabica varieties cultivated around the world (Chaparro *et al.,* 2004). Another possibility could be a drastic loss of genetic diversity during glaciation phases of the quaternary period (Lashermes *et al.,* 1993).

The structural design of the coffee tree is a feature of a tree growing in tropical forests. It has a main vertical trunk (orthotropic) and primary, secondary, and tertiary horizontal branches (plagiotriopic). The growth is by a typical form of monopodial branching where the branches (primaries) remain subsidiary to the main stem, which continues to grow indefinitely by extension of the apical bud (Wrigley,1988). Depending on ecological conditions, the coffee plant takes approximately 3 years to develop from seed germination to first flowering and fruit production. A well-managed coffee tree can be productive for up to 80 years or more, but the economic life span of a coffee plantation is rarely more than 30 years (Witgens, 2004).

The root consists of a stout central root, often multiple, tapering more or less abruptly, and rarely extending as a recognizable unit more than 30 to 45 cm from the soil surface. The stem and leaf tissues all originate in the dome shaped shoot apex, which measures 220-360μm in diameter and 48-120 μm in height. The leaves are born in opposite pairs on the sides 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 into a new branch, or an inflorescence with one or more flowers, or remains undifferentiated. When the flower buds are 4-5 mm long, they remain dormant until stimulated into flowering. The stigma of the flowers is receptive for only more than 48hrs in 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 triage, elephant beans, pea berry, empty beans, and misshapen beans (Wrigley, 1988).

2.2 Coffee Ecology

Arabica coffee is a tropical plant and needs the right balance of environmental factors to be successfully grown; the right balance of sunlight, rain, wind, soil quality and temperature are required to successfully farm coffee and does not respond well to frost (Leroy *et al.,* 2006).

The ideal temperature for coffee plants depends on the plant species; for example, Coffea robusta can tolerate hotter temperatures than coffee arabica. Altitude also affects the success of coffee farming (Wrigley, 1988).

The rainfall should be well distributed with a definite dry season, preferably in the cooler part of the year, with mists and or low cloud frequent in the hotter part of the year. Rainfall is of fundamental importance to the cultivation of all species of coffee and a minimum of 1200mm to 1500mm per year without too long a hot, sunny dry season, is considered necessary for good regular crops (Wrigley, 1988) with optimum temperature of 15 ^{o}C to 23 ^{o} C (Anonymous, 2003).

In Honduras coffee growing regions, high altitudes and rainfall of less than 1500mm were favorable factors for the sensory quality (Decazy *et al.,* 2003). Arabica coffee prefers a deep, well drained, loamy soil, slightly acid, rich in humus and exchangeable bases preferably potassium. The total amount of phosphorus seems to be of less importance, but it is essential, particularly at flowering. Soil moisture and oxygen should be available throughout the rooting depth, which varies between coffee growing areas according to the soil, the total rainfall and its distribution and the length of the dry seasons. There are so many measures like pruning, cover crops, shade and mulching which modifies the environment in coffee farm (Wrigley, 1988). The environment has a strong influence on coffee quality. The micronutrient minerals frequently show a non-linear correlation between their concentration and cup quality (Ernesto, 2001). Climate, altitude, and shade play an important role through temperature, availability of light and

water during the ripening period. Rainfall and sunshine distribution have a strong influence on flowering bean expansion, and ripening (Leroy *et al.*, 2006).

2.3 Production System of Arabica Coffee in Ethiopia

There are four major production system of coffee in Ethiopia, namely forest, semi forest, garden coffee and plantation coffee production system (Workafes and Kassu, 2000). The forest and semi forest production system are regarded as a part of Forest coffee ecosystem (FCE).

In the forest coffee, which is also referred to as wild coffee, coffee regenerates in natural forests without human intervention as an under story plant. It grows in Afro-montane rain forests of west, southwest and south eastern Ethiopia, which represents about 9 percent of the total land coverage of coffee and also contributes about 5-6 percent of the national coffee production. The productivity of this production system is very low, and has been estimated to be 200-250 kg/ ha (Paulos and Demel, 2000).

On the other hand, semi-forest coffee represents the production system in which forest coffee is manipulated through thinning of over story trees, removal of ground vegetation and enrichment of empty spaces in the forests by transplanting naturally regenerated or raised seedlings. This system represents about 24 percent of the total land covered by coffee, and contributes about 20 percent of the total coffee production in the country and estimated average yield to be in the range of 400-500kg/ha (Paulos and Demel, 2000; Woldemariam *et al*., 2002). In total, the forest coffee accounts for 33 percent of the land covered by coffee and 25 percent of the coffee produced, while the garden coffee and modern plantation coffee production systems contributes 70 percent and 5 percent of coffee production in the country, respectively (Tadesse *et al.,* 2008). In plantation coffee system, coffee is cultivated after land clearing with systematic soil preparation and seedling planting, and managed in order to maximize the volume of production and productivity. This sector includes a few large private and state farms mainly located in the south-west, as well as many smallholder plantations spread all over the coffee.

growing areas. It accounts for about 10 % of national production (Labouisse *et al.*, 2008). Local farmers use traditional practices to produce the coffee in the forest coffee ecosystem, which serves as the means of livelihood for millions of people (Woldemariam *et al*., 2002). Hence, apart from its value as the world's most important gene pool, the existing coffee forests also contribute considerably to Ethiopian coffee production (Kassahun, 2006).

2.4 Coffee Genetic Diversity

Since Ethiopia is the primary center of origin and genetic diversity of Arabica coffee (C. arabica L.) (Feyera, 2006 and Kassahun, 2006), considerable phenotypic diversity has been observed in cultivated and traditionally recognized landraces of Arabica coffee (Montagnon and Bouharmont, 1996). This was further confirmed by the existence of many important characteristics observed in the coffee population, such as resistance to organ leaf rust (Hemileia vastarix Berk and Br.) (Wondimu, 1998), nematodes (Meloidogyne incognita), coffee berry disease (Colletotrichum kahawae Waller and Bridge) (Van der Graaff, 1981), as well as variation in green bean biochemical compounds (caffeine, chlorogenic acids, sucrose and trigonelline) (Yigzaw, 2005), tree size and shape, bean size, shape and colour and in cup quality (Wondimu, 1998).

The outbreak of Coffee Berry Disease (CBD) in Ethiopia was confirmed in 1971 (Bayetta, 2001) and since then the disease became an important production constraint of Ethiopia (Mesfin and Bayetta, 1983, 1984 and Melaku, 1982). Identification of several coffee berry diseases (CBD) resistant and high yielding cultivars in a short period of time and cultivation of the crop under diverse environmental conditions also demonstrate the existence of diverse Arabica coffee genetic resources in Ethiopia (Bayetta *et al*., 2000 and Bayetta, 2001). Ethiopia is well known not only for being the home of Arabica coffee, but also for it is very fine quality coffee acclaimed for its aroma and flavour characteristics. The coffee types that are distinguished for such unique characteristics include Sidamo, Yirga chefe, Harerge, Gimbi and Limu types (Workafes and Kassu, 2000). Study also indicated the existence of variations in resistance levels of coffee

genotypes in Ethiopia for coffee wilt disease caused by a fungus *Gibberella xylarioides* (*Fusarium xylarioides*) (Girma and Hindorf, 2001). On the other hand the out break of coffee leaf rust (CLR) in Sirlanka in 1869 and in Java and Sumatra in 1876 (Indonesia), which completely wiped out the coffee industries in these countries, was the consequence of the use of coffee varieties with narrow genetic base, or lack of genetic diversity in the coffee population. But, economic production of coffee in Ethiopia has not been threatened by leaf rust, because the land races being grown have various level of resistance to the disease. Similarly, the out break of CBD in 1971 did not lead to abandon the production of coffee in Ethiopia due to the existence of genetic variation large enough to withstand the disease (Paulos and Demel, 2000). These all indicate the existence of genetic diversity of Arabica coffee in its center of origin in Ethiopia.

The forest coffee ecosystem (forest and semi forest coffee) and farmers' traditional production system which have conserved the Arabica gene pool in its center of origin are now seriously threatened by several factors including, among others, increasing population pressure, expansion of farm lands, forest land use conflicts, human settlements, priority for others food and other cash crops and other socioeconomic factors (Paulos and Demel, 2000; Woldemariam *et al.,* 2002 and Feyera, 2006). Recent survey conducted by Schmitt *et al.* (2005) in four forest fragments of Bonga region indicated that the wild coffee forests were not only endangered by the conversion in to agricultural lands and settlements, but also by high intensities of coffee management, that led to a disturbance of the forest structure and to a change in the species composition of the natural forest, which is the natural reservoir for Arabica coffee. According to Woldemariam *et al.* (2002), currently only 2000 km^2 undisturbed forests are left with wild coffee populations, whereas the remaining is fragmented. In order to maintain the genetic variability of wild and cultivated coffee populations it is urgently required to conserve the natural coffee farms around the country, especially the natural forest coffee ecosystems. Erosion of this vast genetic resource base is being caused by destruction of habitats by deforestation, the replanting of a narrow spectrum of varieties so that conservation of the coffee germplasm both in situ and ex situ is the major concern of the world (Tadesse, 2003). In situ conservation involves maintaining genetic resources in the

natural habitats where they occur, while the *ex situ* approach involves conservation outside the native habitat like seed storage, filed gene banks and botanical gardens. Within *ex situ* strategies, there have been no alternatives for field collections for long-term germplasm conservation in coffee Arabica, because coffee seeds are recalcitrant and with use of conventional seed storage methods, the coffee seeds will only be viable for a maximum of 3 years (Van der Vossen, 1985). On the other hand, the center for development Research (ZEF) of the Bonn University (Germany), in collaboration with the Ethiopian Agricultural Research Organization has started and assessed the genetic diversity and the economic value of Ethiopian coffee gene pool and uses of genetic resources of Arabica coffee in its center of origin and diversity in Ethiopia. Based on the research findings of the project, the *in situ* conservation of wild coffee offers an interesting approach in biodiversity conservation as the conservation of coffee genetic diversity is connected with the conservation of forest species diversity (Tadesse *et al*., 2008).

2.5 Coffee Quality Profile

Ethiopia is the homeland of Arabica coffee where the plant grows wild in the forests of Kaffa, Illubabor and Gamogofa. The country produces some of the world's finest 'original' coffees such as Yirgacheffe, Limu and Harar. Around 4500 different Ethiopian coffee accessions are preserved in coffee filed gene bank at Jimma Agricultural Research center and its sub centers, a good indication of the rich diversity of the Ethiopian coffee population (ITC, 2002).

Some quality assessments done on large number of selections and the high quality of Harer, Yirgacheffe, Gimbi/ Nekemte and Limu coffee that fetche premium price on the world market clearly confirm the presence of genetically diversified Arabica coffee quality that provides immense possibilities for quality improvement (IAR, 1969-1996; Brown bridge and Eyasu, 1968). Furthermore, Walyaro (1983) reported the presence of large inherent differences among genotypes for bean and cup quality attributes. Similarly,

Van der Vossen, (1985) observed variation for cup quality characters among varieties and crosses of Arabica coffee. Yigzaw (2005) reported the presence of genetic variability among Ethiopian coffee selection for green bean physical characteristics and cup quality, contents. Results of some studies indicate that a larger potential than previously reported is present in the germplasm collection of coffee arabica from Ethiopia, which can be used to improve popular commercial varieties such as Caturra. With the help of more elaborate molecular markers, such as the currently developed micro satellite set, new cultivars can be generated by introgression of wild alleles, oriented towards resistance and coffee specialty markets (Cristancho *et al.,* 2004). Since quality is the most important single factor dictating world coffee market, utilizing the existing high genetic variability in Ethiopia is inevitable (IAR, 1969-1996; Brown bridge and Eyasu, 1968). Promotion and production of high quality coffee along with diversification of farms is expected to play a key role in developing of consistent performances under a wide range of economic condition. Interestingly, the quality of Arabica coffee in Ethiopia has its own reputation, not only because of the richness in coffee genetic diversity but also in agro-ecology and vegetation covers, which are conductive to coffee growth and production (Makuria *et al.,* 2004).

Ethiopian coffees are among the world most varied and distinctive. It is commonly traded as Harar, Sidamo, Ghimbi/Nekemte, Yirgacheffe, and Limu. All marks contribute rich range of quality profile variations. Harar coffees are the most widely available of fancy Ethiopian coffees. It is found as long berry Harar (large bean), short berry Harar (smaller bean), or Mocha Harar (Pea berry, or single bean). It is dry processed and organic (free of chemicals) and taste is of medium acidity and heavy body. A washed coffee from the western part of Ethiopia is usually sold as Ghimbi/Nekemet (Davids, 2001). It shares the pronounced winy tones of the Limu coffee with a richer, more balances profile and somewhat heavier, light acidic and longer-finishing body (Davids, 2001). The washed coffees of southern Ethiopia exhibit related but different flavor tendencies. Sidama is characterized by smooth, gentle coffee that is almost fruit like or flowery. Pleasantly sweet, balanced acidity and round cup flavor. The profile of Yirgacheffe is described as a rich coffee with a pleasant finish and lingering after taste. Real mocha, medium bodied

with tart acidity. The other two southwestern marks are Limu and Kaffa. Limu is characterized as having excellent balanced flavor with good acidity and medium body. While Kaffa types are good aroma with light to medium acidity, a body and balanced cup (Davids, 2001).

2.6 Coffee Quality

According to the International Standardization Organization (ISO, 1992) a standard for green coffee quality requires several pieces of information, like the geographical and botanic origins of the coffee, the harvest year, the moisture content, the total defects, the proportion of insect-damaged beans and the bean size. These ISO standards define methods of measurement for several of these qualities: defects, moisture content, bean size, some chemical compounds and preparation of a sample to perform cup tasting (Leroy *et al.,* 2006).

Coffee quality begins with the plant DNA or genetic make-up and the genes that generate the chemical compounds that behave as aroma agents either directly or as aroma precursors to be expressed during the roasting process. When it comes to selecting the cultivar to be planted, cup quality must be the first priority. Only after this should agronomic characters and possible pest and disease resistance be considered as appropriate traits (Ernesto, 2001). Coffee quality traits are subject to different sources of variation. Some of them are exclusively dependent on the harvest and post harvest procedures (moisture content, number of defects in coffee batches for instance) whereas others will depend on pedo-climatic conditions ("terrors"), physiological and genetic factors. If harvest, post harvest procedures and the physiology of the plant affect coffee quality, its genetic origin (species and genotypes) will also greatly influence coffee quality (Leroy *et al.,* 2006).

Post harvest procedures (moisture content, number of defects in coffee batches for instance) whereas other will depend on pedo-climatic conditions ("terrors"), physiological and genetic factors. If harvest, post harvest procedures and the physiology

of the plant affect coffee quality, its genetic origin (species and genotypes) will also greatly influence coffee quality (Leroy *et al*., 2006).

2.7 Organoleptic quality

When assessing organoleptic quality, one has to take into account that consumers have a specific taste according to their nationality that leads to an unreliable definition of organoleptic quality. Expert assessors can describe organoleptic quality profile. It is a complex procedure that uses some specific descriptors. Expert assessors (at least 5) have to be trained to use the vocabulary. Flavor obtained in a coffee cup is the result of multiple aromatic compounds present in the coffee (more than 800 in the roasted coffee) (Belitz *et al.,* 2004). Since measurement of the composition in 800 aromatic compounds present in roasted coffee is not a viable method to assess coffee organoleptic quality, development of indirect predictors of coffee organoleptic quality through biochemical compounds is found inevitable and efforts are underway (Leroy *et al.,* 2006). The success of a new variety of Arabica coffee (*Coffea arabica* L.) depends to an important extent on its liquors. Selection for these traits is however constrained by the prevalence of large genotype-by-environment (GxE) interactions in connection with the low genetic variability characteristics of this species (Agwanda *et al.*, 2003). Walyaro (1983) reported relatively lower genotype x environment interaction effects on quality characters. However, Van der Vossen (1985) reported non-significant genotype x environment interaction effects on quality characters, such as bean size and cup quality.

Organoleptic quality attributes variation was accounted for genetic, environment and genetic x environment interaction. Therefore, the presence of strong genotype x environment interaction for arabica coffee quality, limits development of wide adapting varieties, initiates coffee quality mapping, conservation of coffee genetic resources and establishment of core collections with respective origins (Getu, 2009).

2. 8 Phenotypic and Genotypic Coefficients of Variation

Variation is the occurrence of differences among individuals due to the 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 genotypic 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 heteortic hybrid cultivars through crossing (Mesfin and Bayetta, 1983, 1987), and Van der Graaff (1981) are indicators of genetic variability. The existence of phenotypic variation among Ethiopian arabica coffee germplasm was reported for different characters by several researchers (Montagnon and Bouharmont, 1996 and Yigzaw, 2005). Yigzaw (2005) observed PCV in the range of 4.5% for fruit width to 53.4% for number of secondary branches and GCV in the ranges of 3.3% for bean thickness to 51.7% for number of secondary branches. Yigzaw (2005) studied sixteen coffee germplasm using 18 morphological characters and observed high genotypic coefficient of variation, broad sense heritability and genetic advance for characters such as average green bean yield per tree (40.5%, 83%, 76.2%), number of secondary branch/tree (51.7%, 94%, 103.4%), canopy diameter (17.2%, 93%, 34.3%), tree height (16.4%, 83%, 30.8%) and 100 green bean weight (14%, 94%, 27.8%).

2.9 Heritability

As stated by Falconer (1983), heritability in broad sense is the ratio of variance of genotypes to variance of phenotype, and expresses the extent to which individuals' phenotypes are determined by their genotypes, whereas heritability in narrow sense expresses the extent to which phenotypes are determined by the genes transmitted from the parents. 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 (Stoskopf *et al.,* 1999). 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 Vossen (1985) estimated from diallel crosses of 11 Carapace cultivars that most growth and bean size characters such as girth of main stem (64%), tree height (70%), canopy radius (65%), internode length (74%), angle of primary with main stem (60%), and 100 bean weight (74%) had 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 intermediate broad sense heritability for seedling height (42.4%), internode 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 showed greater than 50% broad sense heritability except bean thickness (38%)

and percentage of bearing primary branches (39%) for eighteen characters studied on coffee arabica germplasm, indicating high heritability for most of the characters.

2.10 Expected Genetic Advance

Genetic advance measures the expected genetic advancement that would result from selecting the best performing genotypes for a character being assessed (Allard, 1999). It is a function of the heritability of the trait, the amount of phenotypic variation and the selection differential that the breeders use (Allard, 1999). Heritability in it self provides no indication of the amount of genetic progress that would result from selecting the best individuals. 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). 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.

2.11 Correlation Studies

According to Stoskopf *et al.* (1999), coefficient of correlation is the term used to explain the degree or amount of correlation between independent variables. If both traits are increased the result is a positive correlation. If one is increased and the other is decreased there will be a negative correlation. The correlation coefficient always lies between -1 and +1. Negative one indicates perfect linear negative relationship between two variables, positive one indicates perfect positive linear relationship and zero indicates lack of any linear relationship (Steel *et al.,* 1997). According to Dancer (1964) and 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. Moreover, Mesfin (1982) observed positive and significant correlations between total growth and girth diameter growth and number of fruits (0.69) and growth and number of nodes on primary branches In addition, Mesfin and Bayetta (1983) reported positive

correlations 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). Similarly, Yigzaw (2005) reported correlation analysis performed among 18 agro-morphological characters indicated positive associations 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

Genotypic 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 (Sylva and Carvalho, 1997). The association between two characters that directly observed is the phenotypic correlation. This is determined from the measurements of the two characters in number of individuals of the population (Singh, 1990). In relation to coffee, Dancer (1964) reported that morphological characters such as stem girth, width of canopy, number of primary branches and number of secondary branches influenced yield in coffee. Based on 4 years observations on yield, stem diameter, height, and number of primaries on arabica coffee, Dancer (1964) found significant genetic correlation between the said morphological traits and yield. Charier (1978) obtained high and positive correlation between height and stem diameter of arabica coffee, According Berthaud and Charrier, (1988), among the seven vegetative characters studied in thirty four Coffee arabica populations in Ivory cost, number of nodes of the side branches and of the main stem and their basal diameter were found to have positive correlation.

2.12 Genetic Diversity

The concept of genetic distance has been of vital importance in many contexts and more so in differentiating well defined populations Van Hintum (1995), cited by Hodgkin *et al.,* (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 coffee arabica. Exploitation of such traits increases our knowledge of the genetic diversity available and strongly facilitates breeding for wider geographic adaptability, with respect to biotic and abiotic stress. Inaddtion, genetic diversity needs to be described and measured if it is to be effectively incorporated into breeding strategies and management of plant genetic resources (Agwanda, 2003).

2.13 Cluster Analysis

Clustering analysis is 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., *etal.,*1995). One of the stages in a 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 algorithm 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 or 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 include coffee (*Coffea arabica* L.) (Mesfin and Bayetta, 2008).

3. MATERIALS AND METHODS

3.1 Description of the Study Area

The experiment was conducted at Agaro Agricultural Research site. It is located at 45 km in the south west of Jimma town at an altitude of 1630 m a.s.l. It is situated at 7 “50’35” - 7”51’00”N latitude and 36”35’30”E longitude. The mean annual rainfall of the area is 1616 millimeters with average maximum and minimum temperatures of 28.4 ^{O}C and 12.4 ^{O}C, respectively.The major soil type is Mollic Nitisols with soil pH 6.20, Organic mater (7.07 %), nitrogen (0.42%), phosphorus (11.9ppm), and CEC (39.40) mol $(+)_{kg}^{-1}$ (Elias, 2005).

3.2 Experimental Material

The study was carried out on the already established batch II forty nine Limu coffee trial during 2009/2010 main cropping season on six years old including standard checks (744 and F-59). The coffee germplasm accessions were collected in 2003 year from the potential and representing areas in the Limu-Kossa Wereda of Jimma Zone. The collections were planted in August 2004. Their geographical origin is given in Table 1.

Table 1. Geographical origin of coffee accessions used in the study

No	Accession	Region	Zone	Wereda	Collection place	Altitude
1	L-1/2003	Oromiya	Jimma			
	L-2/2003					
	L-3/2003			Limu kossa	Miaa	1670
	L-4/2003					
	L-5 /2003					
	L6 /2003					
2	L7 /2003	Oromiya	Jimma	Limu kossa	Cheraki	1640
	L8 /2003					
3	L9 /2003	Oromiya	Jimma	Limu kossa	Babo	1610
	L10/2003					
4	L11/2003	Oromiya	Jimma			
	L12 /2003					
	L13 /2003					
	L14/2003			Limu kossa	Kosa sate farm	1610-1850
	L15/2003					
	L16/2003					
	L17/2003					
5	L20/2003	Oromiya	Jimma			
	L22/2003			Limu kossa	Tenebo	1650
	L23/2003					
	L24/2003	Oromiya	Jimma			
	L25/2003					
	L26/2003			Limu kossa	Buya	1650-1680
	L27/2003					
	L28/2003					
6	L29/2003	Oromiya	Jimma	Limu kossa	Ajamo	1680
	L30/2003					
	L32/2003	Oromiya	Jimma			
	L33/2003					
	L34/2003			Limu kossa	Genji	1640-1720
	L35/2003					
	L47/2003					
	L48/2oo3					
7	L36/2003	Oromiya	Jimma	Limu kossa	Bidaru	1640
	L37/2003					
8	L38/2003	Oromiya	Jimma	Limu kossa	Gindacha	1640
	L39/2003					
9	L40/2003	Oromiya	Jimma			
	L41/2003			Limu kossa	Alge	1690
	L42/2003					
10	L43/2003	Oromiya	Jimma			
	L44/2003			Limu kossa	Kelecha	1670-1690
	L45/2003					
	L46/2003					
11	L49/2003	Oromiya	Jimma			
	L50/2003			Limu kossa	Sombo	1710-1720
	51/2003					
12	744	SNNPRS			Bonga	1770
13	F-59	SNNPRS			Bonga	1770

3.3 Experimental Design, Management and Season

The study was conducted during 2009/2010 main cropping season on six years old forty nine coffee germplasm accessions including standard checks (744 and F-59). The experiment was superimposed on that were planted in a 7*7 simple lattice design with 2 replication and seven accessions per incomplete block. Six trees per accessions were planted in 2m*2m spacing. All the management practices such as shading, weeding and fertilization were uniformly applied to all plots as per the recommendation (IAR, 1996).

3.4 Experimental Procedure

Ripe Red coffee cherries were handpicked. Before pulping fully ripened and healthy berries were separated from foreign materials and unripe green cherries and green bean coffee samples were prepared during 2009/2010 cropping season. A total of 98 samples were prepared from forty nine accessions (six trees per accessions bulked together).

Samples were prepared from six trees per accession per replication at peak harvest period. The samples were carefully prepared using wet processing method (pulping, fermentation, and drying) following the recommended processing method.

Pulping: Fully ripened beans of berries were separated from the skin and pulp by using a pulping machine that squeezes the berries between fixed and moving surfaces.

Fermentation: The beans were then stored in a fermentation tank for 48 hrs till first washing was made. Then, samples were stored for 24 hrs for final washing**.**

Drying: Samples were placed on mesh wire under sun for drying. During drying, the moisture content of the bean was measured by moisture tester H-E50 to maintain the moisture level at 10-12% for all samples uniformly. About 300g of green coffee bean samples were prepared per accession per replication separately for each accession for organoleptic quality characteristics analysis. To attain homogenous bean size and healthy

beans for organoleptic quality analysis, samples were screened through a mesh sieve 15 (5.95mm). Then, samples on screen 15 and above screen 15 were used for analysis. These were used to evaluate the organoleptic quality characteristics of the Limu coffee germplasm accessions. By combining the different coffee cupping techniques followed at French Agricultural Research Centre Coffee processing unit and Liquoring laboratory for International Development (CIRAD), and coffee liquoring unit of Ethiopia (CLUE), the sensorial quality analyses were carried out at Jimma Agricultural Research Center by well trained cup tasters as per the standard.

3.4.1 Roasting and grinding

The roaster machine, probatBRZ6, was first heated at about 160-200^{o}c. About 150-200 g of green coffee bean sample prepared per accession per replication was used for roasting. When the roast starts to crackle (burst open), the gas were turned down. When the coffee was considered medium roast (7 minutes on average) it was tipped out into the cooling try. Cold air was blown through the coffee to produce rapid cooling off .When the roast was cool (4 minutes on average) it was blown to remove the loose silver skins before grinding. Variability in roasting was controlled by measuring weight loss. The weight loss found was between 8-10% and these matches from medium to dark roasting degree reported by Agwanda. *et al*, (2003). About 12g medium seized ground coffee was prepared using Mahlkoing electrical grinder with middle adjustment.

3.4.2 Brewing

Soon after grinding, coffee powder weighing about 8g was placed in a cup with a capacity of 180 ml. Then, boiling water was poured on to the ground coffee up to about half way in the cup. Soon after, volatile aromatic quality and intensity parameters were recorded by sniffing. Then, the contents of the cup were stirred to ensure an infusion of all coffee grounds. The cup was then filled to the brim with boiled water. The brew was made ready for panelists within 8 minutes.

3 4.3 Cup tasting

Cup tasting was carried out once the beverage cooled to around 60 ^{0}C (Drinkable temperature). Two cups per sample were prepared for tasting session. The genotypes and the replicates were arranged at random. Aroma (aromatic quality and intensity), flavor, acidity, bitterness and astringency were scored using scales ranging from 0 to 5 (Appendix Table1). Typical flavor was assessed as an after taste aromatic quality that could vary from winy to flowery (winy, fragrant, floral, citrus, moka, spicy and others). There was also an overall standard for liquor quality based on the above attributes that ranged from 0 to 5 (Appendix Table 1). Mean of each variable by the panel was used for statistical analysis. However, variation among assessors for a given variable was not. Sensorial vocabulary (ISO, 1992) is presented in Appendix Table 2.

3.5 Data Collection

3.5.1 Morphological Quantitative and Qualitative data

The data on 22 morphological quantitative traits were recorded on tree basis (three trees from each accession) per replication by random sampling method (Table 2). For both quantitative traits and qualitative characters, the coffee descriptor by IPGRI (1996) was adopted and data for 10 qualitative characters were recorded on plot basis. Details of the quantitative and qualitative characters studied are depicted in (Tables 2 and 3) respectively.

Table 2. Quantitative traits studied and their code descriptions

Traits	unit	Descriptions
Bean length	mm	Average of ten normal beans of each tree was measured at the longest part using digital caliper
Bean width	mm	Average of ten normal beans of each tree was measured at the widest part using digital caliper
Fruit length	mm	Average of ten normal and mature green fruits of each tree was measured at the longest part using digital caliper
Fruit width	mm	Average of ten normal and mature green fruits of each tree was measured at the widest part using digital caliper
Fruit thickness	mm	Average of ten normal and mature green fruits of each tree was measured at the thickest part using digital caliper
Hundred bean weight	g	100 beans weight of each tree was recorded using digital bean balance by oven drying at 100^{o}C temperature for 24 hours to 0 % moisture content and was converted by 0.89at11%M.C (bean weight at 0% moisture*100)/(bean number*0.89=bean weight at 11% moisture content) (IPGRI,1996)
Yield	kg	Was estimated from weight of cherries per tree and was converted into weight of clean coffee per tree
Plant height	cm	The length from the ground level to the tip of the tree w as measured using tape meter
Stem diameter	cm	Was measured as a diameter of the main stem at five centimeter above the ground using vrnier caliper
Angle of primary branches	degree	Average angle of six branches (two from the top, two from middle and two from bottom parts of tree) were measured using protractor

Table 2. Continued

Traits	unit	*Descriptions*
Number of stem nodes	count	*Was Recorded by counting the total number of nodes on the main stem*
Canopy diameter	cm	*Average length of tree canopy was measured twice, east-west and north- south, from the widest portion of the tree canopy using tape meter*
Average internodes of stem	cm	*Height of tree (from the first primary branch up to the shoot tip) divided by the total number of nodes on main stem minus one (TH-HFPB)/ (TNNMS-1) where, TH=tree height, HFPB=height up to the first primary branch, TNNMS=total number of main stem nodes*
Average length of primary branches	cm	*Average length of six primary branches were randomly sampled each two from the top, middle and bottom part of the tree were measured using tape*
Averageinternode length of primary branches	cm	*Was estimated from each two from top, middle and bottom six primaries per tree using pocket meter. The six undamaged primaries from the three parts were selected. For each primary the length was divided by the number of nodes. And inter-node length for each tree was taken as the average value of the six primaries.*
Numberofprimarybranches	count	*Total number of primary branches were counted per tree*
Number of secondary branches	count	*Total number of secondary branches were counted per tree*
Percentage bearing primary branches	%	*Were Computed per tree as (NBPB/NPB) * 100 where, NBPB=number of bearing primary branches per tree, NPB=total number of primary/ tree*
Leaf length	cm	*Average of ten normal (> node 3 from the terminal bud) leaves were measured from petiole end to apex using graduated ruler*
Leaf width	cm	*Average of ten normal (> node 3 from the terminal bud) leaves, measured at the widest part using graduated ruler*
Leaf area	cm^2	*Was estimated from the product of leaf length and width in centimeter square times 0.66*
Height up to first primary branches	*cm*	*Height up to the first primary branch Was measured using tape meter*

Trait	Code	*Description*
Growth habit	1	*Open*
	2	*Intermediate*
	3	*Compact*
Stipule shape	1	*Round*
	2	*Ovate*
	3	*Triangular*
	4	*Deltate*
	5	*Trapezium*
Branching habit	1	*Very few primary branches*
	2	*Many primaries with few secondary branches*
	3	*Many primary and secondary branches*
	4	*Many primary, secondary and tertiary branches*
Angle of insertion of primary on the main stem	1	*Drooping*
	2	*Horizontal spreading*
	3	*Semi-erect*
Young leaf tip colour	1	*Greenish*
	2	*Green*
	3	*Brownish*
	4	*Reddish-brown*
	5	*Bronzy*
Leaf shape	1	*Obovate*
	2	*Ovate*
	3	*Elliptic*
	4	*Lanceolate*

Table 3. Qualitative traits studied and their code descriptions

Table 3. Continued

Trait	Code	*Description*
Leaf apex shape	1	*Round*
	2	*Obtuse*
	3	*Acute*
	4	*Acuminate*
	5	*Apiculate*
	6	*Spatulate*
Fruit shape	1	*Round*
	2	*Obovate*
	3	*Ovate*
	4	*Elliptic*
	5	*Oblong*
Stem habit	1	*Stiff*
	2	*Flexible*
Seed shape	1	*Round*
	2	*Obovate*
	3	*Ovate*
	4	*Elliptic*
	5	*Oblong*

3.5.2 Organoleptic data

Data on organoleptic quality parameters was collected at JARC's coffee liquoring unit with 10 well-trained and quality grader coffee tasters of JARC panel. Aromatic intensity, aromatic quality, acidity, astringency, bitterness, flavor, and overall standard were recorded with 0 to 5 scales.

3.6 Statistical Analysis

The variability present among accessions assessed by employing analysis of variance, by simple measures like range for means, mean, phenotypic and genotypic variances and coefficients of variation were computed for the entire accessions and multivariate analysis (cluster analysis and principal component statistical analysis were also employed).

In order to identify the variability among coffee germplasm accessions, all the 22 quantitative and 8 organoleptic quality considered in the study were statistically

analyzed using Lattice analysis of variance format design by using the statistical procedures described by Gomez and Gomez (1984). All statistical and data processing were performed Using XLSTAT (XLSTAT, 2007), Computer program and SAS (SAS, 2002) version9.2 software. The relative efficiency of simple lattice design over RCB design and CV (%) of both design was estimated and found that the use of the 7x7 simple lattice designs estimated to have increased the experimental precision over that which would have been obtained with a RCB design (Appendix Table 3). Therefore, due to this, the quantitative data were analyzed using simple lattice design. For characters having significant mean differences, the difference between treatment means was compared using LSD at 5%of probability level. Analysis of variance for the quantitative traits considered was done using the following ANOVA model (Singh, 1987):

ANOVA model for simple lattice design

$$y_{ijklm} = \mu + \tau_i + \beta_j + \chi_k + \gamma_l + \pi_m + \sum_{ijk\ lm}$$

$$\begin{cases} i=1, 2\ldots, 49 \\ j=1, 2\ldots, 2 \\ k=1, 2\ldots, 7 \\ l=1, 2, 14 \\ m=1 \end{cases}$$

Where:

Yij = response of Y trait from the ith accession, jth replication.

μ = over all mean effect

τ_i = effects of ith level of Treatments (unadjusted)

β_j = effects of jth level of replication

χ_k = effects of the kth level of the Blocks within Replications (adjusted for treatments)

γ_l = effect of the lth level of the intra block error

π_m = effect of the mth Randomized Complete Block Error

$\sum_{ijk}$ = is a random error component

3.7 Estimation of phenotypic and genotypic coefficient of variation

The phenotypic variances and coefficients of variations were estimated as per Singh and Chaudhary (1985)

Genotypic variance, ($\sigma^2 g$)

$$\sigma^2_g = \frac{MSg - MSe}{r}$$

Where, r = number of replication

MSg = mean square due to genotypes (accessions),

MSe = mean square of error (Environmental variance),

Environmental variance ($\sigma^2 e$)

Where,$\sigma^2 e$ = error mean square (MSe)

Phenotypic variance ($\sigma^2 p$)

$\sigma^2 p = \sigma^2 g + MSe$

Where, $\sigma^2 g$ = genotypic variance and

MSe = mean square of error (Environmental variance)

Phenotypic coefficient of variation (PCV)

$$PCV = \frac{\sqrt{\sigma^2_p}}{\bar{X}} * 100$$

Where $\sigma^2 P$ = phenotypic variance and

$\bar{X}$ = mean of the character

Genotypic coefficient of variation (GCV)

Where, $\sigma^2 g$ = genotypic variance and

$\bar{X}$ = Mean of the character

$$GCV = \frac{\sqrt{\sigma^2_g}}{\bar{x}} * 100$$

3.8 Heritability in broad sense

Heritability in broad sense for all character (22 quantitative characters and 8 organoleptic quality attributes was computed using the formula suggested by Singh and Chaudhary (1987).

$$H^2 = \frac{\sigma^2_g}{\sigma^2_p} \times 100$$

3.9 Expected genetic advance

The genetic advance expected under selection, assuming selection intensity of the superior5%of the genotypes was estimated in accordance with the methods illustrated by Johnson *et al.* (1955) and Allard (1999):

$$GA = K * \sigma_p * H$$

Where: GA = expected genetic advance

H = Heritability in broad sense

K = a constant (k = 2.056 at 5% selection intensity)

σp = phenotypic standard deviation on mean basis

The genetic advance as % of mean (GA) was computed as:

$$GA = \frac{GA}{\bar{X}} * 100$$

Where: $\bar{X}$ = population mean

GA = genetic advance as percent of mean

3.10 Phenotypic and genotypic correlations

Phenotypic and genotypic correlations were computed following the method described in Singh and Chaundhary (1987).

$$r_p = \frac{p\,\mathrm{cov}\,x.y}{\sqrt{\sigma^2 px\sigma^2 py}}$$

$$r_g = \frac{g\,\mathrm{cov}\,x.y}{\sqrt{\sigma^2 gx\sigma^2 gy}}$$

Where: ^{r}p = phenotypic correlation coefficient

Pcovxy = phenotypic covariance between variables x and y

σ^2p.x = phenotypic variance for character x and

σ^2py =phenotypic variance for character y

^{r}g = genotypic correlation coefficient

gcovx.y = genotypic covariance between variables x and y

σ^2gx = genotypic variance for character x, and

σ^2gy = genotypic variance for character y

3.11 Cluster analysis

Clustering of the 49 accessions for 22 quantitative characters and 8 organoleptic quality attributes was performed using the proc cluster procedure of SAS version 9.2 (SAS Institute, 2002) by employing the method of average linkage clustering strategy of observations. The number of clusters was determined by following the approach suggested by Copper and Milligan (1988) by looking into three statistics namely, pseudoF, pseudo t^2 and the cubic clustering criteria (CCC). The number of cluster was decided where the CCC and pseudo F statistics combined with a small value of the pseudot^2 statistics and large pseudo t^2 statistics for the next cluster fusion**.**

Genetic divergence between clusters was determined using the generalized Mahalanobis D^2 statistics. Mahalanobis (1936) developed this method to determine divergence prevailing among population in terms of generalized group distance (Sharma, 1998). D^2statistics is defined by the following formula:

$$D^2ij = (\bar{A}i - \bar{A}j)S^{-1}(\bar{A}i - \bar{A}j)$$

Where: D2ij = total generalized distance between class i and j,

(Ai__Aj) = difference in the mean vectors of i^{th} and j^{th} germplasm accessions

S-1 = var- covariance matrix of pooled error

Testing the significance of D^2 values obtained for a pair of clusters were taken as the calculated value of chi-square (χ^2) and will be tested against the tabulated value of χ^2 for P degrees of freedom (P is the number of characters) (Singh and Chaundhary, 1985) at appropriate probability level, that was considered.

3.12 Principal component analysis

Principal component analysis was performed using correlation matrix by employing procedure SAS (SAS, 2002) in order to examine the relationships among 22 quantitative characters and 8 organoleptic quality attributes that are correlated among each other's by converting into uncorrelated traits called principal components. These new sets of traits are linear combinations of the original variables, which are derived in decreasing order of importance (Chatfield and Collins, 1991). The objective of this analysis was to extract the first few principal components accounted for most of the variation in the original data. Consequently, it defines; the patterns of variation between the accessions by summarizing the data into a reduced number of independent factors (the quantitative and the organoleptic quality trait in this case).

The principal components were derived as follows. Suppose $x^T = x_1 \ldots x_p$ is a p dimensional random variable with mean μ and covariance matrix $\sum$. Then, $Y_i = a_{1\,j}\, x_1 + a_{2j}x_2 + \ldots a_{pj}\, x_p = a^T{}_j x$

$Y_j = Y_1, Y_2, Y_p$ are principal components

$a^{T}_{j} = a_{1j}, \ldots apj$ is a vector of constants (eigenvectors)

$$a_j^T a_j = \sum_{k=1}^{p} a^2_{kj} = 1$$

$Var(Yi) = Var(a^T_1 x) = a\, t_1 \sum a_1$

Where, x is a character (trait), a is a character coefficient (eigenvector), Y is principal component, Var (Y) is variance of Y, p is number of characters and j is number of principal components. Important characters in each principal component were identified by using the formula suggested by Johnson and Wincher (1988): X= trait coefficient divided by standard deviation of the respective eigenvalues where, x > 0.5 indicates the significant contribution of the trait in question.

3.13 Shannon-Weaver diversity index (H') for qualitative traits

Shannon-Weaver diversity index, (H') which has been widely used in measuring the phenotypic diversity of germplasm collections (Jain, 1975) was estimated on the frequency data. The Shannon-Weaver diversity index is defined as follows,

$$H' = -\Sigma (pi \ln (pi)$$

Where, i=is the relative abundance of each trait, ln (pi) = is the natural logarithm of the relative abundance, pi ln (pi) = is the relative abundance of trait, multiplied by the natural logarithm of the relative abundance (pi). Σ pi ln (pi) is the sum of the pi ln (pi) products,-Σ pi ln (pi) = is the negative sign of the sum that we calculate. This gives us H', the Shannon Diversity Index. Chi-square analysis was performed on the frequency data to assess the distributions of the characters. The significance of proportions for each particular trait state was tested with chi- square using formula suggested by Clewer and Scarisbrick (2001).

$$\chi^2 = \frac{(O - E)^2}{E}$$

Where χ^2 = chi- square

O = observed frequency in characters category.

E = Expected frequency in characters category.

Expected frequency is calculated as the procedures suggested by Clewer and Scarisbrick (2001) using the formula

$$E = \frac{(RT) * (CT)}{GT}$$

Where, RT= Row total

CT=Column total

GT=grand total

The degrees of freedom for chi-square in contingency table having 'r' rows and 'c' columns are (r-1) * (c-1). The calculated values of χ^2 were compared with tables of χ^2 distributions at 0.05 and 0.01 probability levels.

4 RESULTS AND DISCUSSION

4.1 Analysis of variance

4.1.1 Quantitative characters

The mean squares of the analysis of variance for the 22 quantitative traits are given in Table 4. The results indicated significant ($P< 0.05$) variability of coffee accessions for most of measured quantitative characters. However, the results not indicated variation for characters such as stem diameter, canopy diameter, average internode length of stem, average length of primary branches, average internode length of primary branches, number of primary branches, and percentage of bearing primary branches (Table 4 and Appendix Table 4). These significant variations among test materials for the characters studied indicated the existence of variability to have an effective selection. In view of this, it may be reasonable to state that there is a good chance to improve coffee accessions through selection and crossing. Such a view is endorsed by the work of earlier researchers (Catter, 1992 and Leroy., *et al.* 1993). The prevalence of such variability in an autogamous species like *C.arabica* appears to be important. This may be attributed either to the evolutionary tendencies as the species is native to Ethiopia or to the natural mutation occurring to the population of the crop (Avice And Hamric, 1997 and Hedrick, 2000).

The variations observed for measured quantitative characters in this study were in agreement with the earlier findings of Bayetta (1991) who reported the presence of significant variation in coffee growth characters and Mesfin and Bayetta (2005) reported the significant difference among the genotypes in 100 Hararge coffee accession germplasm using 14 quantitative characters. These results are also in agreement with the findings of Mesfin *et al.* (2007) who reported the significant difference in forty one South Ethiopian coffee selection evaluated for seven morphological agronomic character and yield. Similarly, Gichimu and Omondi (2010) reported that morphological characterization of five newly developed lines of arabica coffee as compared to commercial cultivars in Kenya.

The mean performance of accessions for 22 quantitative characters compared for parameter that showed significant difference. These accessions were differentiated by list significant difference test at (5%) and the mean performance of the accessions along with Least Significant Difference (LSD), Coefficients of Variation (CV) and Standard Deviations (S.D) are presented in Appendix Table 5.

Table 4. Mean square for 22 quantitative characters in 49 coffee arabica accessions

Characters	*Mean square*		
	Treatment unadjusted	Treatment adjusted	*Error (intra block)*
Bean length,	0.49	0.42**	*0.09*
Bean width,	0.21	0.18**	*0.03*
Fruit length	1.03	0.89**	*0.31*
Fruit width	0.96	0.94**	*0.33*
Fruit thickness	1.05	0.89*	*0.42*
Hundred bean weight	7.55	6.64**	*0.84*
Plant height	899.45	560.87*	*255.14*
Stem diameter	0.64	0.35ns	*0.33*
Angle of primary branch	39.09	30.91**	*10.63*
Number of main stem nodes	29.62	18.24ns	*10.54*
Canopy diameter	427.39	379.78ns	*376.57*
Averageinternode length of main stem	*0.84*	*0.68ns*	*0.51*

Table 4. Continued

Characters	*Mean square*		
	Treatment unadjusted	Treatment adjusted	*Error (intrablock)*
Average length of primary branch	75.29	52.98ns	*54.97*
Averageinternode length of primary branch	0.38	0.29ns	*0.16*
Number of primary branches	129.07	83.19ns	*51.38*
Number of secondary branches	11614	9114.90*	*3794.94*
Yield	0.17	0.14*	*0.06*
Percentage of bearing primary branches	68.38	51.07ns	*49.08*
Leaf length	0.96	0.68*	*0.37*
Leaf width	0.47	0.36**	*0.11*
Leaf area	68.41	44.73*	*24.61*
Height up to first primary branch	31.71	33.33*	*13.39*

**, ** = Significantly different at probability level of 0.05 and 0.01 values, respectively; Ns= non significant*

Note: degrees of freedom for treatments adjusted, un adjusted and intra block error for all the 22 characters were 48,48 and 36 respectively

4.2 Estimates of variability

4.2.1 Estimates of range and mean

The range and mean for the 22 quantitative traits are given in Table 5. A great genetic variability among the coffee accessions was verified, as indicated by results obtained from the characters studied. The results of range revealed a wide range of variation in traits like stem diameter (3.56 -6.75cm), number of secondary branch (91.50-545.50), height up to first primary branches (21.66-42.16cm),and yield (0.13-1.43kg per tree) indicating that their greatest role to the total variability observed among the coffee accessions. Moreover, the differences between the minimum and maximum mean values for other characters were also high, indicating the availability of variation for improvement through selection.

Based on mean value, the average mean value was almost twice of the minimum mean value for traits like, green bean yield of coffee per tree and secondary primary branches indicating that their maximum contribution to the total variability observed among the coffee accessions. The variations observed for measured quantitative characters in this study were in agreement with the findings of Yigzaw (2005), Mesfin and Bayetta (2008). This high range and mean value for each trait of interest suggests that great opportunity to improve the various desirable traits without much effort through selection as short term strategy and through hybridization as long term strategy.

4.2.2 Phenotypic and genotypic coefficient of variation

Genotypic and phenotypic variance ranging from 0.04 to 3952.83 and 0.13 and 5805.82, respectively were found for the traits considered in this study (Table 5). Consequently, the maximum phenotypic variance value of 5805.82 was noted for number of secondary branch and 450.46 for plant height. Similarly, the genotypic variances for these characters were also high indicating that the genotype could be reflected by the phenotype and the effectiveness of selection based on the phenotypic performance for

these characters. The estimate of genotypic and phenotypic coefficient of variations is presented in (Table 5).

According to Deshmukh *et al.* (1986), phenotypic and genotypic coefficient of variation values greater than 20% are considered as high, whereas values less than 10% are to be low and values between 10% and 20% as medium. Accordingly, characters which showed high phenotypic and genotypic coefficients of variation were number of secondary branches and medium phenotypic and genotypic coefficients of variation were recorded for hundred beans weight and height up to first primary branches. All other characters grouped under low phenotypic and genotypic coefficients of variation. This result is in agreement with the findings of Seyoum and Bayetta (2007) and Yigzaw (2005) in arabica coffee.

4.2.3 Heritability in the broad sense

The estimate of the broad sense heritability is presented in Table 5. According to Verma and Agarawal (1982), heritability values greater than 50% are considered as high, whereas values less than 20% are to be low and values between 20% and 50% as medium. Accordingly, characters which showed high heritability values were bean length (76.29%), bean width (65.08), fruit length (64.57%), fruit width (64.57%), plant height (63.57%), number of secondary branches (68.08) and height up to first primary branches (60.06%), number of primary branches, average internode length of primary branches, number of stem nodes, hundred bean weight and leaf width, suggesting that effect of environment on the phenotypic expression of the characters is minimum which is good for improvement through selection. Medium heritability values were recorded for stem diameter (32.09%), angle of primary branches (48.6%), leaf length (38.79%), leaf area (48.21%). yield of green bean clean coffee (27.48%) and fruit thickness (40.78%). The result is in agreement with Walyaro and Van der Vossen (1979) reported medium heritability values of quantitative characters in coffee. However, canopy diameter (1.51%), average internode length of stem (0.09%), average length of primary branches (16.03%) and percentage of bearing primary branches were grouped under low

heritability. The result was contradictory to Van der Vossen (1985), Bayetta (2001) and Mesfine and Bayetta (2008) reported high broad sense heritability estimates for all the quantitative characters measured in coffee arabica.

Table5. Variability parameters for quantitative traits in coffee germplasm accessions

Characters	Range		Grand mean	σ^2 P	$\sigma\delta^2$ g	PCV %	GCV %	H^2 %	GA	*GA %*
	Min	Max								
Bean length	8.45	10.78	9.61	0.34	0.26	6.11	5.31	76.29	0.92	*9..57*
Bean width	6.15	7.53	6.72	0.18	0.12	6.31	5.21	65.08	0.58	*8.60*
Fruit length	14.20	17.35	15.54	0.57	0.36	4.86	3.86	64.57	0.98	*6.3*
Fruit width	12.03	15.75	13.59	0.56	0.36	5.51	4.42	64.57	0.99	*7.28*
Fruit thickness	8.02	11.68	9.43	0.58	0.24	8.11	5.21	40.78	0.65	*7.00*
100 bean weight	12.80	21.95	16.73	3.76	3.05	11.59	10.44	81.13	3.24	*19.37*
Plant height	256.33	333	293.58	450.46	286.35	7.23	5.76	63.57	27.79	*9.47*
Stem diameter	3.56	6.75	5.11	0.39	0.125	12.22	7.11	32.09	0.41	*8.02*
Angle of primary branch	51.76	69.73	61.83	19.49	9.47	7.14	4.98	48.6	4.42	*7.15*
Number of main stem nodes	26.50	44.50	37.01	15.15	8.42	10.52	7.84	55.59	4.46	*12.05*
Canopy diameter,	174	248.08	208.18	212.23	1.61	7.21	0.61	1.51	0.22	*0.11*
Average internodes length of main stem	*6.31*	*7.98*	*7.27*	*0.45*	*0.07*	*9.23*	*3.64*	*0.09*	*0.22*	*3.03*

Table5. Continued

Characters	Range		Grand mean	σ^2 P	$\sigma\delta^2$ g	PCV %	GCV %	H^2 %	GA	*GA %*
	Min	Max								
Average length of primary branch	59.67	90.51	78.95	37.56	8.14	7.76	3.61	16.03	2.74	*3.47*
Internode length of primary branch	3.56	5.43	4.59	0.26	0.13	11.11	7.71	50.08	0.53	*11.55*
number of primary branches	43.83	77.16	62.84	63.79	35.78	12.71	9.52	56.09	9.23	*14.69*
Number of secondary branches	91.50	545.50	252.49	5805.82	3952.83	30.18	24.90	68.08	106.86	*42.32*
percentage of bearing primary branches	65.76	94.43	83.75	35.15	3.62	7.08	2.27	10.3	1.27	*1.52*
Leaf length	11.17	13.93	12.54	0.49	0.19	5.58	3.48	38.79	0.56	*4.47*
Leaf width	4.09	6.16	5.18	0.25	0.14	9.63	7.22	54.97	0.58	*11.21*
Leaf area	32.98	54.56	43.75	34.09	16.43	13.35	9.26	48.21	0.51	*1.21*
Height up to first primary branch	21.66	42.16	30.79	15.89	9.54	12.95	10.03	60.06	4.93	*77.64*
Yield	*0.13*	*1.43*	*0.80*	*0.13*	*0.04*	*45.11*	*25.00*	*27.48*	*0.23*	*28.75*

4.2.4 Expected genetic advance

The expected genetic advances for 22 quantitative characters in Coffee arabica accessions are presented in Table 5. Genetic advance (GA%) that could be expected from selecting the top 5% of the genotype as percent of mean varied between 0.11% to 77.64% (Table 5). The characters height up to first primary branches, number of secondary branches, hundred green coffee bean weight and yield of clean green coffee per tree (28.75) in arabica coffee accessions showed higher heritability and genetic advance, indicating their ease for selection (Srinivassan, 1988). These results are in agreement with the findings of Yigzaw (2005) in coffee Arabica.

4.2.5 Phenotypic and Genotypic Correlation for Quantitative Traits

The phenotypic and genotypic correlation coefficients for 22 quantitative characters are presented in Table 6. The analysis showed positive and significant association (both at $P< 0.05$ and $P< 0.01$) among the characters both at phenotypic and genotypic level but the frequency of positive and significant phenotypic correlation was less compared to genotypic correlation. This may be attributed to considerable influence of environment on the expressions of characters. Such a view is endorsed by the reports of earlier researchers (Sylva and Carvalho, 1997).

Among the characters plant height, stem diameter, canopy diameter, hundred green coffee bean weights and number of main stem nodes per plant in particular showed positive and significant correlations with majority of the characters both at phenotypic and genotypic levels. Percentage of bearing primary branches was the only characters that showed positive and significant phenotypic correlation with clean coffee yield per tree. Furthermore, positive significant correlations were obtained between coffee yield and percentage of bearing primary branches both at phenotypic and genotypic level. However, significant positive correlations were obtained between coffee arabica yield, bean width, fruit length, hundred bean weights, plant height, and canopy diameter, leaf area, leaf length and height up to primary branches, at genotypic level. But significant

negative correlations were obtained between clean coffee yield and number of secondary branches at genotypic level.

In general, it was observed that the genotypic correlation coefficients were found to be higher in magnitude than the corresponding phenotypic ones. It was obvious that association of characters at phenotypic level was less pronounced as compared to that of genotypic level in terms of significance. This may be attributed to considerable influence of environment on the expressions of traits. Such a view is approved by the reports of earlier researchers (Sylva and Carvalho, 1997).

Accordingly, percentage of bearing primary branches was the only characters that positively and significantly correlated with twelve of quantitative characters (Table 6). Leaf area and leaf width each correlated positively and significantly with ten characters. Likewise yield of clean coffee per tree positively and significantly correlated with nine quantitative characters.

Quantitative characters, canopy diameter and plant height each positively and significantly correlated with eight characters. Stem diameter and number of main stem node each positively and significantly correlated with seven characters. Except for leaf width, leaf area, height up to primary branches and number of secondary branches, the rest of the quantitative characters manifested positive and significant association with more than two characters at genotypic level. In view of this, it may be reasonable to conclude that percentage of bearing primary branches, leaf area and leaf width, yield of clean coffee per tree, canopy diameter and plant height, stem diameter and number of main stem node are the most important characters with respect to characterization. Similar, view is held by other workers (Leroy *et al.,* 1993).

Selection for a character based on its close association (positive and significant) with other characters is very useful for simultaneous improvement of all the associated characters. On the other hand, for characters, manifesting negative association, simultaneous improvement of characters could be quite difficult and independent

selection may have to be carried out to improve such characters (Sylva and Carvalho, 1997). For instance, selection for stem diameter based on the results of this study is likely to result in simultaneous improvement of the characters plant height, number of stem nodes, canopy diameter, number of primary branches, number of secondary branches and percentage of bearing primary branches, since these characters exhibited positive and significant association with stem diameter both at phenotypic as well as genotypic level (Table 6). This is in agree with the observations of Charier (1978), Berthaud *et al.* (1979) and Walyaro (1983). However, selection for number of primary branches per plant could affect the improvement of plant height, average internode length of stem and internode length of primary branches per plant negatively as these characters showed negative and significant correlation with number of primary branches per plant. Likewise, selection for internode length of primary branches per plant could affect the improvement of bean width, fruit width, fruit thickness, hundred green coffee bean weight, stem diameter, number of stem nodes, average length of primary branches, number of primary branches and number of secondary branches negatively as these characters showed negative and significant correlation with internode length of primary branches per plant. Likewise, selection for number of secondary branches could affect the improvement of fruit width, angle of primary branches, number of stem nodes, average internode length of stem, internode length of primary branches negatively as these characters showed negative and significant correlation with number of secondary branches per plant.

Selection for percentage of bearing primary branches could affect the improvement of fruit width, fruit thickness, canopy diameter, internode length of primary branches negatively as these characters showed negative and significant correlation with percentage of bearing primary branches per plant. In the same way, selection for leaf area could affect the improvement of canopy diameter negatively as these characters showed negative and significant correlation with leaf area per plant. Selection for leaf width could affect the improvement number of primary branches, percentage bearing primary branches negatively as these characters showed negative and significant correlation with leaf width per plant. Moreover, selection for leaf area could affect the improvement percentage bearing primary branches negatively as these characters showed negative and

significant correlation with leaf area per plant. Selection for quantitative trait such as height up to first primary branches could affect the improvement of hundred green coffee bean weight and leaf area negatively as these characters showed negative and significant correlation with height up to first primary branches per plant. Selection for yield could affect the improvement of number of secondary branches and leaf width negatively as these characters showed negative and significant correlation with clean coffee yield in kilogram per tree. Selection for number of stem node could affect the improvement of fruit thickness, average internode length of stem and internodes length of primary branches negatively as these characters showed negative and significant correlation with number of stem node per tree.

Selection for angle of primary branches could affect the improvement of fruit thickness, stem diameter and number of secondary branches negatively as these characters showed negative and significant correlation with angle of primary branches per tree. Selection for stem diameter could affect the improvement of fruit length fruit width average internode length of stem and internode length of stem negatively as these characters showed negative and significant correlation with stem diameter per tree.

Finally, selections for fruit thickness could affect the improvement of internode length of primary branches negatively as these characters showed negative and significant correlation with fruit thickness per tree. This implied that the selection for any one of these characters is not likely to result in improvement of the others. In view of this, it is suggested that independent selections may have to be carried out for such a character (Sylva and Carvalho, 1997).

Table 6. Estimates of genotypic (below diagonal) and phenotypic (above diagonal) correlation coefficients of 22 quantitative characters in coffee accession

	trait	1	2	3	4	5,	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	*22*
1	BL	-	0.22	0.72**	0.01	0.05	0.66**	0.11	0.16	-0.20	-0.02	0.03	0.17	0.14	0.13	0.09	0.03	0.01	0.03	0.18	0.09	-0.01	-0.01
2	BW	0.14	-	0.47**	0.15	0.12	0.48**	0.15	0.12	0.02	0.17	0.14	-0.08	0.03	-0.13	0.19	0.15	0.04	0.17	0.17	0.21	-0.12	0.16
3	FRL	0.93**	0.54**	-	0.34*	0.34	0.69**	0.16	-0.06	0.12	0.02	0.04	0.13	0.09	0.03	0.06	-0.09	0.16	0.29*	0.29*	0.23	0.12	0.15
4	FW	-0.07	0.1	0.32*	-	0.83**	0.34*	0.01	-0.04	0.05	0.03	-0.08	-0.11	-0.07	-0.23	0.08	-0.15	-0.04	0.27*	0.26*	0.3	-0.15	0.15
5	FT	-0.04	-0.04	0.57**	0.34**	-	0.26*	0.16	0.02	0.01	0.06	-0.01	-0.08	-0.09	-0.25*	0.11	-0.08	0.08	-0.07	0.24*	0.22	0.02	0.24
6	HBW	0.71**	0.63**	0.84**	0.48**	0.56**		-0.01	0.04	0.08	0.12	-0.02	-0.09	0.09	-0.14	0.21	-0.01	0.11	0.25*	0.01	-0.06	-0.14	0.14
7	PLH	0.04	0.16	0.17	0.06	0.01	-0.05	-	0.42**	0.34*	0.68**	0.48**	-0.11	0.38**	-0.16	0.69**	0.25*	0.37**	0.02	0.01	0.09	0.19	0.22
8	SD	0.15	-0.13	-0.48**	-0.27*	-0.03	-0.13	0.71**	-	-0.04	0.59**	0.47**	-0.33*	0.39**	-0.33*	0.60**	0.63**	0.13	0.05	-0.07	-0.06	0.07	0.01
9	APB	-0.15	-0.11	0.18	0.07	-0.34**	0.24	0.31	-0.27*	-	0.25*	0.02	-0.12	-0.06	-0.07	0.21	-0.24**	0.18	0.08	-0.06	0.02	0.22	0.08
10	NSN	-0.03	0.03	-0.08	-0.01	-0.29*	0.13	0.86**	.90**	0.13	-	0.41**	-0.67**	0.36**	-0.49**	0.89**	0.45**	0.38**	0.12	-0.10	-0.05	-0.02	0.17
11	CD	0.39**	0.16	0.17	0.56**	0.04	-0.05	0.26*	.41**	0.41**	0.42**	-	-0.13	0.66**	-0.01	0.49**	0.23	0.10	0.15	0.15	0.14	0.21	0.11
12	AILS	0.69**	0.19	0.32*	0.01	0.42**	-0.31	-0.44*	- .91**	0.18	-0.83**	0.06	-	-0.03	0.46**	-0.59**	-0.29**	-0.22	0.12	0.16	0.21	0.02	-0.14
13	ALPB	0.17	-0.28*	-0.05	-0.40**	-0.57*	0.04	0.42**	0.09	-0.35*	0.24*	0.14	0.82**	-	0.21	0.30	0.18	0.20	0.14	0.15	0.09	-0.02	0.05
14	ILPB	0.19	-0.30*	0.07	-0.31*	-0.41**	-0.28*	0.85**	- .25**	-0.15	-.91*	0.48**	.68**	-0.38**	-	-0.42**	-0.38**	-0.21	0.09	0.19	0.09	0.09	-0.11
15	NPB	-0.01	0.09	0.05	0.16	-0.09	0.23	-0.48**	0.98**	0.14	0.96**	0.15	-0.85**	0.27*	-0.98**	-	0.51**	0.34**	0.02	-0.09	-0.08	0.02	0.15
16	NSB	0.01	0.17	-0.17	-0.29*	-0.05	-0.01	0.41**	0.99**	-0.57**	-0.57**	-0.13	-.98**	-0.03	-0.70**	0.75**	-	0.01	-0.19	-0.14	-0.19	-0.07	-0.15
17	PBPB	0.14	0.16	0.29**	-0.36*	-0.27*	0.84**	0.42**	0.93**	0.51**	0.51**	-0.48**	.58**	.67**	-0.31*	0.95**	0.42**	-	0.16	-0.05	-.0.01	0.26*	0.53*
18	LL	0.01	0.16	0.19	0.49**	0.29*	-0.15	0.01	0.43**	0.11	0.11	-0.27*	0.65**	0.86**	0.63**	0.09	-0.14	0.01	-	0.50*	0.73**	-0.08	0.13
19	LW	0.33*	0.31*	0.48**	0.31*	0.25*	0.05	0.14	0.16	-0.17	-0.17	-0.04	0.80**	0.49**	0.59**	-0.27*	-0.16	-0.75**	0.43**	-	0.86**	-0.13	0.05
20	LA	0.16	0.43**	0.36**	0.54**	0.17	-0.11	0.48**	0.24*	0.00	0.01	-0.13	0.97**	0.52**	0.44**	-0.22	-0.15	-0.52**	0.72**	0.91**	-	-0.23	0.12
21	HPB	-0.07	-0.09	0.35**	-0.22	0.19	-0.26*	0.28*	-0.01	0.48**	0.48**	0.14	0.32*	-0.11	0.18	0.07	-0.21	0.98**	0.09	-0.14	-0.39**	-	0.04
22	Yld	0.13	0.47**	0.61**	0.24	0.21	0.59**	0.28*	0.14	-0.17	-0.17	0.29*	0.23	0.14	0.09	0.11	-0.44**	.62**	0.30*	-0.24	0.27*	0.40**	-

*, ** = Significant at probability level of 0.05 (r=0.246) and 0.01 values (r=0.342), respectively

BL = Bean length, BW = Bean width, FL = Fruit length, FW = fruit width, FT = Fruit thickness, HBW = hundred bean weight, Yld = yield, PLH = plant height, SD = Stem diameter,APB = Angle of primary branch, NSN = Number of main stem nodes,

CD = Canopy diameter, AILS = Average internodes length of main stem,AILPB = Averageinternode length of primary branch,

ALPB = Average length of primary branch, NPB = number of primary branches,

NSB = Number of secondary branches,PBPB = percentage of bearing primary branches, LL = Leaf length, LW = Leaf width, LA = Leaf area, HPB = Height up to first primary branch.

4.3 Cluster Analysis

4.3.1 Quantitative characters

Grouping of Coffee arabica accessions for morphological quantitative traits using Agglomerative hierarchical clustering and determining similarity between accessions using Mahalanobis distance method for quantitative traits are presented in Table 7. Cluster analysis based on coffee quantitative traits grouped 49 coffee genotypes into four clusters. The first, second, third and fourth groups consisted 26(53%), 7 (14.29%), 15 (30.61%) and 1(2.04%) accession respectively indicating that coffee accessions of the same cluster group were at least morphologically similar. The clustering pattern of the accessions revealed the existence of genetic diversity in the coffee accessions for the characters studied (Table 7 and Fig 1). Interestingly, genotypes were not only clustered according to area of collection. This can be substantiated by the fact that accession collected from collection place such as Mia, Babo, Kossa state farm, Tenebo, Buya, Genji, Bidaru, Gindacha, Alge, Sombo were clustered in cluster I. Likewise accessions collected from Kossa state farm, Tenebo, Alge, Kelecha, and Genji were also clustered together in cluster II. Finally, accession collected from Mia, Cheraki, Kossa state farm, Buya, Ajamo, Gindacha, Kelecha and Sombo were grouped in cluster III. This could be attributed to the unrestricted movement of coffee seed from area to area by man as well as wild animals (Yigzaw, 2005). This gene flow in coffee can be further attributed to human interference due to the fact that the coffee accessions were collected from area which is always under human pressure with respect to movement of coffee seeds that are distributed by government extension workers and non –governmental organization and planted by the farmers. Esayas (2005) reported based on molecular marker analysis clustering of coffee populations on the bases of their geographic origin but failed to cluster according to their respective populations due to the presence of substantial gene flow between local populations in the form of young coffee plants.

The standard check improved cultivar, F-59 with medium (Intermediate open type) of growth habit was grouped in cluster I whereas 744 (open growth habit) was grouped in Cluster II. Bayetta (2001) reported that morphological variation is more important than variation in geographical origin as an indicator of genetic diversity in Coffee. The present study was in agreement with Mesfin and Bayetta (2005) who studied 100 Harrarge coffee accessions for phenotypic diversity under field condition. and identified six main groups in the coffee accession. Seyoum *et al.* (2004) also evaluated 81 coffee accessions of the Ethiopian coffee germplasm for fifteen seedling parameters based on cluster analysis grouped the accessions into six major groups consisting of one to fifty- four accessions at Jimma Agricultural Research Center. Mesfin *et al.* (2007) clustered the 41 south Ethiopian coffee selection and the two south west Ethiopian origin CBD resistant cultivar using seven morphological characters and yield into 9 clusters suggesting the prevalence of wide phenotypic variation in the coffee population.

Table 7. Distributions of 49 coffee genotypes over four clusters using quantitative trait

ClusterI		Cluster II	Cluster III	Cluster IV
744*	L32/2003	F59*	L01/2003	L17/2003
L02/2003	L33/2003	L15/2003	L03/2003	
L04/2003	L34/2003	L20/2003	L07/2003	
L05/2003	L35/2003	L42/2003	L08/2003	
L06/2003	L36/2003	L43/2003	L11/2003	
L09/2003	L37/2003	L47/2003	L12/2003	
L10/2003	L38/2003	L48/2003	L13/2003	
L14/2003	L40/2003		L28/2003	
L16/2003	L41/2003		L29/2003	
L22/2003	L49/2003		L30/2003	
L23/2003	L50/2003		L39/2003	
L24/2003	L27/2003		L44/2003	
L25/2003	L26/2003		L45/2003	
			L46/2003	
			L51/2003	
26(53%)		7(14.29%)	15(30.61%)	1(2.04%)

*=represents standard checks used for the study

4.3.2 Cluster characterizations using quantitative trait

All clusters were characterized by different 22 quantitative characteristics (Table 8). Considerable differences in cluster means were noticed for all quantitative traits. Accessions in cluster one were characterized by the highest mean value for fruit thickness, fruit width, yield per tree, leaf length, leaf width and leaf area and by the lowest bean width. Likewise, Cluster II was characterized with the highest mean value of bean length, bean width, fruit length, hundred bean weight and average length of primary branches while by the lowest mean values of angle of primary branches and height up to first primary branches. The highest average internode length of stem and internode length of primary branches and the lowest plant height stem diameter, number of stem node, canopy diameter, and number of secondary branches, percentage bearing primary branches, and height up to first primary branches. Finally, the highest mean values of plant height, stem diameter, angle of primary branches, total number of nodes on main stem, canopy diameter, number of primary branches, number of secondary branches, height up to first primary branches and average percentage of bearing primary branches also characterized cluster IV and by the lowest values of all the rest of characters except bean width. The present study was in agreement with Mesfin and Bayetta (2005) who studied 100 Hararge coffee accessions for phenotypic diversity under field condition.

Table 8. Cluster means for quantitative traits

Traits	I	II	III	IV
Bean length	9.53	10.01**	9.61	9.02*
Bean width	6.65*	6.89**	6.75	6.72
Fruit length	15.45	15.87**	15.59	14.60*
fruit width	13.65**	13.50	13.58	12.55*
Fruit thickness	9.53**	9.34	9.35	8.59*
100beanweight	16.19	18.24 **	17.13	14.15*
yield	0.87**	0.82	0.69	0.53*
plant height	293.44	304.55	287.04*	318.33**
Stem diameter	5.12	5.52	4.79*	6.76**
Primary angle	61.53	59.08*	63.49	63.77**
Number of main stem nodes	37.12	40.17	34.96*	43.17**
Canopy diameter	207.22	213.63	205.94*	228.42**
Internode length of main stem	7.20	6.97	7.59**	6.52*
Average length of primary branch	77.96	83.48**	78.63	77.63**
Average internode length of primary branches	4.56	4.46	4.78**	3.57*
Number of primary branches	63.12	70.40	57.87*	77.50**
Number of secondary branches	253.58	356.19	182.69*	545.50**
Percentage of bearing primary branches	84.63	83.06	82.37*	86.62**
Leaf length	12.56**	12.48	12.55	12.35*
Leaf width	5.22**	5.11	5.17	4.83*
Leaf area	44.25**	43.76	43.76	39.42*
Height up to first primary branch.	31.31	30.81*	30.81*	38.17**

4.3.3 Divergence analysis for quantitative traits

Mahalanobis distance (D^2) of the 4 clusters of 49 coffee accessions based on 22 quantitative traits is given in Table 9. The inter cluster distance (D^2) analysis showed a highly significant ($P<0.01$) and significant ($P<0.05$) difference between clusters I and IV (61.92), cluster II and cluster IV (48.04) and cluster III and cluster IV (93.74) (Table 9) respectively. The smallest inter cluster distance (5.24) was observed between clusters I and III while the highest and highly significant inter cluster distance (93.74) was between cluster III and cluster IV suggesting the coffee materials among clusters were divergent from each other. The significant inter cluster distances indicated that there is a high opportunity for obtaining transgressive segregates and maximizing heterosis by crossing accessions belonging to different clusters as there is a higher probability that unrelated genotypes would contribute unique desirable alleles at different loci (Peters and Martinelli, 1989).

Souza and Sorrels (1991) pointed out that categorizing germplasm accessions into morphologically similar, more particularly genetically similar groups is useful for selecting parents for crossing.

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Moll and Stuber (1974) and Falconer (1996) reported that genetic diversity has probably arisen through diversity in origin (geographical separation), ancestral relationship, gene frequencies and morphology. These workers indicated that plants differing in either one or more of these factors would differ by a significant number of genes. Similarly Van der Graff (1981) reported that the discovery of coffee berry disease resistant cultivars and superior hybrids are practical evidences for the presence of genetic diversity.

Table 9.Mahalanobis distance (D2) of the 4 clusters of 49 coffee accessions based on 22 quantitative traits

Distance between pairs of clusters			
	I	II	III
II	8.76		
III	5.24	21.14	
IV	61.92**	48.04*	93.74**

*= Significant at P<0.05 (χ^2) = 46.19 , **Significant at P<0.01((χ^2)=53.49

4.3.4 Principal component for quantitative traits

Eigenvalues, percent of total variance, percent of total cumulative variance, and eigenvectors for 22 quantitative characters in 49 coffee accessions were given in Table 10. Principal component analysis was performed to assess the relative importance of each quantitative character for characterization of accessions and results were given in Table10. About 85.74% of the variation present among accessions was explained by ten principal components. The first principal component which accounted for 17.96% of the total variability among accessions were due to discriminatory traits like number of primary branches, plant height, canopy diameter, average length of primary branches, number of main stem nodes, and number of secondary branches. Quantitative characters such as fruit length, fruit width, hundred bean weight, fruit thickness, bean length, average length of primary branches, leaf length, leaf width, and leaf area contributed chiefly to the variation of principal component two (14.55%). The third principal component that explained 10.36% of the variability among genotypes was attributed to variation in bean length, bean width, fruit length and hundred-bean weight. The traits internode length of stem, leaf area, leaf width, leaf length, internode length of primary branches contributes variations in principal component four (9.41%). The characters explained 7.27% variation in principal component five were intern ode length of

primary branches, average length of primary branches, intern ode length of stem and bean length. Percentage of bearing primary branches, angle of primary branches, and yield contributed variations most to principal component six (6.73 %). Quantitative characters bean length, stem diameter, leaf length, leaf width and leaf area explained (5.09%) variation for principal component seven. Fruit width, fruit thickness, internodes length of primary branches, height up to first primary branches contributes (5%) variations in principal component eight. The variation (4.73%) explained in principal component nine was contributed by yield per tree, fruit width and internodes length of primary branches. Finally, for the variation (4.64%) explained in principal component ten contributed by characters angle of primary branches and height up to first primary branches. Amongst characters studied, bean length, hundred green coffee bean weight, leaf length and leaf width contributed to the variations in three principal components out of the ten principal components (Table 10). Thus, these characters were identified as the main source of variation among Limu coffee accessions. This finding is similar with the finding of Tikader *et al*. (1999).

The present study confirmed that Limu coffee accessions showed variations for the characters studied. This trait diversity evident among the Limu coffee accessions suggests presence of opportunities for genetic improvement through selection directly from the accessions and or selection of diverse parents for hybridization programs and conservations of the germplasm for future utilization. The existence of broad morphological and agronomic diversity among coffee accessions is in agreement with the previous work of Mesfin and Bayetta (2008) and Yigzaw (2005).

Table 10. Eigenvalues, total variance, cumulative variance, and eigenvectors for 22 quantitative characters

Trait	Eigen vector									
	PC1	PC2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10
BL	0.06	0.21	0.24	-0.06	0.31	0.08	0.22	0.08	-0.19	-0.17
BW	0.06	0.14	0.27	-0.13	0.12	-0.15	-0.04	-0.40	0.06	0.09
FL	0.06	0.23	0.34	0.05	0.20	0.07	0.17	0.06	-0.06	-0.03
FW	0.03	0.24	0.21	0.09	-0.30	-0.03	-0.02	0.27	0.17	0.10
FT	0.05	0.24	0.20	0.03	-0.31	0.01	-0.01	0.32	0.15	-0.15
HBW	0.07	0.25	0.33	-0.17	0.22	0.04	-0.03	-0.09	0.07	0.08
Yld	0.12	0.13	0.04	0.10	-0.06	0.27	-0.34	-0.10	0.23	-0.44
PLH	0.31	0.04	-0.08	0.11	-0.01	0.24	0.15	0.01	0.15	0.03
SD	0.26	0.05	-0.18	-0.10	0.09	-0.14	0.28	0.18	-0.05	-0.18
APB	0.06	0.01	0.01	0.02	-0.08	0.46	0.17	-0.13	-0.04	0.59
NNS	0.31	0.09	-0.16	-0.18	-0.08	0.09	0.15	-0.16	-0.04	0.03
CD	0.25	0.09	-0.19	0.14	0.17	-0.06	-0.08	0.14	-0.08	0.09
AILS	-0.16	-0.09	0.15	0.31	0.23	0.05	-0.02	0.02	0.17	-0.01
ALPB	0.18	0.17	-0.24	0.12	0.32	-0.07	-0.18	0.10	0.09	0.09
ILPB	-0.2	0.04	-0.08	0.28	0.32	0.09	-0.07	0.20	0.16	-0.04

Table 10. Continued

Characters	Eigen vector									
	PC1	PC2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10
NPB	0.34	0.09	-0.13	-0.16	-0.06	0.06	0.09	-0.07	0.08	0.05
NSB	0.23	0.07	-0.09	-0.19	0.02	-0.31	0.06	-0.02	-0.07	-0.25
PBPB	0.15	0.08	-0.04	0.01	-0.11	0.41	-0.21	-0.18	-0.14	-0.37
LL	0.01	0.21	-0.06	0.29	-0.17	0.01	0.27	-0.05	-0.13	-0.05
LW	0.01	0.20	-0.01	0.38	-0.07	-0.16	0.21	-0.16	-0.10	-0.05
LA	-0.02	0.21	-0.02	0.39	-0.14	-0.15	0.25	-0.19	-0.10	-0.06
HPB	0.09	-0.12	0.04	0.06	0.04	0.35	-0.03	0.41	-0.44	0.01
Eigenvalues	3.95	3.20	2.28	2.07	1.60	1.48	1.12	1.10	1.04	1.02
%of total variance	17.96	14.55	10.36	9.41	7.27	6.73	5.09	5.00	4.73	4.64
%of cumulative Variance	17.96	32.51	42.87	52.28	59.55	66.28	71.37	76.37	81.1	85.74

BL = bean length, BW = bean width, FL = fruit length, FW = fruit width,
FT = fruit thickness,HBW = hundred bean weight,
Yld = yield, PLH = plant height, SD = stem diameter,APB = angle of primary branch,
NSN = number of main stem nodes, CD = canopy diameter,
AILS = average internodes length of main stem,
AILPB = average internode length of primary branch,
ALPB = average length of primary branch, NPB = number of primary branches,
NSB = number of secondary branches,
PBPB = percentage of bearing primary branches, LL = leaf length, LW = leaf width,
LA = leaf area,
HPB = height up to first primary branches

4.4. Shannon-Weaver diversity index

Shannon-Weaver diversity indices (H`) were calculated to compare phenotypic diversity among qualitative characters for each collection site as indicated in Table 11. Higher value of H' indicates the existence of more descriptors states of equally common frequency class for individual trait and express diversity for that trait. Individual traits had different pattern of distribution and revealed different level of diversity in different selection site. Traits such as growth habit, leaf shape, stipule shape and fruit shape showed high level of diversity for all selection sites except low diversity of growth habit for sombo accessions, stipule shape for sombo, leaf shape for gindacha, and fruit shape for ajamo selection site. On the other hand, qualitative traits such as Branching habit, angle of insertion of primary branches and leaf apex shape, angle of primary branches, leaf apex shape, young leaf tip color, stem habit, and seed shape exhibited low to intermediate. In no cases, monomorphic classes were observed. Generally, the result revealed the existence of diversity in the collection sites of coffee accessions, indicating the presence of variability for these traits among evaluated coffee accessions. The present study is in agreement with the result reported by Yigzaw (2005) in arabica coffee.

Table 11.Estimates of diversity index and chi square values for ten qualitative traits

Collection site	GH	BH	SS	AOI
Miaa	0.92(7.44*)	0.48(0.06)	0.98(7.19*)	0.66(0.67)
Cheraki	0.74(8.60)	0.18(().07)	0.88(5.07*)	0.24(0.22)
Babo	0.83(9.60)	0.18(().09)	0.78(8.71*)	0.24(0.24)
Kossa	0.94(8.64*)	0.60((7.12*)	0.70(5.9*)	0.78 (0.78)
Tenebo	0.76(7.20)	0.24(0.05)	0.84(5.95*)	0.36(0.33)
Buya	0.86(6.18*)	0.42(0.13)	0.72(6.63*)	0.54(0.56)
Ajamo	0.74(7.60*)	0.18(0.14)	0.78(6.85*)	0.24((0.23)
Genji	0.72(7.44*)	0.48(0.17)	0.88(5.94*)	0.66(0.68)
Bidaru	0.94(10.6*)	0.18(().16)	0.98((9.73*)	0.24(0.24)
Gindacha	0.24(2.46)	0.18(().14)	0.78(6.67*)	0.24(0.25)
Alge	0.93(7.20*)	0.24(0.17)	0.94((6.47*)	0.36(0.33)
Kelecha	0.88(9.20*)	0.36(0.12)	0.86(7.61*)	0.42(0.45)
Sombo	0.36(3.72)	0.24(0.15)	0.24((3.45)	0.36(0.33)

Table 11.continued

	YLTC	LS	LAS	FSH	STHT	SSH
Miaa	0.36(0.33)	0.66(5.80*)	0.66(0.58)	0.66(6.3*)	0.54(0.47)	0.24(0.25)
Cheraki	0.12(0.11)	0.78(6.92*)	0.18(0.19)	0.64(5.19*)	0.18(0.16)	0.12(0.08)
Babo	0.12(0.12)	0.75(7.80*)	0.18(0.18)	0.62(6.21*)	0.18(0.17)	0.12(0.09)
Kossa	0.36(0.39)	0.88(6.80*)	0.03(0.68)	0.72(7.45*)	0.66(0.55)	0.30(0.29)
Tenebo	0.18(0.17)	0.70(9.80*)	0.30(0.29)	0.60(5.27*)	0.24(0.25)	0.12(0.23)
Buya	0.30(0.28)	0.87(6.83*)	0.48(0.48)	0.54(5.36*)	0.42(0.39)	0.24(0.21)
Ajamo	0.12(0.11)	0.78(5.98*)	0.18(0.19)	0.24(0.22)	0.18(0.16)	0.12(0.08)
Genji	0.36(0.33)	0.66(5.87*)	0.66(5.9*)	0.66(6.39*)	0.54(0.47)	0.24(0.25)
Bidaru	0.12(0.11)	0.78(7.92*)	0.18(0.19)	0.74(6.18*)	0.18(0.16)	0.12(0.08)
Gindacha	0.12(0.11)	0.18(0.18)	0.18(0.18)	0.64(7.15*)	0.18(0.16)	0.12(0.08)
Alge	0.18(0.17)	0.70(7.93*)	0.30((0.29)	0.73(7.31*)	0.24(0.25)	0.12(0.23)
Kelecha	0.24(0.22)	0.76(7.96*)	0.36((0.39)	0.84(6.78*)	0.30(0.31)	0.18(0.17)
Sombo	0.18(0.17)	0.73(6.95*)	0.30(0.39)	0.75(7.27*)	0.24(0.25)	0.12(0.23)

*, ** represents significant at P< 0.5 and P <0.01 probability level respectively.
The value in the bracket indicated chi- square (χ^2) .
GH= growth habit, BH= branching habit, SS= stipule shape, AOI= angle of insertion,

YLTC= young leaf tip colour, LS= Leaf shape, LAS= leaf apex shape, FSH= fruit shape

STHT= stem habit, SSH= seed shape

4.5 .Organoleptic Quality

The analyses of variance revealed the presence of significant ($p \leq 0.05$) differences among coffee accessions for organoleptic quality except aromatic intensity, astringency, body, and bitterness (Table 12). These significant variations among coffee accessions for the traits studied indicated the existence of variability to have an effective selection. Similarly, different studies indicated the existence of high genetic diversity of arabica coffee for quality specifically in major coffee growing areas (Brownbrige and Eyasu, 1968; IAR, 1969-1996; Yigzaw, 2005; Yonas, 2005; and Getu, 2009) of Ethiopia and Kenya (Walyaro, 1983). The mean performance of accessions for 22 quantitative characters compared for parameter that showed significant differences. The accessions mean performance for trait considered differentiated by list significant difference value at (5%) (Appendix Table 6).

Table4. Mean squares of genotypes for organoleptic quality traits

	Mean square	
Trait	Genotype	*Error*
Aromatic intensity,	0.0560 ^{ns}	*0.0465*
aromatic quality	0.1468**	*0.0617*
acidity	0.2477**	*0.0950*
astringency,	0.0446 ^{ns}	*0.0955*
Bitterness	0.0508 ^{ns}	*0.0661*
body	0.0462 ^{ns}	*0.0427*
flavor	0.1873*	*0.1137*
over all standard	0.2084**	*0.1028*

**, Significant at= 0.05 probability level, **Significant at= 0.01 probability level, ns = Non-significant*

4.5.1 Variance components

Genetic variance of quality attributes was observed less as compared to environmental variance except aromatic quality (Table 13). Bitterness, astringency and body variation was mainly influenced by environment. The estimate of the broad sense heritability is presented in Table 14. According to Verma and Agarawal (1982), heritability values greater than 50% are considered as high, whereas values less than 20%are to be low and values between 20% and 50% as medium. Accordingly, higher estimates of broad sense heritability (%) were observed for aromatic quality (64.74%) and medium broad sense heritability values were recorded for Acidity (43.64%), over all standards (40.77%), and Flavor (39.70%). However, aromatic intensity (12.11%), astringency (0.00%) bitterness (0.00%) and body (0.00%) were grouped under low heritability range. Variations of genotypes for bitterness, astringency and body were due to environmental factors and thus broad sense heritability was estimated to be small. Thus, the study revealed that, bitterness, astringency and body are appropriate parameters to control variation due to roasting problem during liquoring. Therefore, these attributes are less important to evaluate organoleptic performance of genotypes.

Phenotypic coefficients of variation values ranging from 10.56% to 37.50% and genotypic coefficient of variation values ranging from 0.00 to 9.51% were obtained in this study (Table13). Organoleptic cup quality attributes were influenced by both environment and genotype. Genotypes respond differently for quality attributes and their magnitude is measured by Phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) values greater than 20% are regarded as high, whereas values less than 10% are to be low and values between 10% and 20% to be medium(Deshmukh *et al.,*1986).

High phenotypic coefficient of variation (PCV) was recorded for astringency and Bitterness. Medium phenotypic coefficient of variation was obtained for aromatic quality, acidity, flavor, and over all standard. Low values of phenotypic coefficients of variation also recorded for aromatic intensity and body. All quality attributes categorized under low GCV range.

Environmental variation had large effect on the expressions of astringency, bitterness and body where difference between genotypic coefficients of variation (GCV) and phenotypic coefficients of variation (PCV) was relatively large. Thus, selection on phenotypic basis of these attributes may not be effective for the genetic improvement .However, relatively, small difference was obtained for other attributes indicating both environmental and genetic variation contributed towards expressions of the traits and selections on phenotypic basis for this trait may improves the population for coffee quality.

High heritability, genotypic coefficient of variation coupled with high genetic advance as percent of mean for aromatic quality attribute implies the potential for the coffee genotype improvement through selection. Phenotypic coefficient of variability, were although greater for quality attributes aromatic intensity, aromatic quality, acidity, flavor and over all standard than respected genotypic ones but a narrow gap was found indicating little influence of environment in the expression of quality trait. The present study is in agreement with the work reported by Getu (2009).

Table 13. Variability parameters for organoleptic quality trait in coffee accessions

Trait	$\sigma^2 g$	$\sigma^2 P$	H^2	PCV%	GCV%	GA	GA%
AI	0.01	0.11	12.11	9.09	3.28	0.06	1.90
AQ	0.09	0.15	64.74	11.95	9.51	0.49	14.90
AC	0.06	0.15	43.64	11.92	7.81	0.33	10.20
AS	0.00	0.07	0.00	110.24	0.00	0.00	0.00
BI	0.00	0.06	0.00	37.50	0.00	0.00	0.00
BO	0.00	0.07	0.00	8.370	0.00	0.00	0.00
FL	0.05	0.12	39.70	10.560	6.79	0.25	7.80
OVS	0.06	0.16	40.77	12.48	7.86	0.33	10.30

4.5.2 Phenotypic and genotypic association

4.5.2.1 Phenotypic association

The results of phenotypic Correlation for organoleptic traits are given in Table 14. In this study, significant positive phenotypic association was observed among aromatic quality, aromatic intensity, over all standard, body, acidity, and flavor. Yigzaw (2005) indicated positive association among good cup quality attributes. Agwanda (1999) identified flavor as an all round organoleptic attribute to be considered during selection to develop superior coffee genotypes. Attributes, which correlated strongly and positively with flavor, were considered as good cup quality attributes. Flavor revealed negative association with bitterness. Therefore, aromatic quality, aromatic intensity, acidity, body and over all standard were described as good cup quality attributes, whereas bitterness were considered as poor cup quality attributes. Body was positively and significantly associated with good cup quality attributes such as aromatic intensity, aromatic quality,

flavor and over all standards. Expression of characters of crop plants is correlated due to genotypic and/or environmental factors. Direct observable phenotypic association of characters resulted from genotypic and/ or environmental correlations (Falconer and Mackay, 1996). Therefore, these organoleptic quality attributes contributed to good final cup quality. Thus, considering good cup quality attributes like flavor (Agwanda, 1999 and Yigzaw, 2005) during selections would improve future target population for quality.

4.5.2.2 Genotypic association

The results of genotypic association for organoleptic quality attributes were given in Table14. In this study, positive and significant genotypic association was observed among aromatic intensity, aromatic quality, acidity, astringency, bitterness, body, flavor, and overall standard. Yigzaw (2005), Getu *et al.* (2009) and Kathurima, (2009) indicated positive association among good cup quality attributes. Similarly, Agwanda (1999) indicated that flavor has got strong genetic association with preference and therefore it is the best selection criteria for the genetic improvement of arabica coffee liquor quality. Moreover, flavor used for discriminating among varieties because it was found as an all round beverage quality attribute which in corporate other aromatic attributes and well associated with good cup quality attributes like acidity and body

Table 14. Senso phenotypic (above diagonal) and genotypic (below diagonal) Correlation

trait	AI	AQ	AC	AS	BI	BO	OVS	FL
AI	1	0.54**	0.28*	0.05	-0.11	0.36**	0.40**	0.33*
AQ	0.97**	1	0.33*	0.24	-0.05	0.38**	0.66**	0.61**
AC	0.99**	0.58**	1	0.09	-0.51**	0.11	0.52**	0.49**
AS	0.98**	0.91**	0.99**	1	0.12	0.18	0.22	0.19
BI	0.94**	0.99**	0.91**	0.91**	1	0.07	-0.09	-0.17
BO	0.97**	0.90**	0.97**	0.93**	0.99**	1	0.43**	0.39**
OVS	0.92**	0.92*	0.68**	0.96**	0.93**	0.95**	1	0.91**
FL	0.90**	0.93*	0.90**	0.99**	0.98**	0.99**	0.87**	1

*, **, significant at P< 0.05, 0.24 and P<0.01, 0.34 respectively. AI =Aromatic intensity, AI=aromatic intensity, AQ=aromatic quality, AC= acidity, AS= astringency, BI=bitterness, BO= body, FL= flavor, OVS = over all standard

4.6 Cluster Analysis

4.6.1 Cluster composition

Cluster distributions of 49 coffee genotypes using organoleptic quality traits is given in Table 15. The number of accessions classified in each cluster was 31, 17, and 1, in cluster I, II, and II, respectively. Cluster I composed of 31 accessions (63.27%), Cluster II 17 accessions (34.69%) and Cluster III 1(2.04%) indicating how closely related different genotypes were grouped together (Table15 and Fig 2). The first group comprised 31 coffee accessions that were characterized by low organoleptic quality. The second cluster comprised 17 that were characterized by medium in organoleptic quality and the third remaining cluster comprised of 1 coffee accession, which was relatively superior in organoleptic quality. The present study was in agreement with previous findings that reported by Dessalegn *et al.* (2008) and on forty-two Ethiopian collections of arabica coffee genotypes.

Table15. Cluster distributions of 49 coffee genotypes using organoleptic quality traits

ClusterI		Cluster II	Cluster III
744*	L-27/2003	L-05/2003	L-12/2003
F-59*	L-29/2003	L-06/2003	
L-01/2003	L-32/2003	L-09/2003	
L-02/2003	L-33/2003	L-16/2003	
L-03/2003	L-35/2003	L-17/2003	
L-04/2003	L-38/2003	L-20/2003	
L-07/2003	L-39/2003	L-23/2003	
L-08/2003	L-40/2003	L-24/2003	
L-10/2003	L-43/2003	L-28/2003	
L-11/2003	L-44/2003	L-30/2003	
L-13/2003	L-45/2003	L-34/2003	
L-14/2003	L-46/2003	L-36/2003	
L-15/2003	L-47/2003	L-37/2003	
L-22/2003	L-49/2003	L-41/2003	
L-25/2003	L-51/2003	L-42/2003	
L-26/2003		L-48/2003	
		L-50/2003	
31 (% 63.27)		17(% 34.69)	1 (2.04%)

*, Represent check variety used

4.6.2 Cluster mean characterization of organoleptic quality attributes

Mean organoleptic quality attributes of clusters for 8 organoleptic quality attributes in 49 coffee accessions was given in Table 16. Cluster III and cluster I was found relatively different because distant and divergent groups constituted these clusters and thereby characterized by extreme values of organoleptic quality attributes. High mean values of aromatic intensity, aromatic quality, acidity, body and flavor and overalls standard characterized cluster III while the lowest mean values of these attributes characterized in turn cluster I. Mean of clusters therefore, indicated the presence of two quite different groups (I and III) consisted of contrasting sensorial quality attributes. Cluster II was average for good cup quality attributes except astringency. Coffee genotypes (improved) (744, F-59) were used as check to identify Limu coffee accession that perform similar to the check and the checks were grouped in cluster I, indicating more than half percent of limu coffee accessions had similar quality attributes with the standard checks. The present finding is in agreement with previous findings of Yigzaw (2005) and Dessalegn *et al.* (2008).

Table 16.Mean organoleptic quality attributes

cluster	AI	AQ	AC	AS	BI	BO	FL	OVS
I	3.28*	3.22*	3.00*	0.29**	0.25**	3.18*	2.99**	3.03*
II	3.39	3.42	3.53	0.23	0.08	3.33	3.39	3.42
III	3.71**	4.38**	4.29**	0.25	0.00*	3.46**	4.33**	4.58**

*, **, represented the lowest and highest mean values respectively. AI=aromatic intensity, AQ=aromatic quality, AC= acidity, AS= astringency, BI=bitterness, BO= body, FL= flavor, OVS = over all standard

4.6.3 Distances between clusters

Squared mahalanobis distance between clusters for organoleptic quality attributes indicated that most of the clusters were significantly distant from each other at P <0.01 (Table 17). Significant distance analysis and association of genotypes to specific cluster group indicated the presence of genetically distant materials and the association of genotypes with specific cluster group of distinct characteristics. Cluster I showed the maximum and significant genetic distance (38.82) from Cluster I. Indicated that cluster III had maximum genetic distance (38.82 %) From cluster I. Cluster III the inter cluster distances between clusters, II and III, I and III in that order were found to be significant. This confirms that the presence of genetically diverse materials for the characters considered Dessalegn *et al*. (2008).

Table 17. Mahalanobis distance (D2) of the three clusters for organoleptic quality trait

	I	II
II	4.66ns	
III	38.82**	23.21**

* D^2 significant at p = 0.05(χ^2) = 14.07 , ** D^2 =Significant at p=0.01 (χ^2) =18.48

4.6.4 Principal component

Three principal components (PC) PC1, PC2 and PC3 with eigen values of 4.23, 1.42, and 1.01 respectively, explained 81.37% of the total variance (Table 18). The first two principal components PC1 and PC2, with percent variability of 52.87 % and 17.77%, respectively, explained 70.64 % of the total variance. All organoleptic quality attributes had contribution to genotype classification. However, some of the characters had relative values closer to unity in the first principal component (PC1) and thus contributed more to the classification (Chahal and Gosal, 2002). Aromatic quality, acidity, flavor and over all standard had higher score as compared to others and contributed the highest variability in PC1. Therefore, these quality attributes were the cases of diversity among genotypes

Table 18. Eigenvalues, total variance, cumulative variance, and eigenvector for 8 quality traits

Trait	Eigen vector		
	I	II	III
AI	0.29	0.38	-0.39
AQ	0.41	0.20	-0.33
AC	0.43	-0.23	-0.02
AS	-0.08	0.65	-0.13
BI	-0.26	0.52	0.11
BO	0.24	0.28	0.83
FL	0.46	0.01	0.07
OVS	0.47	0.04	0.11
Eigen value	4.23	1.42	1.01
% of total variance	52.87	17.77	10.73
%of cumulative variance	52.87	70.64	81.37

AI=aromatic intensity, AQ=aromatic quality, AC= acidity, AS= astringency, BI=bitterness, BO= body, FL= flavor, OVS = over all standards

5. SUMMARRY AND CONCLUSIONS

Ethiopia is endowed with immense potential of diverse coffee materials and contrasting ecological condition for coffee cultivation. Arabica coffee (*Coffea arabica* L.) is an economically important crop, which is contributing the highest of all export revenues in Ethiopia. However, the productivity of coffee per unit area remains very low as compared to world average. One among the major factors contributing to low yield includes lack of adaptable cultivars for each ecological zone of the different regions for each of the very diverse environment. An extraction of information about individual accessions is highly essential for efficient utilization of the genetic potential existing within germplasm accessions

A field experiment was laid out using 49 Limu coffee accessions for characterizing them based on quantitative, qualitative and organoleptic characters and determine the extent of genetic diversity. Data were collected on 22 quantitative, 10 qualitative and 8 organoleptic traits. Both univariate and multivariate analysis of variance showed that there were significant differences among accessions for most of characters measured indicating the existence of variability and possibility for improvement coffee arabica accessions. The results of the analysis of range revealed a wide range of variation in traits like stem diameter (3.56 -6.75cm), number of secondary branch (91.50-545.50), height up to first primary branches (21.66-42.16cm), and yield per tree (0.13-1.43kg) indicating that their greatest role to the total variability observed among the coffee accessions. Moreover, the differences between the minimum and maximum mean values for other characters were also high indicating the availability of variation for improvement through selection.

Heritability in broad sense was estimated for the 22 quantitative characters studied on 49 coffee germplasm accessions. High heritability values were obtained for bean length (76.29%), bean width (65.08), fruit length (64.57%), fruit width (64.57%), plant height (63.57%), number of secondary branches (68.08) and height up to first primary branches (60.06%), number of primary branches, average internode length of primary branches,

number of stem nodes, hundred bean weight and leaf width. For the rest of the characters medium and low heritability values were obtained. In view of this, it can be concluded that the above mentioned characters could be of potential importance to genetic diversity analysis and utilizations in Limu coffee germplasm since they also manifested high genotypic correlation.

The phenotypic and genotypic correlation analysis for the 22 quantitative traits showed positive and significant association among the characters both at phenotypic and genotypic level but the frequency of positive and significant phenotypic correlation was less compared to genotypic correlation. Among the characters plant height, stem diameter, canopy diameter, hundred green coffee bean weights and number of main stem nodes per plant in particular showed positive and significant correlations with majority of the characters both at phenotypic and genotypic levels. Strong positive association was found among good quality attributes both at phenotypic and genotypic levels. Characterizations of germplasm accessions based on the quantitative and organoleptic quality traits using the average linkage method of hierarchical cluster analysis of observations resulted in grouping of the germplasm accessions into four and three clusters at 75 percent of similarity level, respectively, while the standard checks fell into different clusters for quantitative traits whereas in one cluster for organoleptic quality traits.

The maximum inter-cluster distance (93.74) was obtained between clusters III and IV, while the minimum (10.12) was observed between clusters I and III. The significant inter- cluster distances between clusters I and IV, II and IV, III and IV indicated that there is a high opportunity for obtaining transgressive segregates and maximize hetrosis by crossing germplasm accessions belonging to these clusters. Therefore, the grouping of accessions by multivariate methods as carried out in the present study could be of considerable practical value to the coffee breeders so that representative accessions could be chosen from such clusters for hybridization programs. Results of the generalized squared distance analysis discovered that among the 49 coffee accessions, to the extent

that genotypes were heterogeneous with respect to quality attributes such as aromatic intensity, aromatic quality, flavor, bitterness, body, acidity and overall standard.

Principal component analysis for the 22 quantitative characters showed that the principal components that had eigenvalues greater than unity explained 85.74 % of the total variation prevalent among 49 coffee accessions. The first and the second principal components accounted for17.96% and 14.55 % of the total variation, respectively. When individual traits are considered, number of primary branch, plant height, canopy diameter, average length of primary branch, number of main stem nodes, number of secondary branches, stem diameter, percentage of bearing primary branches, fruit length, fruit width, hundred bean weight, fruit thickness ,bean length, average length of primary branch, leaf length, leaf width, and leaf area were the most important ones contributing to 32.51% of the total variation represented by the first and second principal components. In view of this, the above mentioned characters could prove useful for Limu coffee improvement program.

In principal component analysis of forty nine arabica coffee accessions for 8 organoleptic quality attributes measured, the first three principal components with eigen values greater than one explained 81.4% of the total variation. The first two principal components accounted with percent variability of 52.87% and 17.77%, respectively explained 70.64% of the total variability among the coffee accessions.

Shannon diversity for qualitative traits revealed the existence of heterogeneity for most of individual trait and express diversity for that trait. In no cases, monomorphic classes were observed. Traits such as growth habit, leaf shape, stipule shape and fruit shape showed high level of diversity for all collection sites except low diversity of both growth habit and stipule shape for sombo accessions, leaf shape for gindacha, and fruit shape for ajamo collection site.

It must be known that Limu coffee is of a restricted environmental importance. In view of this, the germplasm accessions considered in the present study represented collections from Limu and these were some of accession only. It is, however, necessary that the expression of different characters need to be studied with additional accessions and characterization results need to be confirmed. In such an effort, consideration of yield and pest/disease reactions must receive due attention.

6. REFERENCES

A vice, J.C. and J.L. Hamric. 1997. Conservation genetics: Case histories from nature. Chapman and Hall cop., New York.

Agwanda C.O., P.C Baradat, C. Cilas, and A. Charier. 1999. Prediction of yield stability in Arabica coffee based on the stability of morphological components. In: 18th international coffee science conference, ASIC, Helsinki (CD-ROM).

Agwanda, C.O., P.., Baradat, A.B. Eskes, C cilas and A. charier. 2003. Selection for bean and liquor qualities within related hybrids of Arabica coffee in multi-local field trials Euphytica, **131**: 1-14

Alemayehu, T. Esayas, K. and Kassu, K. 2008. Coffee development and marketing improvement plan in Ethiopia. In: Proceedings of a national workshop four decades of coffee research and development in Ethiopia 14-17 August 2007, EIAR. Addis Ababa, Ethiopia Pp. 375-390

Allard, R.W. 1999. Principles of Plant Breeding, 2n d ed. John Wiley and Sons Inc., New York. pp. 254.

Anonymous 2003. Coffee. An environmental education program of the Prague program post endowment fund. Stone circles**,. 4,** issue no.7

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

Bayetta, B. 1991 Hetrosis and combing ability study in arabica coffee. MSc. Thesis, Alemaya University of agriculture: Alemaya, Ethiopia.

Bayetta, B. 2001. Arabica coffee breeding for yield and resistance to coffee berry disease (Colletotrichum kahawae sp. nov.) PhD Dissertation, University of London, Imperial College Wye, UK.

Bayetta, B. and Labouisse Jean-Pierre. 2006. Arabica coffee (C. arabica L.) local land races development strategy in its center of origin and diversity. In: Proceedings of the 21th International Scientific Colloquium on Coffee, Paris, France.

Bayetta, B. Behailu, A. and Fiqadu, T.. 2000. Breeding for resistance to Coffee Berry Disease in arabica coffee: Progress since 1973. In: Proceedings of the workshop on control of Coffee Berry Disease in Ethiopia, 13-15 August 1999, EARO, Addis Ababa, Ethiopia. Pp.85-98.

Beer, S.C., J. Goffreda, T.D. Phillips, J.P. Murphy and M.E. Sorrells. 1993. Assessment of Genetic Variation in Arena sterilis using Morphological Traits, isozymes, and RFLPs. Crop Science,**33:** 1386-1393

Belitz, H.D, Grosch, W. and Schieberle, P. 2004. Food chemistry. Springer, Gemany.

Berthaud, F.R and J. Pernes. 1979. Variability observed for quantitative variables of coffee. Pl. Breed. Abs.**42**: 668

Berthaud, J and Charrier, AF. 1988. Genetic resources of Coffea. In: Clarke, RJ and Macrae, R (eds.) Coffee**, 4**, Agronomy, pp.1–42.Elsevier Applied Science, Chichester.

Beuselinck, P.R. & J.J. Steiner, 1992. A proposed framework for identifying, quantifying, and utilising plant germplasm resource. Field Crops Res**. 29**: 261–272.

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

Bridson, D., 1987. Nomenclatural notes on Psilanthus, including Coffea sect. Paracoffea (Rubiaceae tribe Coffea). Kew Bull., **42**: 453-460.

Brown bridge, J.M., and Eyasu Gebregzabher, 1968.The quality of some of the main Ethiopian mild coffees. Turrialba, **18**:361-372

Carvalho, A. 1988. Principles and practice of coffee plant breeding for productivity and quality factors: Coffea arabica. In: Clarke, R.J. and Macrae, R (eds.), Coffee,. **4**, Agronomy, pp.129-160. Elsevier Applied Science, London.

Catter, R.1992. Study and structure of the phenotypic variation of coffea arabica from Ethiopia. TROPAG Data Base. pp.51.

Chahal, G.S. and S.S. Gosal. 2002. Principles and procedures of plant breeding: Biotechnology and conventional approaches. Narosa publishing House, New Delhi. 604p.

Chaparro, A.P., M.A. Cristancho, H.A. Cortina and A.L. Gaitan, 2004. Genetic variability of Coffea arabica L. accessions from Ethiopia evaluated with RAPDs. Genet. Resour. Crop Evol., **51**: 291-297.

Chatfield, C. and A.J. Collins. 1991. Introduction to Multivariate Analysis. 5th ed. Chapman and Hall, UK. P.246

Clewer, A.G and Scaris brick, D.H. 2001. Practical statistics and experimental design for plant and crop science . John Wiley and Sons, Ltd, Chichester, PP. 332.

Copper, M.C. and Milligan, G.W. 1988. The effect of error on determining the number of clusters. In: Proceeding of international workshop on data analysis, decision support and expert knowledge representation in marketing and related areas of research, pp.319-328.

Cristancho M.A., 2004. Genetic variability of coffea Arabica L. accessions from Ethiopia evaluated with RAPDs. In: 20th international coffee science conference, ASIC, Bangalore, India (CD-ROM).

Crossa, J., Delacy, I. H. and Taba, S. 1995. The use of multivariate methods in developing a core collection. In: Hodgkin, J., Brown, A .H. D., Van Hintum, Th.J.L. and Morales, E .A. V (eds.) Core Collections of Plant Genetic Resources, pp.77-92. John Wiley & Sons, Chichester.

CTA. 1999. Uniqueness of Ethiopian coffee. P28-30. In: Ethiopia the cradle of the wonder bean Coffea arabica (abissinica). Coffee and Tea Authority (CTA), Addis ababa.
Dancer, J. 1964. The measurement of growth in coffee. The relationship between components of shoots and stem diameter at the base of the shoot. East Africa Journal of Agricultural Science **33**:21-25.

Davids, K., 2001. Coffee: A Guide to Buying, Brewing, and Enjoying, 5th Edition New York: st. Martin's Griffin.

Decazy F., J.Avelino, B. Guyout, J.J. perritot, C. pineda, and C.Cilas. 2003. Quality of different Honduran coffee in relation to several environments. Journal of food science, **68**:7

Deshmukh, S.Ns.N., M.S. Basu and P.S. Reddy. 1986. Genetic variability, character association and path coefficient analysis of quantitative traits in viginia Bunch varities of ground nut. Indian journal of Agricultural Science **56:** 515-518

Dessalegn Y, Labuschagne MT, Osthoff G, Herselman L (2008). Genetic diversity and correlation of bean caffeine content with cup quality and green bean physical characteristics in coffee (Coffea arabica L.) Society of Chemical Chemistry. J. Sci. Food Agric **88**:1726-1730.

Ernesto. 2001. The factors of quality in green coffee beans. In: The first Asian regional round table on sustainable, organic and specialty coffee production processing and marketing FAO. Ed: Keith Chapman suranat subhadrabandhu. Chiang Mai, thailan Available at http://www.fao.org/docrep.

Eli as, A. 2005. Economics of Coffee Bean Marketing: A Case Study of Gomma District in Jimma Zone of Ethiopia

Esayas, A. 2005. Molecular genetic diversity study of forest coffee tree (Coffea arabica L.) populations in Ethiopia: implications for conservation and breeding, PhD thesis, Swedish University of Agricultural Sciences. pp.79.

Falconer D.S. and Mackay F.C., 1996. Introduction to Quantitative Genetics. Long man, New Delhi

FAO. 1968a. FAO coffee mission to Ethiopian 1964 –1965. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO/WFP. 2008. Special Report FAO/WFP Crop and Food Supply Assessment Mission to Ethiopia 24 January 2008.

Feyera, S. 2006. Biodiversity and ecology of Afromantane Rain forests with Coffea arabica L. Populations in Ethiopian. PhD thesis, Ecology and Development series No 36, CurillierVerlage Cottingen. pp.144.

Fiqadu, T. Melaku, A.Bayetta, B.Behilu,A.Tadesse, B. and Ashenafi, A.(2008). Developing improved pureline coffee varieties for different coffee growing areas of Ethiopia In:girma A, Bayetta B.,TesfayeS., EndaleT.,and Taye, K., (eds).Coffee Diversity and Knowledge . P67.procedings of a national work shop .Four Decades of Coffee Research and Development in Ethiopia 14-17August 2007. EIAR.Addis Ababa, Ethiopia.

G. B, J. Burkhardt, Taye. K., Tadesse. Gole, Abebe, Y., 2009. Variability and association of Sensorial and physical quality attributes of forest arabica coffee (Coffea Arabica L.) Collections at Jima

Getu, B. 2009. Genotype x Environment interaction of arabica coffee (Coffea arabica.) For bean biochemical composition and organoleptic quality characteristics. MSc. Thesis, Alemaya University of Agriculture: Alemaya, Ethiopia. pp 115

Gichimu, B.M. and C.O. Omondi, 2010. Morphological characterization of five newly developed lines of arabica coffee as compared to commercial cultivars in Kenya. Int. J. Plant Breed. Genet. **4:** 238-246

Girma, A. and Hindorf, H. 2001. Recent investigation on coffee Tracheomycosis, Gibberella xylarioides (Fusarium xylarioides) in Ethiopia. 19th International Conference on Coffee Science, May 14th-18th, 2001, Trieste, Italy.

Gomez, K.A. and A.A. Gomez. 1984. Statistical procedures for agricultural Research (2nd).

Hedrick, P.W. 2000.Genetics of populations. 2nd ed. Johns and Bartlett Pub. New York.

Hue, T.T.M., 2005. Genetic variation in cultivated coffee (Coffea arabica L.) accessions in Northern New South Wales, Australia. Masters Thesis, Southern Cross University, pp: 13-14.

Institute of Agricultural (IAR). 1969-96. Coffee Department Progress Report for the period 1967to 1996.IAR, Addis Ababa.

IPGRI. 1996. Description for coffee (Coffea sp. and Psilanthus sp.). International Plant Genetic Resource Institute, Rome, Italy.

ISO (International standard organization). 1992. Sensory analysis Vocavolary.ISo 5492:1992(E/F

ITC (International Trade Center). 2002. Coffee. An exporter's guide. Switzerland.

Jain, A.K. & Dubes, R. (1988). Algorithms for clustering data. New Jersey

Jain, S. 19 75. Population structure and the effects of breeding system. In. Crop Genetic Resources, Conservation and Evaluation. George Allen and Unwin, London. Pp.15-36

Javier, O.F and Marin, H.N. 1972. The characterization of selections of Ethiopian coffee by means of biometrical measurements. Cenicafe 23:29-60.

Johnson, H.W., Robinson, H.F. and Comstock, R.E. 1955. Estimation of genetic and environmental variability in soybeans. Agronomy Journal **47**:314-318

Johnson, R.A. & D.W. Wichern, 1988. Applied Multivariate Statistical Analysis, 2nd ed. Prentice Hall, New York. pp.607.

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 CuvillierVerlag, Göttingen. pp.147.168.

Kathurima, C.W., Kenji, G.M., Muhoho, S.M and Boulanger, R. 2009. Evaluation of beverage quality and green bean physical characteristics of selected Arabica coffee genotypes in Kenya as a contribution to conservation and use planning, Development Series No. 46 CuvillierVerlag, Göttingen. pp.157.169.

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

Lashermes P., J. Cros, P. Marmey and A. Charrier, 1993. Use of random amplified DNA markers to analyse genetic variability and relationships of Coffea species. Genetic Resources and Crop Evolution. **40**: 91-99.

Leory T., F. Ribeyre, B. Bertrand, p. charmetant, M. Dufour., c.montagnon, p Marraccini and D. pot. 2006. Genetics of coffee quality. Brazilian journal of plant physiology, **18**(1) 229-242

Leroy, T., C. Montagnon, A. Charrier, and A.B. Eskes. 1993. Reciprocal recurrent selection applied to Coffea canephora Pierre. I. Characterization and evaluation of breeding populations and value of inter group hybrids. Euphytica**.67**:113-125.

Mahalanobis, P.C. 1936. On the generalized distance in statistics. Pro. Nat. Inst. Sci. India **2**:49-55.

Mekuria T., D. Neuhoff, and U. Kopke. 2004. The status of coffee production and the potential for organic conversion in Ethiopia. Conference on international Agricultural Research for

Melaku, W. 1982. Coffee genetic resources in Ethiopia, conservation and utilization with particular reference to CBD resistance. In: Proceedings of the 1st Regional Workshop of Coffee Diseases. Addis Ababa, 19 – 23, July, Ethiopia. pp. 203 – 211

Melaku, W. 1988. Diversity and the genetic resource base. Ethiopian Journal of Agricultural Science 10:39-52

Mesfin A. and Bayetta, B. 1984. Resistance of the F1 to coffee berry disease in six parent diallel crosses in coffee. In: Proceedings of the first regional workshop on Coffee Berry Disease. Association for the advancement of agricultural sciences in Africa, Addis Ababa. Pp.167-177.

Mesfin Kebede and Bayetta Bellachew. 2005. Genetic divergence of Hararge coffee (Coffee Arabica L) Germplasm Accessions at pre- Bearing stage. 20th In. Sci. colloq. On coffee. ASIC, Bangalore, India.

Mesfin Kebede, Bayetta Bella chew and Seyoum Seifu. 2007. Diversity in the south Ethiopian coffee. 21st Int. Sci. colloq. On coffee. ASIC, Montpellier, France.

Mesfin, A. 1982. Heterosis in crosses of indigenous coffee (Coffea arabica L.) selected for yield and resistance to coffee berry disease. I. At first bearing stage. Ethiopian Journal of Agricultural Science **4:** 33-43.

Mesfin, A. 1986. The significance of Ethiopian coffee genetic resources to coffee improvement. In: Proceedings of an international symposium on the conservation and utilization of Ethiopian germplasm, 13-16 October, 1986, Addis Ababa, Ethiopia. Pp.247-253.

Mesfin, A. and Bayetta, B. 1987. Field evaluations of resistance to stress conditions in cross and parents of coffea arabica L. In: African coffee, Inter-African Coffee Organization/Bull. No. 14**, 2**. II. No. 2. Abidjan 4-9.

Mesfin, A. and Bayetta, B. 1987. Genotype x Environment interaction in coffee (Coffea arabica L.). Pp476-482. In 14th international scientific colloquium on coffee 4 June 3 July 1987, Montreux, France.

Mesfin, A. and Bayetta, Be. 1983. Hetrosis in cross of indigenous coffee selected for yield and resistance to Coffee Berry Disease II-First three Years. Ethiopian Journal of Agricultural Sciences **1**: 13-21.

Mesfine Kebede and Bayetta Bella chew .2008. Phenotypic diversity in the Hararghe coffee (coffea arabica L.) germplasm for quantitative traits. East African Journal of Sciences **2(**1**):** 13-18.

Montagnon, C. and Bouharmont, P. 1996. Multivariate analysis of phenotypic diversity of Coffea arabica L. Genetic Resources and Crop Evolution **43**: 221-227.

Paulos, D. and Demel, T. 2000. The need for forest coffee germplasm conservation in Ethiopia and its significance in the control of coffee diseases. In: Proceedings of the workshop on control of coffee berry disease in Ethiopia, August 13-15, 1999. EARO, Addis Ababa, Ethiopia. Pp.125-135.

Paulos, D. and Demel, T. 2000. The need for forest coffee germplasm conservation in Ethiopia and its significance in the control of coffee diseases. In: Proceedings of the workshop on control of coffee berry disease in Ethiopia, August 13-15, 1999. EARO, Addis Ababa, Ethiopia. Pp.125-135.

Peeters, L.P. and Martinelli, J.A. 1989. Hierarchical cluster analysis as a tool to manage variation in germplasm collections. Theoretical Applied Genetics 78:42-48.
SAS Institute. 2002. SAS user's guide: statistics. 5th ed. SAS Inst., Cary, NC.

Schmitt Christine, Feyera Senbeta, Manfred Denich, Helmut Preisinger, Tadesse Woldemariam and Sebsebe Demissew. 2005. Sustainable management of the montane rain forests with wild coffee (Coffea arabica L) in the Bonga region of southwest Ethiopia in Conference on International Agricultural Research for Development, Stuttgart-Holenhiem, October 11-13, 2005, Tropentag.11-15 September, 2006.

Seyoum Seifu and Bayetta Bella chew. 2007. Variability and inter relationships between coffee (Coffee arabica L.) Seedling characters and their implication in selection. 21st International conference on coffee science, Montpellier, France, 11-15 September, 2006.

Seyoum Seifu, singh. and Bayetta Bellachew. 2004. Diversity in the Ethiopian coffee (Coffea arabica.) germplasm .20th International conference on coffee Scince 11- 15 October, 2004, Bangalore, India

Singh, B.D. 2003. Plant Breeding, Kalyani Publishers, New Delhi

Singh, R.K. and Chaudhary, B.D. 1987. Biometrical Methods in Quantitative Genetic Analysis. Kalydni Publishers, New Delhi. pp.318

Souza, E.and M.E. Sorrels. 1991. Relationships among 70 North American oat germplasms: Cluster analysis using quantitative characters. CropSci. **31**: 605-611.

Srinivasan, C.S. 1982. Pre- Selection for yield in coffee. Indian Journal of Genetics and Plant Breeding **42**: 15-19.

Srinivasan, C.S. 1988. A comparative study of juvenile growth characters of coffee varities in north east India, J. Coffee Res . **18**(1). 33-38.

Steel, Robert G.D., Torrie, James H. and Dickey, David A. 1997. Principles and Procedures of Statistics: A Biometrical Approach, 3rd ed. McGraw-Hill Book Co., New York. pp.666.

Stoskopf, N., Tomes, D.T. and Christie, R.B. 1999. Plant Breeding: Theory and Practices. Scientific Publishers, Jodhpur, India. pp.531.

Sylva, R.L.C. and A. Carvalho. 1997. Shoot and root evaluation on seedlings from Arabica coffee genotypes. Bragantia**. 56:**59-68.

Tadesse, W. 2003. Vegetation of the Yayu forest in SW Ethiopia: impacts of human use and implications for in situ conservation of wild Coffea arabica L. populations. Ecology and Development Series No.10, Cuvillier Verlag, Göttingen. pp.162

Tadesse, W. Manfred, D. Franz, G. Girma, B. and Demel, T. 2008. In-situ conservation of genetic resources of wild arabica coffee in montane rainforests of Ethiopia. In proceedings of a national workshop four decades of coffee research and development in Ethiopia 14-17 August 2007, EIAR Addis Ababa, Ethiopia. Pp.29-34.

Tikader, A., Avindran.V., Grishaik, P. Mukherjiee and K.Thangavelu.1999. Divergence analysis in different mulberry species. Indian J.Genet.Pl.Breed.**59 (**1):62-88

Van der Graaff, N.A. 1981. Selection of Arabica coffee types resistant to Coffee Berry Disease in Ethiopia. Doctoral thesis, University of Wageningen, Netherlands.

Van der Vossen, H.A.M. 1985. Coffee selection and breeding. In: coffee botany, Biochemistry and production of beans and Beverage Eds. M.N. Clifford and K.C. Wilson croom Helm, London, New york,Sidney.

Van Hintum, Th.J.L. 1995. Hierarchical approaches to the analysis of genetic diversity in crop plants. In: Hodgkin, J., Brown, A.H.D., Van Hintum, Th.J.L. and Morales, E.A.V. (eds.) Core Collections of Plant Genetic Resources, pp.23-34. John Wiley & Sons, Chichester.

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

Verma, P.S. and V.K. Agarwal. 1982. Genetics. S. Chand and Co.Ltd. Ram Nagar, New Dehlhi. P555.

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. Available at: [http://www.springerlink.com/content/w1g865u1r4q14682/]

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

Wellman FL (1961) .Coffee, botany, cultivation and utilization. Leonard Hill Books, London.

Wintgens, J.N. 2004. Coffee: Growing, Processing, Sustainable production. Agidebook for growers, processors, traders, and researchers.weinheim.

Woldemariam, T., Denich, M. Teketay, D. and Vlek, P.L.G. 2002. Human impacts on 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.

Wondimu, M. 1998. The genetic diversity of Ethiopian coffee. Kaffa Coffee **1**: 25-30

Workafes Wolde Tsadik and Kassu Kebede. 2000. Coffee production system in Ethiopia. In: Proceedings of work shop on control of coffee berry disease in Ethiopia 13-15th August 1999, EARO, and Addis Ababa, Ethiopia. Pp.99-106.

Wrigley, G.1988. Coffee. tropical Agriculture Serious. Longman Scientific and Techinical, Long man group UK Limited, England.

XLSTAT – Addinosoft, 2008. Users' Guide. Paris, France.

Yigzaw D. 2005. Assessment of cup quality, morphological, biochemical, and molecular diversity of Coffea arabicaL.genotypes of Ethiopia .A PhD Dissertation presented to University of Free State, South Africa.Avaliable at http://etd.uovs.ac.Za/etd-db/these.

7. APPENDICES

Appendix Table 1. Descriptors used by the sensory panel to describe the sensory

Scales	Attributes	*Description of scales used*					
		0	1	2	3	4	*5*
0-5	AI	nill	Verylight	light	medium	strong	*Very strong*
0-5	AQ	nill	Verylight	light	medium	strong	*Very strong*
0-5	AC	nill	Verylight	light	medium	strong	*Very strong*
0-5	AS	nill	Verylight	light	medium	strong	*Very strong*
0-5	BI	nill	Verylight	light	medium	strong	*Very strong*
0-5	BO	nill	Verylight	light	medium	strong	*Very strong*
0-5	FL	nill	Verylight	light	medium	strong	*Very strong*
0-5	OVS	unacceptable	bad	regular	good	very good	*Excellent*

AI=aromatic intensity, AQ=aromatic quality, AC= acidity, AS= astringency, BI=bitterness, BO= body, FL= flavor, OVS = over all standard

Appendix Table 2. Organoleptic quality analysis vocabulary

I General terminology	Definition
Assessor	Any person taking part in a sensory test
Attribute	Perceptible characteristic
organoleptic	Relating to an attribute of a product
Panel	Group of assessors chosen to participate in sensory test
sensory	Relating to the use of sense organs
Intensity	The magnitude of the perceived sensation
Aroma	French sense: organoleptic attribute perceptible by the olfactory organ via the back of the nose when tasting
Acid (taste)	Describes the basic taste produced by dilute aqueous solutions of most acid substances (e.g. citric acid and tartaric acid
Acidity	Organoleptic attribute of pure substances or mixtures which produces the acid taste
Astringency	Organoleptic attribute of pure substances or mixtures which produces the astringency
Astringent	Describes complex sensation accompanied by shrinking, drawing or puckering mucosal surface in the mouth, produced by substances like tannins and sloe tannins
Bitter (taste)	Describes the basic taste produced by dilute solutions of various substances such as quinine and caffeine
Bitterness	Organoleptic attribute of pure substances or mixtures which produces the bitter taste
Body	Richness of flavor or impression of consistency given by a product
Flavor	Complex combination of the olfactory and trigeminal sensations perceived during tasting, never may be influenced by tactile, thermal, painful, unaesthetic effects
Preference	Expression of the emotional state or reaction of an assessor which leads him /her to find one product better than one or several others.

Appendix Table 3. Efficiency of Simple Lattice Over Randomized Complete Block Design and Coefficients of Variation of both Designs

Characters	Efficiency%	CV%	
		Lattice design	RCBD
BL	19.6	3.04	4.13
BW	5.86	2.67	5.23
FL	1.79	3.61	4.15
FW	same	4.23	4.64
FT	0.97	6.86	8.77
HBW	36.49	5.48	7.12
Yld	37.70	30.16	50.65
PLH	14.37	5.44	6.17
SD	9.42	11.21	14.09
APB	55.96	5.27	7.24
NNS	11.96	8.77	9.92
CD	6.05	9.32	10.09
AILS	17.41	9.78	11.97
ALPB	1.42	9.39	9.71
ILPB	1.13	8.79	10.92
NPB	2.15	11.41	11.91
NSB	same	24.39	24.11
PBPB	13.01	8.36	9.48
LL	6.78	4.86	6.18
LW	33.95	6.27	9.09
LA	24.01	11.34	13.57
HPB	same	11.88	11.56

BL = Bean length, BW = Bean width, FL = Fruit length, FW = fruit width, FT = Fruit thickness, HBW = hundred bean weight, Yld = yield, PLH = plant height, SD = Stem diameter,APB = Angle of primary branch, NSN = Number of main stem nodes, CD = Canopy diameter, AILS = Average internodes length of main stem,AILPB = Averageinternode length of primary branch, ALPB = Average length of primary branch, NPB = number of primary branches, NSB = Number of secondary branches,PBPB = percentage of bearing primary branches, LL = Leaf length, LW = Leaf width, LA = Leaf area, HPB = Height up to first primary branch.

Appendix Table 4. Simple lattice analysis of variance between the 49 coffee accessions for 22 quantitative traits

Characters	Source of variation					F-Value	Pr > F
	Replication	Treatment		Error			
		Unadjusted	Adjusted	Intra Block	RCBD		
BL	0.01	0.49	0.42**	0.09	0.30	4.85	<.0001
BW	0.23	0.21	0.18**	0.03	0.04	5.56	<.0001
FL	0.13	1.03	0.89**	0.31	0.34	2.85	0.0007
FW	4.88	0.96	0.94**	0.33	0.32	2.84	0.0008
FT	2.49	1.05	0.89*	0.42	0.44	2.12	0.0104
HBW	5.75	7.55	6.64**	0.84	1.35	7.90	<.0001
Yld	1.27	0.17	0.14*	0.06	0.09	2.45	0.0031
PLH	785.74	899.45	649.96*	0.33	0.40	2.55	0.0022
SD	1.96	0.64	0.35^{ns}	0.62	0.33	1.07	0.4231
APB	24.10	39.09	30.91**	10.63	19.79	2.91	0.0006
NSN	261.22	29.62	18.24ns	10.54	13.29	1.73	0.044
CD	4429.20	427.39	379.78^{ns}	376.57	439.23	1.01	0.495
AILS	10.38	0.84	0.68^{ns}	0.51	0.68	1.35	0.177
ALPB	355.05	75.29	52.98^{ns}	54.97	58.77	0.96	0.552
ILPB	0.69	0.38	0.29^{ns}	0.16	0.17	1.82	0.032
NPB	781.07	129.07	83.19ns	51.38	55.89	1.62	0.067
NSB	10340.59	11614	9114.90*	3794.94	3704.61	2.40	0.0036
PBPB	16.68	68.38	51.07ns	49.08	62.78	1.04	0.4556
LL	1.71	0.96	0.68*	0.37	0.44	1.82	0.0321
LW	0.12	0.47	0.36**	0.11	0.17	3.36	0.0001
LA	11.27	68.41	44.73*	24.61	35.38	1.82	0.0322
HPB	79.02	31.71	33.33*	13.39	12.99	2.49	0.0027

Appendix Table 5. Mean value of 22 quantitative characters of 49 arabica coffee accessions

Acce	BL	BW	FL	FW	FT	100BW	Yld	PLH	SD	APB	NMSN	CD
744	9.9	6.96	16.30	12.03	9.92	17.70	1.23	301.33	5.26	61.88	38.5	216.75
F59	9.56	6.93	15.43	12.55	8.71	16.30	1.38	330.67	5.48	65.33	43.00	225.75
L01	9.73	6.61	15.73	13.63	9.18	15.75	0.56	296.67	5.06	62.20	34.00	210.25
L02	9.1	6.86	15.4	14.18	9.70	16.30	0.95	269.17	5.13	63.26	37.33	210.00
L03	9.21	6.55	14.88	13.34	9.38	15.75	0.81	293.67	5.46	62.65	34.50	197.17
L04	9.93	6.60	15.78	13.25	8.95	16.20	0.13	260.00	4.96	62.48	36.50	189.67
L05	9.68	6.48	15.45	14.43	10.75	15.30	0.70	313.00	5.56	62.68	38.66	197.08
L06	10.00	6.15	15.65	13.93	9.90	16.95	1.06	292.00	5.16	66.83	39.00	207.67
L07	10.05	6.66	16.11	13.65	8.85	18.15	0.83	288.67	4.26	67.7 5	34.66	204.67
L08	9.00	6.45	14.6	13.18	9.40	14.60	0.45	257.00	4.91	59.08	34.66	210.83
L09	9.26	6.78	15.05	13.46	8.88	17.70	1.00	294.50	4.92	62.51	42.00	204.58
L10	9.21	7.06	15.11	13.65	9.29	16.40	0.93	268.83	5.08	53.75	37.50	217.75
L11	9.83	6.83	16.13	14.6	10.36	19.65	0.71	300.67	5.41	66.10	38.00	212.83
L12	9.50	6.90	16.21	12.35	7.89	16.60	0.55	327.83	4.55	66.46	35.50	220.58
L13	9.43	6.86	15.21	13.66	9.86	16.15	0.71	279.83	4.90	68.68	35.66	221.67
L14	9.10	6.25	14.30	12.35	8.02	14.95	0.73	288.50	4.45	64.03	35.50	188.17
L15	9.36	7.08	15.18	13.43	9.19	16.90	0.36	291.67	4.86	55.16	38.66	215.67
L16	9.85	6.58	15.78	13.43	9.90	15.50	0.90	318.67	4.75	63.05	41.50	212.25
L17	9.01	6.71	14.60	12.55	8.59	14.15	0.53	318.33	6.75	63.76	43.16	228.42
L20	10.70	7.13	17.01	13.91	10.20	20.85	1.43	297.00	5.31	52.11	39.50	213.58
L22	8.98	6.78	14.96	13.85	9.46	13.78	0.95	320.50	5.41	61.16	40.83	216.08
L23	9.48	6.95	15.40	14.28	10.14	18.30	1.05	305.83	5.43	67.20	44.33	201.92
L24	9.33	6.66	16.43	15.75	11.68	18.70	1.25	310.33	4.61	63.08	32.83	207.83
L25	9.58	6.45	15.95	13.96	9.64	14.35	0.70	287.67	5.48	51.76	36.00	232.58
L26	10.03	6.78	16.16	13.86	9.22	17.05	1.00	284.67	4.91	66.65	37.50	203.08
L27	10.58	6.56	15.5	13.42	9.35	18.40	1.35	301.50	5.85	59.90	34.66	235.5
L28	9.71	6.43	15.31	12.26	8.10	15.65	0.56	256.67	4.48	55.36	30.83	211.08
L29	8.45	6.53	14.45	13.78	9.31	14.10	0.76	276.50	4.16	63.76	33.16	199.75
L30	9.25	6.83	15.43	14.03	9.97	15.90	1.00	289.67	4.53	59.11	35.00	206.92
L32	9.15	6.31	14.68	13.28	8.80	15.25	1.05	326.67	4.81	69.73	41.33	205.00
L33	9.50	6.30	16.03	14.36	10.02	15.80	0.30	305.33	5.06	60.40	36.00	211.00
L34	8.73	6.63	14.76	13.40	9.02	15.05	1.21	260.00	4.50	58.36	29.66	190.42
L35	9.33	6.00	14.33	12.82	8.49	14.25	0.70	280.33	5.50	57.18	35.33	207.50
L36	9.53	7.53	15.40	13.48	8.88	17.35	0.61	265.67	4.83	59.18	33.16	214.42

Appendix Table 5. Continued

Acce	BL	BW	FL	FW	FT	100BW	Yld	PLH	SD	APB	NMSN	*CD*
L37	9.61	7.10	15.75	13.58	9.32	16.30	0.85	298.50	5.01	60.20	33.83	*191.92*
L38	9.20	6.60	15.08	13.30	10.02	15.40	0.53	275.17	4.61	56.66	32.16	*183.50*
L39	9.70	6.40	15.18	13.23	8.70	16.15	0.71	263.50	4.31	63.95	26.50	*188.25*
L40	9.95	6.80	16.05	13.06	9.19	16.85	0.76	299.83	4.75	63.65	37.33	*193.42*
L41	8.88	6.30	14.20	13.41	9.67	12.80	0.68	289.67	5.41	56.06	38.16	*183.08*
L42	9.60	6.65	15.34	13.01	8.55	15.80	0.50	328.83	6.00	68.01	44.50	*226.67*
L43	9.91	7.00	15.05	13.28	8.97	20.00	0.43	282.50	6.01	56.18	39.50	*209.50*
L44	9.81	6.86	15.56	13.51	9.19	19.40	0.61	303.50	5.81	67.31	41.16	*216.25*
L45	9.96	7.36	16.30	14.40	10.02	20.20	0.70	256.33	3.56	62.86	32.00	*174.00*
L46	10.58	7.50	17.35	13.81	9.56	21.95	0.60	290.83	5.11	63.15	38.50	*192.00*
L47	10.78	6.61	17.00	13.70	9.43	19.40	0.70	295.67	5.60	56.61	35.00	*199.17*
L48	10.08	6.78	16.06	14.61	10.31	18.40	0.91	305.50	5.36	60.13	41.00	*205.08*
L49	10.06	6.50	16.61	13.96	9.55	17.15	0.50	278.67	5.86	67.06	34.83	*218.58*
L49	10.06	6.50	16.61	13.96	9.55	17.15	0.50	278.67	5.86	67.06	34.83	*218.58*
L l50	9.71	6.83	15.48	14.43	10.01	17.05	1.36	333.00	5.58	61.00	40.50	*248.08*
L51	9.86	6.46	15.41	14.15	10.42	16.90	0.78	324.33	5.31	63.88	40.16	*222.83*
LSD 5%	0.64	0.38	1.14	1.17	1.31	2.02	0.53	34.53	ns	7.23	6.99	*ns*
CV%	3.04	2.67	3.61	4.23	6.86	5.48	30.16	5.44	11.21	5.27	8.77	*9.32*
SD	0.29	0.18	0.56	0.58	0.65	0.92	0.24	15.97	0.57	3.26	3.25	*19.41*
Grand mean	*9.61*	*6.72*	*15.54*	*13.56*	*9.43*	*16.73*	*0.80*	*293.58*	*5.11*	*61.83*	*37.01*	*208.18*

Appendix Table 5. Continued

Acc	AILS	ALPB	ILPB	NPB	NSB	ABPB	LL	LW	LA	HPB
744	7.11	83.80	4.68	61.66	274.50	94.43	12.87	5.5.00	46.85	29.16
F59	7.08	88.233	4.68	77.16	296.17	87.78	11.97	5.14	40.81	27.66
L01	7.90	78.95	4.98	49.66	168.67	78.28	13.65	5.99	54.08	27.83
L02	7.41	68.933	3.76	58.33	290.50	81.28	12.86	5.05	50.65	25.00
L03	7.98	79.333	5.05	57.16	209.83	79.66	11.34	5.82	50.08	26.50
L04	6.43	64.20	4.6833	63.16	238.67	65.76	12.27	4.98	40.53	30.66
L05	7.21	70.15	4.183	63.83	237.33	84.78	13.68	5.33	48.25	36.16
L06	6.60	80.45	4.55	67.16	273.83	86.26	13.14	5.79	50.93	30.00
L07	7.86	80.483	5.433	54.16	91.50	80.33	13.21	5.51	48.20	34.16
L08	6.71	84.517	4.166	56.16	191.67	74.96	12.81	4.91	41.80	26.83
L09	6.46	83.30	3.60	69.33	269.83	87.83	11.18	4.49	33.76	32.83
L10	6.46	82.567	4.866	63.33	254.00	86.35	11.53	4.73	36.13	26.83
L11	7.36	80.767	4.183	62.33	215.50	79.81	12.81	5.08	43.30	24.66
L12	8.51	80.25	4.916	63.33	208.83	77.76	11.67	4.95	38.36	34.33
L13	6.85	78.217	4.60	54.66	211.33	80.18	11.86	4.80	38.05	42.16
L14	7.58	73.217	4.683	62.33	239.00	91.11	11.52	4.30	32.98	31.33
L15	7.01	90.51	4.483	66.66	403.17	77.43	12.51	6.16	51.75	21.66
L16	6.93	74.833	4.233	69.50	280.17	89.333	12.27	5.81	46.86	33.16
L17	6.51	77.633	3.56	77.50	545.50	86.61	12.35	4.830	39.41	38.16
L20	6.78	79.917	4.483	67.83	323.67	87.23	12.54	4.80	40.03	29.33
L22	7.11	85.667	4.95	68.00	229.83	83.45	13.44	5.29	47.61	29.66
L23	6.31	80.40	4.20	75.33	258.83	91.30	12.57	5.21	43.65	28.00
L24	7.10	75.533	4.533	67.33	227.17	84.06	12.77	5.44	45.98	32.16
L25	7.38	86.70	5.266	60.83	214.67	79.93	13.49	6.11	54.56	28.16
L26	6.76	80.20	4.5167	66.00	240.50	90.10	13.17	6.00	52.58	31.50
L27	8.30	83.883	5.13	68.667	242.33	83.083	12.43	5.79	48.08	35.83
L28	7.15	76.417	4.88	50.33	197.17	90.58	11.54	4.99	38.41	37.16
L29	7.55	76.55	5.23	56.167	162.50	85.15	13.93	5.62	52.05`	28.33
L30	7.68	79.333	5.00	61.83	191.33	87.31	12.76	5.02	42.46	31.50

Appendix Table 5. Continued

Acc	AILS	ALPB	ILPB	NPB	NSB	ABPB	LL	LW	LA	HPB
L32	7.21	79.25	4.48	71.00	258.50	91.98	13.00	4.63	39.90	29.33
L33	7.50	83.23	5.00	61.66	228.00	86.10	13.51	5.53	49.33	38.33
L34	7.98	78.43	5.08	47.50	239.33	84.21	12.27	4.87	42.98	31.66
L35	6.53	79.83	4.76	59.66	275.33	84.81	12.38	4.83	39.68	33.50
L36	7.31	72.38	4.37	59.16	252.33	72.55	11.82	5.78	49.33	27.50
L37	8.31	70.23	4.23	57.00	265.50	84.80	13.62	5.79	53.06	29.00
L38	8.30	72.48	5.12	49.83	320.50	72.95	11.17	4.43	33.28	30.50
L39	9.60	76.68	5.31	43.83	193.33	74.03	12.47	4.75	39.16	28.16
L40	7.15	72.17	4.23	61.00	235.00	84.83	12.19	4.72	38.23	35.66
L41	6.96	71.22	3.96	60.16	248.17	85.00	12.66	4.93	41.56	29.16
L42	6.70	82.60	4.25	76.66	332.67	82.83	12.96	5.22	44.91	29.50
L43	6.68	81.86	4.30	73.33	425.33	74.26	12.15	4.09	33.06	26.16
L44	6.61	82.00	4.55	73.00	212.67	88.61	12.94	4.81	44.30	31.33
L45	7.16	59.67	4.20	52.00	112.67	87.03	12.02	5.10	41.13	26.66
L46	7.61	86.25	4.61	63.33	189.50	89.16	13.15	5.32	46.41	31.66
L47	7.78	81.37	4.91	57.5	369.17	82.25	12.97	5.30	45.93	28.00
L48	6.71	79.88	4.13	73.66	343.17	89.61	12.20	5.04	40.93	32.33
L49	7.38	85.68	4.88	60.00	247.17	85.75	11.87	4.85	38.23	33.16
L50	7.36	88.13	4.50	69.16	252.17	88.21	12.84	5.31	45.36	35.66
L51	7.31	80.08	4.63	70.00	183.83	82.65	12.00	4.85	38.58	30.83
LSD 5%	ns	ns	0.82	ns	124.94	ns	1.29	0.71	10.83	7.42
CV%	9.78	9.39	8.79	11.41	24.39	8.36	4.86	6.27	11.34	11.88
S.D	0.71	7.41	0.40	7.17	61.60	7.01	0.61	0.32	4.96	3.66
Mean	7.27	78.95	4.59	62.84	252.50	83.75	12.54	5.18	43.75	30.79

Appendix Table 6. Mean value for organoleptic quality attributes

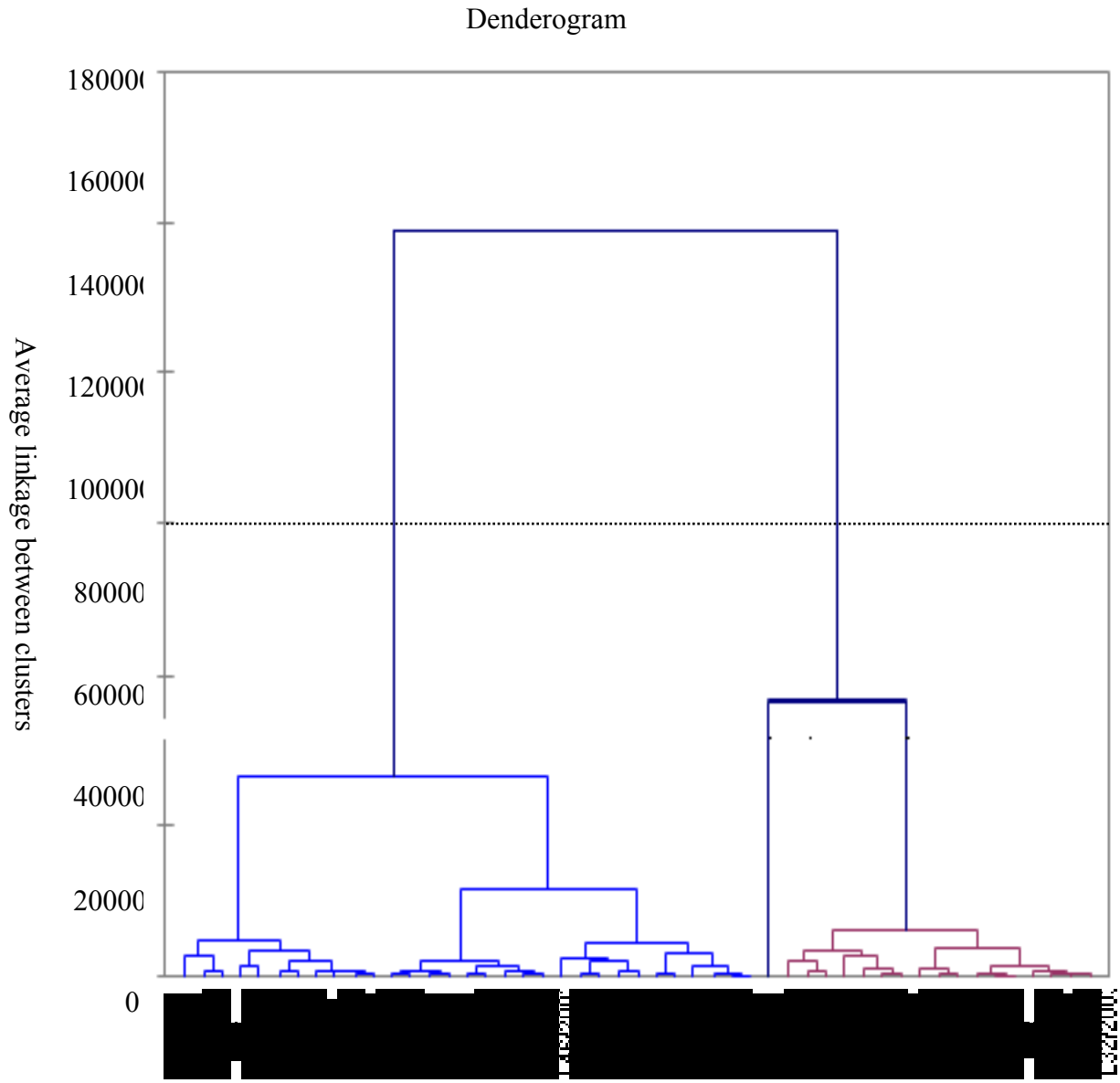
genotypes	AI	AQ	AC	AS	BI	BO	FL	OVS
744	3.39	3.16	2.78	2.78	0.38	3.07	2.78	2.85
F59	3.54	3.47	3.03	3.03	0.30	3.08	3.09	3.02
L01	3.62	3.58	3.12	3.12	0.41	2.91	3.33	3.33
L02	3.41	3.33	3.12	3.12	0.12	3.12	3.16	3.29
L03	3.29	3.29	2.83	2.83	0.29	3.33	3.16	3.16
L04	3.29	3.29	2.70	2.70	0.54	3.45	3.04	3.20
L05	3.58	3.70	3.29	3.29	0.25	3.41	3.29	3.41
L06	3.29	3.29	3.58	3.58	0.12	3.16	3.16	3.29
L07	3.25	2.95	2.58	2.58	0.00	3.29	2.58	2.58
L08	3.12	2.75	2.91	2.91	0.50	3.29	2.79	2.91
L09	3.37	4.00	3.50	3.50	0.00	3.41	3.45	3.45
L10	3.12	3.00	2.95	2.95	0.37	3.12	3.00	3.00
L11	3.12	3.16	3.41	3.41	0.12	3.16	3.16	3.16
L12	3.70	4.37	4.29	4.29	0.00	3.45	4.33	4.58
L13	3.45	3.33	2.91	2.91	0.25	3.29	3.25	3.25
L14	3.29	3.50	2.87	2.87	0.25	3.25	3.20	3.20
L15	3.00	3.16	3.29	3.29	0.00	3.00	3.04	3.16
L16	3.16	3.20	3.45	3.45	0.12	3.41	3.66	3.62
L17	3.61	3.65	3.57	3.57	0.10	3.45	3.51	3.63
L20	3.51	3.44	3.35	3.35	0.06	3.35	3.18	3.35
L22	3.17	3.10	2.87	2.87	0.35	3.28	2.81	2.91

Appendix Table 6. Continued

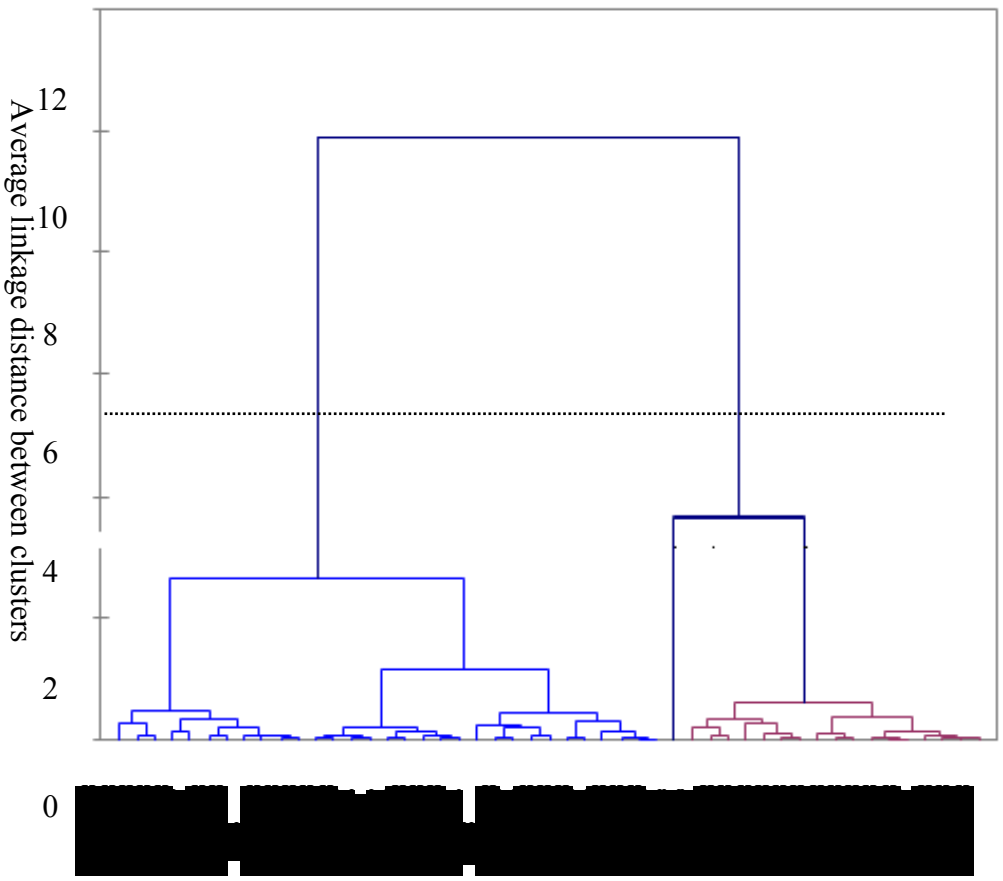
genotypes	AI	AQ	AC	AS	BI	BO	FL	OVS
L23	3.37	3.27	3.61	3.61	0.00	3.32	3.45	3.48
L24	3.24	3.14	3.48	3.48	0.06	3.28	3.45	3.35
L25	3.17	3.24	3.22	3.22	0.22	3.28	2.96	3.12
L26	3.00	3.10	3.10	3.10	0.25	3.02	3.02	2.93
L27	3.24	3.20	3.06	3.06	0.00	3.16	3.02	3.06
L28	3.44	3.34	3.73	3.73	0.06	3.26	3.51	3.51
L29	3.37	3.12	2.87	2.87	0.12	2.83	2.58	2.58
L30	3.51	3.75	3.75	3.75	0.06	3.10	3.48	3.42
L32	3.27	3.27	3.20	3.20	L32	2.90	3.03	3.03
L33	3.27	3.34	3.22	3.22	0.06	3.16	3.16	3.16
L34	3.40	3.47	3.76	3.76	0.06	3.28	3.28	3.35

Appendix Table 6. Continued

genotypes	AI	AQ	AC	AS	BI	BO	FL	OVS
L35	3.02	3.02	2.6	2.6	0.1	3.22	2.86	2.76
L36	3.31	3.27	3.61	3.61	0.00	3.16	3.22	3.22
L37	3.48	3.33	3.54	3.54	0.07	3.53	3.53	3.61
L38	3.40	3.21	3.05	3.05	0.40	3.33	2.90	3.05
L39	3.47	3.22	3.15	3.15	0.41	3.32	3.07	3.15
L40	3.30	3.15	2.89	2.89	0.41	3.16	2.83	2.82
L41	3.22	3.46	3.45	3.45	0.08	3.30	3.38	3.30
L42	3.29	3.30	3.47	3.47	0.00	3.38	3.40	3.39
L43	3.32	3.16	3.29	3.29	0.16	3.30	3.07	3.07
L44	3.54	3.33	3.03	3.03	0.21	3.17	2.95	3.02
L45	3.16	3.16	2.52	2.52	0.48	3.14	2.67	2.67
L46	3.15	3.29	3.00	3.00	0.32	3.32	2.84	2.91
L47	3.30	3.54	3.14	3.14	0.25	3.22	3.21	3.21
L48	3.53	3.29	3.39	3.39	0.16	3.46	3.29	3.29
L49	3.40	3.15	3.21	3.21	0.39	3.22	2.98	3.13
L50	3.23	3.23	3.40	3.40	0.07	3.23	3.23	3.39
L51	3.15	3.38	3.08	3.08	0.08	3.15	3.07	3.15
LSD5%	ns	0.49	0.62	ns	ns	Ns	0.68	0.65
CV%	6.48	7.49	9.59	114.82	136.84	6.38	10.69	10.03
S.D	0.22	0.25	0.31	0.31	0.26	0.21	0.34	0.32
Mean	3.33	3.31	0.31	0.27	0.19	3.24	3.16	3.20



Appendix Figure 1. Denderogram of 49 (Coffea arabica L.) accessions for 22quantitative characters with average linkage clustering strategy.



Appendix Figure 2. Denderogram of 49 coffee (Coffea arabica L.) accessions for 8 organoleptic quality traits with average linkage clustering strategy.