EFFECT OF ALTITUDE, STAGES OF MATURITY AND PROCESSING METHODS ON THE PHYSICAL AND CUP QUALITY ATTRIBUTES OF COFFEE (*Coffea arabica* L.) AT TEPPI GREEN COFFEE FARM

M.Sc. Thesis

Gemeda Nemesa Aga

December, 2015

Jimma, Ethiopia

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In Partial Fulfillment of the Requirements of Degree of Master of Science in Horticulture (Coffee, Tea and Spices)

By

Gemeda Nemesa Aga

December, 2015

Jimma, Ethiopia

School of Graduate Studies, Jimma University

As Thesis Research advisor, I hereby certify that I have read and evaluated this thesis prepared, under my guidance, by Gemeda Nemesa, entitled ' **INFLUENCE OF FRUIT MATURITY STAGE AND PROCESSING METHODS ON THE QUALITY OF ARABICA COFFEE (*Coffea arabica* L.) VARIETY AT TEPPI GREEN COFFEE FARMS** and recommend that to be submitted as fulfilling the thesis requirement.

Ali Mohammed (Ph.D.) ______________________

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Mr. Weyessa Garedew (Ph.D Scholar) ________________________

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As member of the Board of Examiners of the M.Sc. Thesis Open Defense, we certify that we have read and evaluated the thesis prepared by Gemeda Nemesa, entitled 'Influence of fruit maturity stage and processing methods on quality of Arabica Coffee (*Coffea arabica* L.) Variety at Teppi green coffee farms and examined the candidate. We recommend that the thesis be accepted as fulfilling the requirement for the Degree of Master of Science in Horticulture.

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Chairman Signature

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DEDICATION

I dedicate this thesis to my beloved wife, Selamawit Birhanu, to my sons, Sebir and Firahol Gemeda.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree at Jimma University and is reserved at the university library. I solemnly declare that this thesis is not submitted to any other institutions anywhere for award of any academic degree or certificate.

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BIOGRAPHICAL SKETCH

Gemeda Nemesa Aga was born on April 5, 1972 in Western Wollega Zone at Nole Kaba district at a place called Nyaha Dogi. He completed his Elementary School at Nyaho Dogi, Gurach Halata, Nole Kabe and Nejo Hunde Bekumisa Elementary School from 1979 to 1986 and Secondary education at Nejo Senior Secondary School from 1987 to 1991. In 1992, he joined Alemaya University of Agriculture (Now Haramaya University) and graduated in 1995 with B.Sc. degree in Plant Science. In 1996, he was hired as agronomist in Coffee Plantation Development Enterprise (CPDE) and currently working as a deputy general manager of the Teppi Green Coffee Eneterprise.

Finally, in July 2009, he joined the Jimma University College of Agriculture and Veterinary Medicine to pursue his M.Sc. studies in Horticulture specializing in Coffee, Tea and Spices.

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LIST OF ABBREVIATIONS /ACRONOMY/

CBD	Coffee Berry Disease
CGA	Chlorogenic acid
CIP	Coffee Improvement Program
CLU	Coffee Liquoring Unit
CPDE	Coffee Plantation Developmant Enterprise
CRI	Coffee Research Institute
DAF	Days after flowering
ECX	Ethiopian Commodity Exchange
FAQ	Fairly acceptable quality
IAR	Institute of Agricultural Research
ICO	International Coffee Organization
IPGRI	International Plant Genetic Resource Institute
ISO	International standard Organization
ITC	International Trade Center
JARC	Jimma Agricultural Research Center
LMC	Livelihood Coffee market
NG	Nano gram
OTA	Ochra toxin A
SAS	Statistical Analysis System
WAF	Weeks after flowering
WFP	World food program

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ABSTRACT

Modern coffee plantations contribute to about 5-8% of the total production in the country and most of them are found in southwestern. The areas are endowed with diverse and suitable enviroments, which have potential to produce quality coffee that can meet the preference of consumers. The farms are established mainly to produce washed quality coffee with sustainable yield. But, some of the varieties which are high yielder and adapted to these areas have maturity problems. Thus, the objectives of this experiment were to evaluate the influence of altitude (law, medium and high land), stages of maturity (light green, yellow and red cherries)) and processing methods (wet, semi-wet and dry) on the physical and cup quality attributes of Arabica coffee variety. Accordingly, the experiment was conducted at Tepi Green Coffee Plantation from October 2011 to June 2012 using a 3×3×3 factorial experiment arranged in randomized complete block design (RCBD) with three replications. Physical and cup quality parameters were recorded and analyzed using SAS version 9.2 software package. The light green, yellow and red ripe cherries were handpicked from three study sites and evaluated under three processing methods.The results showed significant variations due to altitude, stages of maturity and processing methods for most coffee quality traits. In addition, the interaction effects between the treatments such as shape and make, color, total raw quality and body were significant. Accordingly, the red and yellow stages of maturity were superior and did not show significant difference at all the three altitudes for the total quality. With regard to processing methods, the wet method significantly improved the raw and cup quality over the other practices and resulted in better total quality. Coffee quality improvement due to processing techniques increased in order of dry method, semi-washed and wet method. With regard to altitude, the variety was noted to be more specific to Anderacha high land in terms of its quality, largely due to the influence of microclimate though the variety had unique characteristics in adapting at all sites. Because of this, the 7454 variety remains the best alternative for coffee growing areas of Teppi and Godare. From the present findings, it can be concluded that the quality of the variety can be maximized by harvesting at the red and yellow stages and using the wet method. However, further studies should be progressed mainly in analyses of bio-chemical constituents, nutrient levels, tree management, climate condition at different stages of cherry development and different shade conditions.

1. INTRODUCTION

The coffee bean is obtained from the fruit of the coffee plant, a small evergreen shrub belonging to the genus *Coffea,* family Rubiaceae. Although the genus *Coffea* is diverse and reported to comprise about 124 species (Davis *et al.*, 2011), only two species namely Arabica (*Coffea arabica* L.) and robusta (*Coffea canephora* Pierre) are under commercial cultivation (Anthony *et al.,* 2002). The southwest afromontane rainforests and Bale Mountains in southeast highlands of Ethiopia are the center of origin and diversity of *C. arabica* (Gole *et al.,* 2002). In Ethiopia, coffee grows almost everywhere (Yilma, 1998), under diverse environmental conditions ranging in altitude from 550-2600 mts above sea level and annual rainfall of 1000-2000 mm (Bayeta, 2001). *Coffea arabica* is the only coffee species grown in Ethiopia and the country is the primary centre of origin and genetic diversity for this crop (Vega, 2008). Coffee is one of the most important commodities in the international agricultural trade, representing a significant source of income to several countries of Africa, Asia and Latin America (Taye *et al.*, 2011).

Coffee fruits are harvested when the fruits are in the 'cherry' stage (the fruit turns red as it ripens). Each fruit consists of a peel (exocarp), the pulp (mesocarp) and the parchment (endocarp), which is surrounding the beans (seeds). Within the pulp, the seeds are covered by a thin parchment-like hull. Both the pulp and hull are removed before the coffee beans are roasted (Arya & Rao, 2007). As most of the coffee berries in a plot ripen over a few weeks there is a very limited period to pick the main crop and convert it to green coffee. Ripening period may spread for even five months with about 80% repining in the middle two months. In general the maturation time is fairly constant between six to nine months for any block of Arabica coffee. The length of the period from flowering to ripening is also influenced by temperature; hence altitude and the aspect of the coffee plot whether it is exposed or sheltered (Wrigley, 1988).

Coffee quality is criticaly important to the coffee industry. Quality coffee is a product that has desirable clean raw and roasted appearance, attractive aroma, and good cup test. However it is beyond dispute that in Ethiopia the quality of coffee produced has been deteriorating from time to time (Desse, 2003; Bahilu *et al.*, 2008; Techale *et al.*, 2013).

Coffee beverage quality is based on the characterization of a large number of factors including taste and aroma. These factors are related to the biochemical content of roasted beans (Kathurima *et al.*, 2009) and influenced by the species or varieties cultivated, the plant age, climate and soil characteristics of the area in which coffee is grown, agricultural practices, stage of maturity, harvesting method and timing post harvest processing techniques, all contribute either to exhalation or deterioration of coffee quality (Leroy *et al.*, 2006; Behailu *et al*., 2008). It is estimated that 40% of the quality of coffee is determined in the field, 40% is at the post harvest primary processing, and 20% at secondary/ export/ processing and handling including storage (Nicholas, 2007).

Coffee is the most important crop in the national economy of Ethiopia contributing 25% of the country's total foreign exchange earnings (Abu and Teddy, 2014) and about 10% of the gross domestic product (FAO/WFP, 2008). Over 25% of the populations of Ethiopia are dependent on coffee for their livelihoods (LMC, 2003). Almost 95% of Ethiopian coffee is produced by about 1 million small scale farmers, with average farm size of 0.5 ha, while state owned plantation account for 5-8% (FDRE, 2003) and the 5-8% ownership is changed to private investers.

Since the 1970s, considerable effort has been made by the agricultural research and development sectors to improve the production and productivity of coffee. The improved varieties were developed at the Jimma Research Center under the then Institute of Agricultural Research and have been disseminated to the coffee-producing farmers since 1984 through the coffee improvement program (Admasu *et al.*, 2008). *Taye et al.* (2011) reported that the Jimma Agricultural Research Center (JARC) has released a total of 37 coffee varieties along with agronomic techniques.

Although no exhaustive survey has been made so far about coffee production status, Ethiopia has about 700,000 hectares of coffee coverage and 5-8% categorized as modern coffee (Alemayehu *et al.*, 2008; Taye, 2013). Coffee processing in Ethiopia is executed by both dry and wet processing methods, of which sun drying is widely practices by farmers and hence it accounts for 71% of the total while washed coffee preparation accounts 29% (Musebe *et al*., 2007).

Teppi Green Coffe is one of the modern plantations managing 6400 ha of Coffee Plantations which is located in two National Regional States namely SNNP and Gambela with diverse altitude and rainfall of tropical rainforest ecosystems.At both low land and high lands of Teppi and Godere, the whole farm is replaced and plantd by the released CBD resistant varieties. 7454 variety is one of the highly adapted varieties and its seed is extreemly demanded by local farmers, investors and large plantations. Teppi coffee plantation planted about 13 CBD resistant varieties and 20.90% is covered by 7454 (Appendix Table 2). 7454 is a pure line variety which was released in 1979/80 and collected from high land of kaffa of washi area (Bayetta *et al.*, 1998). 7454 was the first batch of CBD resistant variety released and still it is under production especially in south west of Ethiopia (Muller *et al*., 2004). It is adapted to the area of 1000-2100 masl with the rain fall of >1400 mm (EARO, 2004).

A number of varieties showed poor yield performance in low land areas (Appendix Table 3). Accordingly, except, the intermediate coffee variety 7454 and 7440 which gave a relatively better yield at both Bebeka and Tepi, the rest were inferior (Baye *et al*, 2008). Besides its productivity advantage 7454 variety has good or fair raw and cup quality and commercial acceptance (Appendix Table 1). But the harvest loss of this variety is by far greater than all varieties. Kaffa/Teppi coffee has many unique characteristics when compared with the rest of Ethiopian coffees. This could be expressed by its raw, roast and liquor. The major common defects of coffee are Soiled and earthy, mouldy and pest/insect damaged beans. Inherent flavor is also masked by musty, hardy and other off flavors. The major sun dried coffee quality deterioration of Kaffa/Teppi is the result of environmental impact, poor agronomic and post-harvest practices (Dessie, 2008).

In recent years different coffee producing countries have tremendously expanded their production and their export volume becoming strongly competent in the world market (ICO, 2014) and beverage quality is being an important attribute of coffee (Muschler, 2001; Agwanda *et al.*, 2003) and acts as yardstick for price determination (Walyaro, 1983; Roche, 1995; Agwanda *et al.*, 2003). In view of the present situation making effort to overcome a challenge and threats only through expansion of production does not seen visible for countries like Ethiopia. High quality coffee and reliability helps in establishing relationship in the market and help the producers to hedge their marketing risks (Kuwama, 2003). On the contrary the development of varieties for each locality largely based on their yield performance, adaptability and resistance to major diseases like coffee berry disease (CBD) (Damatta *et al.,* 2008), but factors like the effect of altitude on released quality of varieties, maturity problems and the effect of processing methods must be considered, since the microclimate and the altitude conditions have the greatest influence on the quality of a coffee. Beyond environmental factors processing plays a significant role in the flavor profile of a coffee. After these factors one of the most important considerations is the maturity of coffee cherry used for the processing which is affecting the quality of a variety (Arya & Rao, 2007).

The released CBD resistant variety 7454 has ripening problem which is related to the color of the fruits in all altitudes planted in Teppi and Godere area, because most of the cherries do not change to red color. The variety shows dominantly yellow color and if it is not harvested early the cherries are over matured and subsequently changed to brown color finally resulting in fruit drop. As the reasult, the productivity and quality advantage of the variety can not be utilized and most of the users are in confusion. South western Ethiopia is endowed with high rain fall during the harvesting time and the drop of fruit leads to deterioration of the product for this variety in wich the inherent flavor is masked by musty, hardy and other off flavors as described by dessie (2008).

Despite the confirmed information about the wider adaptability of 7454 variety to all altitudes (EARO, 2004) there is inadequate information about the inconsistent maturity color, the effect of different altitudes and processing methods in south western part of Ethiopia. The microclimate and soil conditions are the major contributors to the flavor profile of a coffee (Decazy *et al.,* 2003) and if processing is done correctly, they become the most important contributors to flavor profile (Arya and Rao, 2007). However, due to the urgency of arresting the progress of coffee berry diseases (CBD) in early 1970s as a serious disease outbreak in the country and lack of trained personal and detail quality evaluation criteria, the early released CBD resistant varieties lack recent quality standards (Elsa *et al.,* 2015). Similarly, due to some natural calamities such as drought, non-seasonal rainfall, and improper processing system, quality deterioration is marked in Ethiopia (Desse, 2008). In this regard, still there are gaps on the influence of the color of maturity and processing method on quality of released CBD resistant *Coffea Arabica* for different agro-ecologies/regions (Elsa *et al.*, 2015). This calls for intensive efforts to identify the pre and post harvest processing techniques to come up with updated technologies to enhance coffe quality (Barel and Jacquet, 1994). Above all, the influence of harvesting, post-harvest processing and altitude on coffee quality has been little studied at Teppi and Godere areas. Hence, this study was designed to address the above mentioned issues thereby forward options that can help growers to produce better quality coffee in the study area. So the objectives of this pepper were:

- To determine the influence of maturity stage and processing method on the physical and cup quality of coffee variety 7454 at Teppi Green Coffee farms.

2. LITERATURE REVIEW

2.1. Botanical Classification and Characteristics of *Coffea arabica* L.

Coffea arabica L. performed better than other species because of its superior quality and continued to be the exclusive contributor of all coffee in the world (Yigzawu, 2005) and, it has numerous botanical varieties (Tadesse *et al*., 2008), mutant and cultivars, which reflect the influence of environment (Van der Vossen, 1985). Among the many varieties, the most important ones are *C. arabica var. typica and C. arabica var. bourbon*. From these two important botanical varieties, a number of important mutants grown commercially and cultivars developed through selection and hybridization, which are now available in the different coffee growing countries (Van der Vossen, 1985). It is also isolated from other species and naturally only occurs on the South and south western montane rainforests of Ethiopia (Feyera, 2006; FAO, 2008). In addition to Ethiopia, wild plants of *C. arabica* were observed in the Boma Plateau of South Sudan (Thomas 1942; Meyer 1965) and Mount Marsabit in northern Kenya (Meyer 1965).

It is an upright, evergreen shrub or small tree up to 5m in height and 7cm in diameter at breast height. The plant may grow with a single stem, but often develops multiple stems by branching at the base or on the lower stem. The bark is light gray, thin, and becomes fissured and rough when old (Coste, 1992). The wood is light-colored, hard, heavy, and tough. Its shoot and root morphological growth characters have been described (Wrigley, 1988; Coste, 1992; Wintgens, 2004). The root system consists of a short, stout central root, secondary roots radiating at all angles, and abundant fine “feeder” roots. The glabrous, shiny, dark-green, opposite leaves have petioles 4 to 12mm long and ovate to elliptic blades 7 to 20cm long, with entire edges, and pointed at both ends. The fragrant, white flowers are in axillary clusters of two to nine. The size and shape of the beans differ depending upon the variety, environmental conditions and management practices. On average, beans are 10 mm long, 6-7mm wide, 3-4mm thick and weigh between 0.15 and 0.20g (Wintgens, 2004). Bean color can be yellowish-grey to slate-grey, bluish or grey-green, depending upon the variety, method of preparation and storage condition (Coste, 1992). Bean shape may be sub-globular, ovoid, oblong, linear oblong, either rounded at both ends or pointed at one end and rounded at the other (Wrigley, 1988; Howard, 1989; Liogier, 1997).

Arabica coffee is primarily propagated and distributed by seeds. Buds that will develop into flowers are usually induced 4 to 5 months before anthesis. Depending on temperature and atmospheric humidity, the time between breaking of the dormancy and anthesis may vary from 4 to 10 days. Flower buds start to wither after 2 days and its all parts drop except the ovaries. It takes 7 to 9 months for coffee fruits to mature, depending on the climatic conditions and coffee cultivars. The seed consists of a horny endosperm containing an embryo, which is wrapped in two husks: the outer parchment and the silver skin just underneath. Depending on the climatic conditions in the area, the coffee plant takes approximately 3 years to develop from germination to first flowering and fruit production (Wrigley, 1988: Coste, 1992; Wintgens, 2004). Arabica requires soil that is slightly acidic (5.2-6.3 PH); it can be grown on more acidic or alkaline soils, but nutrient availability may become a problem (Willson, 1999).

Arabica coffee is monocentric (Harlan, 1992) since its centre of origin and diversity is in Ethiopia (Meyer, 1965; Bayeta *et al*., 2000: Steiger *et al*., 2002: Anthony *et al*., 2002). Considerable phenotypic diversity was observed in cultivated and traditionally recognized landraces of arabica coffee in Ethiopia (FAO, 1968; Teketay, 1999). Many important characteristics were observed in Ethiopian coffee, such as resistance to leaf rust (*Hemileia vastatrix* Berk and Br.) (Eskes, 1983), nematodes (*Meloidogyne incognita*) (Anzueto *et al*., 2001), coffee berry disease (*Colletotrichum kahawae* Waller and Bridge) (Bayeta *et al*., 2000), as well as variation in green bean biochemical compounds (caffeine, chlorogenic acids, sucrose and trigonelline) composition (Silvarolla *et al*., 2000: Ky *et al*., 2001), tree size and shape, bean size, shape and color and in cup quality.

2.2. Economic Importance and Uses of Coffee in Ethiopia

Coffee has been used by Ethiopians before its migration to Arabia Felix (Yemen). However, the history of coffee as economically important crop goes back only to the 15th century when the world supply came from Yemen. Currently, it is the world's most popular non-alcoholic beverage and the second most important commodity in global trade rated after petroleum products (Birhane, 2002; Prakash *et al.,* 2002). It is exported in various forms to more than 165 countries (Birhane, 2002). Coffee is the leading global beverage after water and its trade exceeds US$ 10 billion worldwide (Vega, 2008). Historically, Ethiopia is the oldest exporter of coffee in the world and it is the largest coffee producer and exporter in Africa (Nicolas, 2007; ICO, 2013). Coffee is a means of subsistence for the rapidly growing population of the country as a complement or even sole source of income, and it plays a fundamental role in both the cultural and socio-economic life of the nation (LMC, 2003). Moreover, the processing and marketing of coffee creates employment opportunities for many people, thus making considerable contributions to the economy (Abebe, 2005).

Generally, the majority (90-95%) of coffee production in Ethiopia is produced by smallholder farms (Awoke, 1997; Grundy, 2005; Tadesse and Feyera, 2008). Ethiopian farmers normally produce nine spectra of the finest single-origin/speciality coffees (Jimma, Nekemte, Illubabor, Limu, Tepi, Bebeka, Yirga Chefe, Sidamo and Harar), which are now well diffused into the trade circuits of the coffee industry (Mekuria *et al*., 2004). Ethiopia is currently the fifth largest coffee producer worldwide (ICO, 2014). The average annual production amounts to about 270,000 tones (ICO, 2010). It is by far Ethiopia's most important export crop (1/3 is exported to Germany) and, with 35%, contributes decisively to the country's foreign currency income (IMF, 2007), but Abu and Teddy (2014) estimated down the contribution to 25%.

Although coffee is popular as a non-alcoholic beverage, it combines valuable qualities such as medicine, food and beverage. Traditionally it served human beings since the prehistoric times to medicate different diseases. Shetty *et al*. (1994) demonstrated the medicinal value of coffee by testing coffee extracts for the control of *Staphylococcus aureus, Vibrio cholerae* and *Salmonella typhi*. All 25 tested strains of *Salmonella typhi* were sensitive to coffee extracts.

2.3. Coffee Quality

Quality is a trait difficult to define. According to any dictionary, it is an "inherent or distinguishing characteristic" (Leroy *et al*., 2006). The International Organization for Standardization (ISO) describes quality as "the ability of a set of inherent characteristics of a product, system or process to fulfill requirement of customers and other interested parties" (ISO, 2000).

The quality of a good cup of coffee, as experienced daily by millions of consumers is not a matter of chance. It is the result of a quality assurance program implemented by all the key players of the coffee production to consumer chain (Prodolliet, 2005). Coffee quality is of critical importance to the coffee industry. Quality coffee is a product that has desirable clean raw and roasted appearance, attractive aroma, and good cup taste.

The ISO (2004a) defined a standard for green coffee quality (ISO 9116 standard). It 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.

2.3.1. Quality assurance

Quality as it is defined by ISO (2000) is the ability of a product to satisfy consumer's expectation. The expectations of the consumer regarding coffee quality are rather high. They mainly include: Good sensory characteristics (eg. aroma, flavor, body and acidity), absence of off flavors (eg. mouldy, earthy, fermented, and chemical), and safety (absence of contaminants, like pesticides, mycotoxins), environmental aspects (e.g. organic product).

All these quality characteristics are not a matter of chance. They are the result of planned and systematic activities, prevented measures and precautions taken to ensure that the quality of coffee is attained and maintained day after day. This is the meaning of quality assurance (Dessie, 2008).

The quality of coffee predetermined by the genotype, the climatic conditions and the soil characteristics of the area in which it is grown (Dessie, 2008). Therefore, a quality assurance program has to be implemented by all the key players of the coffee production to consumer chain to achieve the common goal: quality and as a consequence, consumer satisfaction (Prodolliet, 2005).

Quality assurance can be described from the level of a soluble coffee manufacturer, focusing on the main controls carried out from the reception of the raw material up to the release of the finished packed product (Prodolliet, 2005).

2.3.2. Physical and organoleptic variations

The assessment of coffee organoleptic quality is a difficult task. Organoleptic quality measurement relies overall on sensory evaluation. Two types of analysis are commonly used (ICO, 2004). The first one, named "hedonic analysis", evaluates the preference of consumers. It has to be performed on a panel of at least 60 spontaneous assessors that represent the population of whose preference is sought. The second method is termed "descriptive analysis". Trained assessors can discriminate coffees using, for example, a triangular test. Three cups of coffee are served, two cups containing the same coffee. The assessor has to determine which cup is unique. Expert assessors can describe a profile. It is a complex procedure which uses some specific descriptors. There are some existing glossaries (Lingle, 1986; ITC, 2002; ICO, 2004), but ISO elaborated a list of descriptors specific for coffee (Prodolliet, 2005). Expert assessors (at least 5) have to be trained to use the vocabulary. Assessment of coffee organoleptic quality is an extremely demanding exercise; indeed the flavor obtained in a coffee cup is the result of multiple aromatic compounds present in the coffee (more than 800 in the roasted coffee) (Leroy *et al*., 2006).

Aroma is the most important parameter in the appreciation of organoleptic quality of the cup, mainly due to the volatile (Viani, 2003) substances present. 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 is underway. These predictors include quantification of chemical compounds present in green coffee (sugars, lipids, proteins, chlorogenic acids, and methylxanthines) via the traditional wet chemistry method and indirect methods like Near Infrared spectra (Bertrand *et al*., 2005).

Acidity indicates the bitter or acidic balance (Viani, 2003) and the presence of a sweet caramelic after taste (Petracco, 2000). High acidity gives better quality and more intense aroma to the beverage (Clifford, 1985; EAFCA, 2008). The preferred pH range for coffee beverage is 4.9 to 5.2 (Petracco, 2000).

Body is the viscosity of the brew, fullness and weight in the mouth, ranging from thin and watery to thick and heavy, where it is associated with a good body, as shown by the comparison of a correctly prepared cup with a poorly prepared one when using the same blend (Viani, 2003). However, there is no simple relationship between instrumentally measured beverage viscosity and professionally judged body (Clifford, 1985).

Flavor is the coffee's principal character, the mid-range notes, in between the first impression given by the coffee's first aroma and acidity to its final after taste (Agwanda, 1999). It can be indicated by inhaling the vapor arising from the cup or nasal perception of the volatile substances evolving in the mouth (Petracco, 2000). Since 2002, the International Coffee Organization (ICO, 2002) implemented a Coffee Quality Improvement Program (CQP) with recommendation to exporting countries. It is not recommended that coffee be exported with the following characteristics: for Arabica, in excess of 86 defects per 300g sample (New York green coffee classification/Brazilian method, or equivalent). Also ISO (2004b) has established a standard (ISO 10470) that describe defects as: foreign materials of non-coffee origin, foreign materials of non-bean origin, such as pieces of parchment or husks, abnormal beans for shape regularity/integrity, abnormal beans for visual appearance, such as black beans and abnormal beans for taste of the cup after proper roasting and brewing (Leroy *et al*., 2006).

With regard to bean size, ISO defined as grade from a commercial point of view, is an important factor since price is related to the coffee grade (small beans of the same variety can bring lower prices). Roasting should ideally be carried out with beans of the same size. When unevenly sized beans are roasted, the smallest tend to burn and the largest tend to be under-roasted, affecting the visual appearance of the beans and, more importantly, the cup quality (Barel and Jacquet, 1994; Leroy *et al*., 2006).

Bean size is among the most important attributes determining coffee quality (Tesfaye *et al*., 2008). It is determined mechanically using metal screens with round (normal bean) and slotted (pea berry) perforations varying in size. Green bean color is a good indication of freshness, moisture content homogeneity: a green-bluish color of washed Arabica is sign of high quality. Freshly roasted Arabica coffee having a bright and even appearance with white and tight centre-cuts will usually produce a good quality beverage (Van der Vossen, 2004).

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. SL28 had big sized beans and excellent cup quality, while Caturra and Rume Sudan had small sized beans and lower cup quality. On the other hand, Hybrido de Timor had fairly big sized beans but poor cup quality (Van der Vossen, 1985). Owuor (1988) compared Ruiru 11, SL28 and K7 in cup quality and bean characteristics and reported their similarity for both traits.

Generally, both physical and organoleptic attributes are an important attribute of coffee and used for quality evaluation (Kathurima *et al*., 2009). However, Agwanda *et al*. (2003) and Roche (1995) stated that bean physical quality traits were not useful for enhancement of genetic gains on cup quality and vice-versa.

2.4. Factors Affecting Coffee Quality

Coffee quality is a complex trait that relies on multiple factors that are harvest and postharvest procedures (moisture content, number of defects in coffee batches for instance), physiological, non-genetic and genetic factors (Leroy *et al*., 2006) and other factor affecting quality attributes will be presented below.

2.4.1. Genetic factors

Genetic origin (species and genotype) will greatly influence coffee quality (Leroy *et al*., 2006). Comparisons of different varieties based on organoleptic evaluation and several scientific procedures indicate that similarities and differences are attributable to genetic traits (Ky *et al*., 2001; Silvarolla *et al*., 2004). Benoit *et al*. (2006) reported the effects of variety and elevation on cup quality. Substantial variation was also observed in green bean caffeine, chlorogenic acids, sucrose and trigonelline contents (Ky *et al*., 2001; Silvarolla *et al*., 2004), tree size and shape, bean size, shape and color and cup quality.

Flavor is a very complex trait that is affected by many genetic components and non-genetic factors, not all of which are known or well understood (Goff and Klee, 2006). And also, physical quality like shape and make is affected by the type of the variety (Yigzawu, 2005: EAFCA, 2008; Endale, 2008; Mekonen, 2009) and size difference of coffee beans were influenced by botanical variety (EAFCA, 2008).

2.4.2. Environmental factor

Coffee is going through a surplus production crisis, which has caused prices to slump to record lows. Gourmet coffees are resisting the crisis better. Indeed, their taste characteristics, or simply the production methods used, make them original products that fetch a better price, as they are sought after by roasters and consumers. The emergence of these quality coffees on the market explains why coffee producing countries are showing an increasing interest in environmental factors and local techniques that affect quality, ie *terroir* effects (Avelino *et al.*, 2005).

It also depends on the exposure of the slope on which coffee trees are grown. For some cultivated plants the effects of slope exposure on end-product quality have long been known. Such is the case with the grape vine, grapes and wine (Avelino *et al*., 2005).

2.4.2.1. Altitude

The environmental factors most frequently mentioned are altitude and rainfall (Avelino *et al*., 2005). High respiration rate, combined with the generation of heat, causes a loss of weight and dry material in the bean as well as the decomposition of components, like fats, which play an important role in the aroma. Higher altitude favors better aroma and flavor formation. Altitude also tends to have a positive effect on acidity while reducing bitterness (Decazy *et al.*, 2003). Environment, genetic, and the interaction of both factors influence "typicity" of coffee cup quality (Mawardi *et al.*, 2005). Altitude has indirect effect on quality of coffee by affecting the leaf to fruit ratios and higher at high elevations than at low elevations because of leaf life span is longer (Vaast *et al*. 2004). Furthermore, berry flesh ripening is delayed at the lower temperatures encountered at higher elevations, allowing longer and better bean filling (Vaast *et al.*, 2006). In addition, physical quality like shape and make and size of the bean is affected by the environment where the coffee is growing (EAFCA, 2008; Endale, 2008; Mekonen, 2009).

Climate, altitude, and shade play an important role through temperature, availability of light and water during the ripening period (Carr, 2001; Decazy *et al*., 2003). Rainfall and sunshine distributions have a strong influence on flowering, bean expansion, and ripening (Camargo and Marcelo, 2009). For instance, chlorogenic acids and fat content have been found to increase with elevation in *C. arabica* L. (Aluka, *et al.* 2006). Benoit *et al*. (2006) reported the effects of elevation on cup quality. The production system is one of the factors that govern the shape and make quality of the beans (rounded, oval, elongated, bourbon, flat, etc) (Endale, 2008).

2.4.2.2. Soil

The role of soil types has been well studied. It is generally admitted that the most acidic coffees are grown on rich volcanic soils (Harding *et al*., 1987). Literature show that volcanic soils often produce a potent acidity and a good body, and such soils can lead to a more balanced cup (Decazy *et al*., 2003: Bertrand *et al*., 2006). In the natural habitat of coffee, soils are acidic to slightly acidic with limited phosphorus availability (Feyera, 2006). Coffee grown with heavy application of nitrogen fertilizer had poorer, lighter and thinner quality than that from unfertilized fields. On the other hand, magnesium deficiency had an adverse effect on cup quality (Mitchell, 1988).

2.4.2.3. Shade

Shade decreases coffee tree productivity by about 20%, but reduces the alternate bearing pattern (Avelino *et al*., 2007). Shade positively affects bean size and composition as well as beverage quality by delaying berry flesh ripening by up to one month. Higher sucrose, chlorogenic acid and trigonelline concentrations in sun-grown beans than in shade-grow beans suggest incomplete bean maturation and account for increased bitterness and astringency of the coffee beverage (Muschler, 2001; Vaast *et al*., 2006).

Muschler (2001) reported that shade improved the appearance of green and roasted coffee beans as well as the acidity and body of the brew, especially for those produced in suboptimal (low altitude) coffee production zones, by promoting slower and balanced filling and uniform ripening of berries. Likewise, Yilma (1998) reported that shade increased sugar concentration, which is an important factor for creating the aroma of coffee.

2.4.2.4. Temperature

The optimum mean annual temperature ranges from 18 to 22 ^{0}C. Temperature above 23 ^{0}C accelerates the development and ripening of fruits and can provoke loss of physical and beverage quality. High temperature above 30 ^{0}C during blossoming associated with prolonged dry season may cause abortion of flowers. The best quality Arabica coffee is grown at higher elevations with less extreme weather conditions and milder average temperatures. Lower temperatures, and their longer daily amplitudes, tend to induce slower growth and more uniform ripening of the berries, and produce larger and denser beans. Bean size and density is often correlated to aroma, flavor and superior beverage quality.

2.4.2.5. Rain fall

Water availability is one of the most important factors controlling the distribution of plant species at the global scale. It has generally been agreed that *Coffea arabica* needs a prolonged dry period to flower, and a coffee tree has generally low rates of water uptake (Wintgens, 2004). However, depending on soil moisture, the water relations of trees are dectated both by the liquid water coming from the hydraulic system and the subsequent stomatal reaction regulating the water vapour loss. This allows the plant to maintain a certain minimum leaf water status, which is determined by genetics and the environment. For modern varieties of *Coffea arabica*, it was discussed if the hydraulic system was the limiting factor for water transport under drought stress (Tausend *et al*., 2000). In Ethiopia, a good number of improved coffee management practices have been developed by research (Yacob *et al*., 1996), but information on the ecophysiological aspects of water relations and hydraulic properties is lacking.

Plants are frequently subjected to periods of water stress, which ultimately leads to reduced growth and productivity by affecting various physiological and biochemical processes. However, they have evolved different strategies to cope with water deficits through avoidance or postponement of dehydration or stress tolerance (Pugnaire *et al*., 1999). There exist variations among species or between genotypes within a species for acquiring different physiological, morphological and biochemical strategies for survival and even maintenance of some growth and physiological processes under stressful conditions (Kozlowski and Pallardy, 1997; Joshi, 1999). According to an experiments carried out at Jimma Research center, it was observed that there were significant differences among the cultivars released for sensitivity to water stress. Based on mean rate of stress development, cultivar F-59, 7395xF-59, J-19, 7454, 754, 75227 and *Geisha* were identified as more sensitive than 7487, 74110xF-59, 741, J-21, 744, 741xF-59, 74158, 77/85, 7395, F-35, 74148 and 74165, while 7440, 74140, 74110, 74112 and 8/85 were found to be relatively tolerant to the imposed soil drying treatment (Tesfaye and Esmael, 2008).

2.4.3. Physiological aspects

Physiology of the plant affects coffee quality (Leroy *et al*., 2006). Physiological stresses such as over-bearing reduce bean size as a result of carbohydrate competition among berries during bean filling (Bertrand *et al*., 2004; Vaast *et al*., 2006). Tree physiology, plant age, and period of picking all interact to produce the final characteristics of the product. Indeed, it was found that tree age, location of the fruits within the tree, and fruits-to-leaves ratio had a strong influence on the chemical content of green beans (Bertrand *et al*., 2005; Vaast *et al*., 2006). Wellman (1961) reported that samples from young trees are likely to be mild and thin, but fine in flavour while samples from old trees produce strong taste and a harsh characteristic brew. The author also stated that medium aged trees, 15 to 20 years old, bear beans with good flavor as well as acidity and body.

2.4.3.1. Changes during coffee fruit development

In both species of Arabica and robusta, coffee fruits are classified as “drupes”, characterizing a pulpy mesocarp with lignified endocarp. At the beverage quality level, coffee from beans of *C. arabica* is preferred by consumers mainly in view of its lower bitterness and better flavor (De Castro and Marraccini, 2006). It is now well known that some compounds that accumulate in mature coffee beans play an important role in the quality of the beverage. For example, sucrose, which ranges from 6 % to 8.5 % in Arabica and from 0.9 to 4.9 % in Robusta (Campa *et al*., 2004), is considered as one the major contributors to coffee cup quality because its degradation during roasting leads to a wide range of compounds (i.e. aliphatic acids) involved in coffee flavor, either as the volatile aroma compounds, or as non-volatile taste compounds (Ginz *et al.,* 2000). In contrast, caffeine and chlorogenic acids (CGA) are found at higher levels in Robusta than in Arabica, and are responsible for beverage bitterness (Leloup *et al.*, 1995).

2.4.3.2 Tissue evolution and changes

In the genus *Coffea*, the fruit development covering the time between anthesis and full ripening is variable from few (10 to 12) weeks, as in *C. racemosa* and *pseudozanguebariae*, to more than a year for *C. liberica*. For the species of high economic value, *C. arabica* requires 6 to 8 months to mature while *C. canephora* requires 9 to 11 months (De Castro and Marraccini, 2006). Fruit growth is asynchronous during development, with different proportions of various fruits sizes on the same plant. Although possibly related to the several flowering events that may occur in *C. arabica* during each production season, a tendency for synchrony was observed during the later stages of maturation when a significantly higher proportion of fruits entered the largest sized ripe 'cherry' stage (De Castro *et al.*, 2005). Despite the asynchrony in fruit growth and differences in the length of the reproductive cycle between coffee species, key steps of fruit and seed development appear to be identical, at least between the commercial species. In *C. arabica* var. Bourbon, for which a detailed study of tissue evolution was reported, a rapid growth of fruits was observed between 0 and 7 WAF (weeks after flowering), reaching its maximum final size at 17 WAF (Wormer, 1966).

The initial growth coincided with the sudden development of the perisperm up to 11-12 WAF, at the time when the endosperm had also begun to be identified. Thereafter, the endosperm continued to grow gradually, until completely occupying the space (locule) left by the inner portion of the perisperm at around 19 WAF, as observed for *C. Arabica* var. Acaiá Cerrado. At the maturity stage of the coffee fruits, usually occurring around 30 to 35 WAF, only the outer layer of the perisperm tissue remains surrounding the endosperm, sometimes referred to as the "silver skin" (De Castro *et al.,* 2005). The endosperm actually corresponds to the bean that, after the post-harvest treatments, will form the "green coffee" that is sold in the international markets.

2.4.3.3 Cell cycle events

Pericarp*:* The pericarp is composed of several tissues: the exocarp (peel), the mesocarp and the endocarp. The exocarp persists as a green colored tissue during most of the coffee fruit development, becoming transiently yellow and then red at the final stage of development. The change in color is due to the disappearance of chlorophyll pigments and anthocyan accumulation during the last stages of fruit maturation (Marín-López *et al.*, 2003). In some natural mutants of *C. arabica*, also referred to as yellowish ("Amarelo") cultivars, the exocarp does not become red, but apparently remains yellow at the mature stage. Whatever the species considered, the change in color is of great importance since it is the main criterion for fruit maturation, even if the absence of coupling between the maturation of pericarp and endosperm (bean) has also been observed (De Castro and Marraccini, 2006).

The mesocarp, also commonly referred to as the "true pulp", is rich in sugar (both reducing sugars and sucrose) and water. With 0.5-2 mm thickness, it can be divided into the external and internal parts. The former is formed of parenchyma cells with compact and dense cell walls in green fruits that become thinner during maturation, probably due to pectin modifications. However, the cytological structure of the internal mesocarp, also referred to as the mucilaginous tissue in mature fruits, is still controversial (De Castro and Marraccini, 2006).

In the most internal location, the endocarp (also called parchment layer or "pergaminho") is a hard and lignified tissue (De Castro and Marraccini, 2006), and was proposed to protect the coffee seed against digesting enzymes from the gut of frugivorous animals (Urbaneja *et al.,* 1996).

In immature green coffee berries, the exocarp is a photosynthetically active tissue and could contribute to supply the needs of carbohydrates especially during the bean filling stage (Vaast *et al.*, 2006).

Perisperm: The coffee perisperm, which has also been in the past referred to as the "integument" or "spermoderm", develops from the nucellus of the ovule soon after the fecundation. Its persistence up to the mature stage was still a matter of debate since several articles reported the mature coffee bean as being composed of perisperm (West *et al.,* 1995).

At the mature stage, the perisperm appears as a thin pellicle of thick silver skins, and has been characterized as being formed by sclerenchyma cells organized longitudinally, probably arising from absorbed perisperm cells, a phenomenon often observed in dried coffee berries or beans as a result of dehydration (De Castro *et al.*, 2005). Because of the sporophytic origin of the perisperm, it has been proposed that the maternal genome could be in part responsible of some physical final characteristics of the coffee beans, like the final size of the coffee bean (Rogers *et al.*, 1999b).

Endosperm: As in other plants, the endosperm of coffee is a triploid tissue with a non-sporophytic origin. Cytological observations carried out a few days after anthesis already allows its identification, as the embryo sac. However, it can be easily identified and separated from the perisperm because of its milky color only after 90 DAF. Up to this stage, endosperm cells are characterized by thin cell walls that then begin to thicken between 130-190 DAF, due to the deposition of complex polysaccharides like arabinogalactans and galactomannans. At the mature stage (around 230 DAF), the endosperm contains polyhedric cells that could be isodiametrically divided into hard external endosperm, with cells of a polygonal shape, and a soft internal endosperm with rectangular cells (De Castro and Marraccini, 2006).

2.4.3.4. Maturation Classes and Subclasses

The replacement of chlorophyll in the pericarp by red flavonoid pigments indicates maturity. Hence, the color of the cherry is a good marker of maturation (Marín-López *et al.,* 2003). The uneven and slow maturation of coffee cherries (6-8) and (9-11) months for the species of economic value, *C. arabica* and *C. canephora,* respectively results in the coexistence of green (unripe), red (ripe), and dark red (over-ripe) cherries on the same tree. An experiment was done on Robusta green coffee samples (*C. canephora* Pierre ex A. Froehner, Rubiaceae) which were obtained from Cagayan, the Philippines. They used this marker to segregate harvested cherries into three maturation classes, which were called green mature, red ripe, and over-ripe (corresponding to a light green, yellow orange to red, and dark red to brown pericarp, respectively). After postharvest treatment, they observed heterogeneity among the green beans corresponding to each maturation class. Some beans failed to display any integument, commonly called silver skin. They belong to the “no silver skin” subclass. Among the beans harboring a silver skin, green and red-brown silver skins were observed. They belong to the “green silver skin” and “foxy silver skin” subclasses, respectively.

The quantitative distribution of subclasses within maturation classes suggests that the green silver skin turns into foxy silver skin upon contact with the red flavonoid pigments that appear with maturity. The green silver skin subclass was best represented among green mature beans (59.5%), whereas the foxy silver skin subclass was found exclusively among red ripe and over-ripe beans (60 and 64%, respectively). The no silver skin subclass was, however, present in significant amounts in all three maturation classes (21-33%) (Montavon *et al.*, 2002). Based on this experiment, quality improved with maturation. Quality grading of each type of subclass was remarkably consistent across maturation classes. Surprisingly, among all subclasses, the no silver skin subclass achieved highest quality regardless of maturation. This trait is of great interest because it confers the potential to produce quality coffee on immature beans (Montavon *et al.*, 2002).

According to the experiment conducted in Australia a surprising finding occurred with the whole green immature cherry sample. This stage is usually rejected before pulping; however they were sundried as a whole cherry in this trial. The cupping evaluation revealed “a surprising finding that by sun drying green cherry until it is matured and ‘raisin-like’, improves flavour”. This surprising result supports the results of the preliminary trial conducted during the 2008 season where the highest cupping score was achieved by blending immature green cherry with the overripe ‘naturals’(Peasley, 2010). The same author reported that“Overall the coffees in general, the green semi-coloured prime red past prime purple cherry, exhibited smooth, mellow flavour with medium body and low acidity, free of taints and faults. The coffees would lend themselves to being marketed according to ‘terroir’ and possibly stomach friendly.

Maturation has a strong influence on coffee quality. It was explained that yellow or green cherries of *Coffea canephora* Pierre ex Froehn harvested at the end of the picking season contain more mature beans (based on bean size, chemical composition and cup quality) than red cherries harvested at the begining of the picking season. However, for *Coffea arabica* L. in Costa Rica, early picking gives the best coffee (Bertrand *et al.*, 2005).

An Experiment was conducted in Thailand based on cherry maturity and drying temperature by Srirat *et al.* (2007). They reported that Cherry maturity is the other factor affecting coffee quality. Results showed coffee beans from 50% ripe cherries and beans from strip method cherries contained black beans higher than 2% that were considered as the low quality beans according to commercial standard. The black beans occurred should be caused by unripe cherries, the black beans increased corresponding to increasing of unripe cherries. However, treatment of 100% and 75% ripe cherries present good characteristic with slightly broken beans and no brown beans at all and similar result was observed for both cup quality and chemical composition. Therefore, in order to obtain good quality coffee beans, the mature cherries should be used as raw material in coffee processing (Menezes, 1994; Mazzafera, 1999: Srirat *et al.*, 2007).

When the cherry has matured and is ready for picking, it usually turns from green to slightly red and then to glossy red when fully ripe. However, fruits of yellow-fruited varieties such as ‘Yellow Caturra’ or ‘Yellow Catuai’ remain yellow and do not turn red when fully ripe or even overripe. Another test for maturity for harvesting is if the seeds (the parchment coffee with bean inside) can be squeezed out by hand. If the fruit is hard and the seed cannot be squeezed out, the fruit is too immature to pulp. Under conditions of overbearing dieback, the fruit may turn from green to reddish brown. These fruits are usually smaller than normal and probably contain immature, low-quality beans; these fruits generally float and are removed during processing, but according to tests conducted at the CTAHR Kona Research Station a yellowish-green skin; hard-ripe, which is firm and red (or yellow); and soft-ripe, which is overripe, red to dark red, soft, and juicy stages what might be called ripeness stages, were noted as early as 1937 to have similar cupping qualities (Bittenbender and Smith, 2008).

2.4.3.5 Maturation and Phenolic compounds

According to Silva (2000), total CGA levels present and inverse association with coffee quality, with higher CGA content being observed in lower quality samples. The presence of defective coffee beans is also relevant in establishing coffee quality. The CGA content of most defective beans, excluding physical defects (bored, broken, etc.) and defects of extraneous matter (husks, twigs, stones, etc.), appears to vary according to the degree of maturation of the fruit that generates the respective defect (Farah *et al.*, 2006b).

The main defects occur due to strip-picking of immature and overripe fruits along with ripe (cherry) fruits. The five most common defects in coffee that may considerably affect cup quality are immature beans (originated from immature fruits), immature-black beans (immature beans with oxidized skin), black beans (from over-ripened fruits) and sour beans (from fruits fermented on the ground or due to improper processing conditions). Comparing immature and immature-black beans with good quality beans, Mazzafera (1999) observed that the contents of total phenolic substances and 5-CQA were higher in immature and immature–black defective beans. Franca *et al.* (2005) found lower levels of 5-CQA in black defective beans, compared with good quality and immature defective beans. After analysis of eight CGA isomers in defective coffee beans, Farah *et al.* (2006b) also observed that immature and immature-black defective beans contained significantly higher levels of all CGA isomers, particularly CQA and FQA, compared to healthy and black defective beans.

2.4.4. Harvesting and post-harvest handling

Ideal conditions for coffee production such as the agronomic factors of soil nutrition, shading, watering and superior genetics will not yield high cup quality without optimal harvesting, processing, storage and brewing. But, the varieties cultivated, harvesting time and postharvest processing play a predominant role in obtaining a quality coffee (Avelino *et al*., 2005).

Coffee fruits are processed using several different steps for beverage production; these steps have a pronounced effect on the final quality of the resulting beverage (Mazzafera & Purcino, 2004; Bytof *et al.,* 2005; Selamer *et al.,* 2006). Coffee fruits are harvested when the fruits are in the 'cherry' stage (the fruit turns red as it ripens). Each fruit consists of a peel (exocarp), the pulp (mesocarp) and the parchment (endocarp), which are surrounding the beans (seeds). Within the pulp, the seeds are covered by a thin parchment-like hull. Both the pulp and hull are removed before the coffee beans are roasted (Arya & Rao, 2007).

According to Van Der Vossen (2009) only freshly harvested and fully ripe berries should be used in any of the three methods of primary processing. Those methods include washed, semi-dry and dry processing. Hand picking coffee beans is one method for accomplishing such distinction but there are methods of mechanized picking that separate the immature green from the ripe cherry before processing. In the dry method, intact coffee fruits are submitted to natural or artificial drying. The drying must be uniform throughout, and when the sun drying, the beans must be mixed frequently. After drying, the beans are then mechanically peeled, selected and stored as raw green beans (Arya & Rao, 2007). For the semi-dry method, coffee fruits are processed by pulping machines for removal of the peel and pulp before drying.

2.4.4.1. Harvesting

It is agreed by the International Organization for Standardization (ISO), that traditional hand-picking and husbandry labor, as opposed to mechanical harvest, produce the best quality green coffee by decreasing the percentage of defects in coffee batches. Then, depending on the postharvest process, strong consequences on coffee quality can be observed. However, picking of red cherries is one of critical points to have the best quality coffee (Bertrand *et al.*, 2005; Mawardi *et al*., 2005). For instance, if coffee is harvested at immature stage, the end product will show color defect and cause of uneven roasts, i.e. grayish or dark grey beans which leads to bean color and test of coffee classified as undesirable (Anwar, 2010). Unripened coffee beans tend to produce astringent, bitter and "off" flavored beverages but unripened beans can be sorted before processing to mitigate negative effects on batch quality.

In addition, if coffee is harvested after the cherries are over ripe, the beans become foxy and the end product will affect the cup cleanness (Behailu *et al*., 2008). The type of odor that a given coffee sample possesses depends on the way coffee is harvested (Endale, 2008).

2.4.4.2 Coffee processing

Processing methods had been known to be important for coffee quality (Jackels *et al*., 2006). The quality of coffee will be the main stay in the trade especially when the coffee is a surplus commodity and when the coffee prices are at low. In coffee the main indices of acceptability include raw (moisture, size, color, presence of defects, foreign matter etc…) roast bean visual characteristics and cup or liquor quality (body, acidity and aroma) attributes. Processing is a major activity in coffee production chain and the most important from a quality point of view. Coffee processing involves series of stages each of which has a distinct purpose (Velmourougane, 2011). There are basically two methods of coffee processing which differs in complexity and the resultant raw coffee differs in quality characteristics. These are; the wet method by which plantation or parchment coffee is produced and the dry method by which natural or cherry coffee is produced.

2.4.4.3 Comparison of dry and wet method

Coffee fruits are processed using several different steps for beverage production; these steps have a pronounced effect on the final quality of the resulting beverage (Mazzafera & Purcino, 2004; Bytof *et al.,* 2005). Coffee fruits are harvested when the fruits are in the 'cherry' stage (the fruit turns red as it ripens). Each fruit consists of a peel (exocarp), the pulp (mesocarp) and the parchment (endocarp), which are surrounding the beans (seeds). Within the pulp, the seeds are covered by a thin parchment-like hull. Both the pulp and hull are removed before the coffee beans are roasted (Arya and Rao, 2007). After harvesting, the fruits are usually processed by one of the following techniques: the dry method, the semi-washed method and the wet method (Arya & Rao, 2007). Coffee processed by wet method helps to preserve the intrinsic quality of the bean better, producing a green coffee, which is homogeneous and has few defective beans. Hence, the coffee produced by this method is usually regarded as being of better quality and fetches higher prices. Although some sun dried coffees like Sidamo 4, Lekempti 5 and Harar coffees have high demand in the specialty coffee market, others like Jimma 5 are inferior in quality mainly due to poor choice of processing strategy (Desse, 2008).

The chemical composition of the raw coffee beans depends on the processing manner used (Knop *et al.,* 2005). Wet processing is initiated by picking fully red (mature) cherries then followed by sorting of inferior cherries, removing coffee pulp, fermentation, washing, sun drying on the racks or cement concrete (GTZ, 2002; Paulo *et al*., 2007). This method is very important to extract the best cup quality of coffee mainly aroma, flavor and acidity (Clark, 1985). In contrast, in the dry processing, the farmers usually do strip picking, which is mainly dominated by yellow and green cherries, and then the cherries are sun dried for about two weeks over cement concrete or bare soil. Because of the preparation is very poor, dry processed coffee has low aroma, flavor and acidity (Mawardi *et al.,* 2005). It is important to be noted that dry processed coffees provide defect taste of ferment and earthy (Dessie, 2008). Several farmers remove coffee husk soon after the cherries dried; however, some of them store the dried cherries for several months (Mawardi *et al.,* 2005). In contrast, the wet processing coffee provides medium to medium-high of these characteristics (aroma, flavor and acidity). For instance, dry processing is generally avoided for quality samples as it enhances bitterness in the liquor (Barel and Jacquet, 1994). However, dry processed (natural) coffees have a full body and natural sweetness of the beans (Davids, 2001; Selmar *et al*., 2001; Bacon, 2005).

The specific ambient conditions of any type of post harvest processing can have significant impacts on the time course of the metabolic reactions that occur during that processing period. The extent and the time courses of germination in various coffee beans were found to be significantly different between dry and wet processing styles. The highest germination activity was found to occur 2 days after the onset of wet processing and approximately 1 week after the onset of dry processing. It wasconcluded that the substantial differences in flavor between wet and dry processed coffees are the result of the differential expression of germination processes, in other words, they are the result of differences in the metabolic activities that take place in each type of processing (Bytof *et al.,* 2007).

Knopp *et al.* (2005) states that flavor differences in part have to be attributed to differences in the thoroughness applied to either method of post harvest processing as well as the fact that only the fully ripe coffee cherries are typically used for wet processing as opposed to dry processing where fruits of varying stages of ripeness are commonly used. There is a close correlation between the type of post harvest processing and the content of fructose and glucose in the coffee bean. While in washed coffee beans only a small amount of either hexos was present, those in unwashed coffees were significantly higher. It has been revealed that low levels of both fructose and glucose are a result of decrease in the wet process. Fructose and glucose levels stayed near pre processing levels throughout dry processing according to Knopp and his colleagues. Accordingly, it was concluded that the decrease in glucose and fructose in wet processed coffee is as a result of a fermentation enhanced glucose turnover from anaerobic fermentation in the coffee endosperm (Knopp *et al.*, 2005).

In general, washed coffee carefully prepared and handled, is clean in flavor and free from undesirable element.Wet processed Arabica is aromatic with fine acidity and some astringency, while dry processed Arabica is less aromatic but with greater body (Clifford, 1985). The use of ‘under water fermentation, as opposed to ‘dry’ accentuates the formation of acids (Clark, 1985). Dry processing is primarily used to produce coffee of rich “body” and “aroma” and wet processing for fine “aroma” and “acidity” (Viani, 2000).

2.4.4.4 Fermentation

In the washed coffee production, final quality, among other factors is greatly dependent up on the fermentation process (Woelore, 1993). Brownbridge and Michael (1971) have reported earlier results of work done on coffee fermentation in Ethiopia. This studies have led to an amplification of some of the more important aspects of fermentation process, with the result that more efficient procedures of great value to the industry have now be developed. In wet method, the degradation of coffee bean mucilage that enables the mucilage easily separable from the parchment during washing is commonly referred to as ‘fermentation’ of coffee. In wet processing, underwater soaking is one of the important step followed in quality coffee production in India. Under-water soaking is nothing but complete immersion of washed parchment under clean water for specific time. Under-water soaking of washed wet parchment for specified period was reported to improve raw and liquor quality of coffee by way of leaching some of the chemical compounds (diterpenes, poly phenols, tannins etc.) responsible for bitterness and browning of coffee beans (Mburu, 1999). Similarly, for Ethiopian conditions an under water fermentation technique is recommended (Woelore, 1993).

Velmourougane (2011) reported improvement in coffee quality by post-fermentation soaking in 1% sodium bisulphate and sodium metabisulphite solutions respectively. Improvement of quality has also been observed by under-water soaking for 24 hours. In recent time studies have revealed that presence of some acids (Phosphoric, Quinic, Lactic, Citric, Acetic, Malic etc.,) impart specific acidity to the final cup of coffee, the presence and absence of these acids may contribute unique flavours, aroma and sparkle to the brew of high grown coffees. On contrary, Brownbridge and Michael (1971) have reported that the method of removing the mucilage (dry fermentation, under water fermentation, peptic enzyme-accelerated fermentation, or chemical cleaning) has no effect on the liquor quality and there is no evidence that any one method can produce significantly better liquors than another. There is, thus, no quality advantage gained by developing a system of mechanical demucilaging, although such a system may have other attractions.
Acidity is a sharp and pleasing taste, as opposite to sour taste, which may indicate signs of fermentation and best appreciated in a low roasted filter coffee (Viani, 2000). Malic, citric, tartaric, lactic, acetic, phosphoric and cholorogenic acids are the compounds which contribute to overall acidity and give a brew its particular identity (Terry Mabbett, 1999).

2.4.4.5 Influence of the postharvest processing method on polysaccharides and coffee beverages

It has been pointed out that beverages from coffees processed by different methods have significant differences (Selmar *et al.,* 2006; Leloup *et al.,* 2008). The final quality of the beverage depends on several variables, such as the chemical composition of the beans. This composition may be affected when the color and the flavor attributes are changed within the beans during postharvest processing (Mazzafera & Purcino, 2004; Arya & Rao, 2007). It is currently accepted that the metabolic reactions in the coffee fruits that occur during different types of processing can affect the chemical composition of beans and thereby affect beverage quality (Bytof *et al.*, 2005, 2007).

Tarzia *et al. (*2010) reported that the extraction of polysaccharides from the seeds isolated from the unprocessed coffee fruits and from the fruits processed by the dry-, semi-dry and wet postharvest methods showed that the postharvest processing increased the extractability of polysaccharides from coffee beans. Structural aspects of polysaccharides from unprocessed green coffee beans might also differ from those that were submitted to postharvest processing, and the changes are dependent on the mode of postharvest treatment (Tarzia *et al.,* 2010).

Tarzia *et al. (*2010) proved that the polysaccharide for the dry processed and semi-processed fractions, which were obtained from coffee beans that were not subjected to the fermentation step during the postharvest processing, were almost the same. The protein content was also the same for the fractions of semi washed and dry processed. The removal of the coat before drying did not affect the amount of water-soluble protein extracted from the coffee beans processed using the dry method. However, the amount of protein extracted from these beans was lower than from the beans that underwent fermentation (the wet method) (Selmar *et al.,* 2001).

3. MATERIALS AND METHODS

3.1. Description of the Study Site

The study was carried out in 2011/2012 at Teppi Green Coffee Estate Share Company (TGCESC), the former Teppi Coffee Plantation Enterprise (TCPE). It has different coffe farms at high, medium and low altitude coffee growing areas in the southwestern Ethiopia. The TGCESC possesses about 9000 ha of land holding of which 6400 hectare is covered with coffee plantation.The head office is located at 575 km to the south west of Addis Ababa. The company has five sub farms which are located at 4 to 38 km from Teppi town. The study area included Baya, Kabo and Andiracha representing low, medium and high land coffee farms respectively (Table 1). These are located in Southern Nation and Nationality Peoples and Gambela Regional states at specific site of Teppi (south) and Godare Mezangr (Gambela) (Kabo and Andirach) as described below.

3.1.1 Teppi

Teppi (Baya) is geographically located at $7^0$08’ N latitude and $35^0$17’E longitude at an elevation of 1050-1200 m.a.s.l, in Shaka zone. It is 546 km away from Addis Ababa. The mean maximum and minimum air temperature are 15^0C and 30^oC, respectively. The annual rainfall is about 1630 mm. The dominant soil type is Eutric Nitosols with total coffee area of 1975ha (CPDE, 2011).

3.1.2 Godare

Godare is geographically located at $7^0$08’ N latitude and $35^0$13’E longitude at an elevation of 1200-1900m.a.s.l, in Mazangir zone. It is 576 km away from Addis Ababa. The mean maximum and minimum temperatures are 12^0C and 27^oC, respectively with the annual rainfall of about 1737 mm. The dominant soil type is Eutric Nitosols (CPDE, 2011).

Table 1. Description of the three study coffee sub farms

Descriptions	Andiracha (1600-1900 mts)	Kabo (1200-1600 mts)	Baya (1050-1200 mts)
Geographical location	$7^0$08'N&$35^0$13'E	$7^0$08'N&$35^0$13'E	$7^0$08'N&$35^0$17'E
Distance from Addis Ababa (km)	581	576	546
Altitude of the site(masl)	1810	1415	1095
Temperature:Maximum(^{0}C)	27	28	30
Minimum(^{0}C)	12	14	15
Mean(^{0}C)	19.5	21.0	22.5
Annual Rainfall (mm)	1737	1737	1630

Source: CPDE, 2011.

3.2. Experimental Treatments

The experiment has three factors, namely: Altitude, stages of maturity and processing methods.

Factor A= altitude (L) (three level) 1095, 1415 and 1810

Factor B=processing method (Prm) (three level) dry method, semi wet and wet method

Factor C=maturity stages (Matu) (three level) including light green, yellow and red cherry

3.3. Experimental Materials

The experimental area needed to lay out the experiment at each location was 3000m^2. That is three 7454 variety coffee blocks each 20 ha was selected from the three areas depending on maintenance activity, planting and stumping years. The blocks were stumped with in the same year and fertilized with urea and DAP depending on their productivity per hectar. Other tree and field managements were such as pruning, handling and desuckering, shade management and weeding were practiced depending on the tree and field appearance. Three 100m by 10m area of coffee from each block was selected and cherries were harvested accordingly. About 324kg of light green, yellow and red ripe cherries were harvested at each location a total amount of 972kg of green yellow and red ripe cherries were used for the study.

The variety 7454 is one of the CBD resistant coffee varieties which have been released and recommended for the study areas (EARO, 2004). This variety was planted in July 1989 and a spacing of 1.8 m between plants and 2 m between rows were used in the study. For this, the light green, yellow and red color of cherries (12 kg of 9 samples for each maturity stage) were harvested from respective location and processed with the three processing methods (the dry, semi and wet processing) and dried on the mesh wire.

3.4. Experimental Design and Treatments

The experiment was laid out in a 3×3×3 factorial arrangement in a Randomized Complete Block Design (RCBD) with three replications. Therefore, 27 samples (9 samples from each maturity stage) at each location and a total of 81 coffee samples were prepared for the three processing methods at the three altitudes. The samples were kept free from rain during the day and night time and protected from extreme heat of sun light.

3.5. Experimental Procedures

The required amount of fresh cherries were handpicked and prepared from representative three areas of different altitudes at peak harvest period in November, 2011. After harvesting three maturity stages from each replication the cherries were bulked based on the stages and the samples were carefully divided into equal parts and processed accordingly. For each sample, 12kg of cherries was processed by the wet and semi-washed method to obtain approximately 2.00 kg of green coffee beans and 4kg of cherries for dry method to get approximately 2.00 kg of green coffee beans. Before processing, damaged, defect, and infested berries were removed depending on the stages of maturity and finally siphon method was used to separate floating berries.

3.5.1. Harvesting and Processing

For wet, semi-washed and dry processing, red fully ripen cherries, the yellow colored and the light green stages of maturity were manually picked depending on the color of the cherry(color is used as maturity index) and separated from foreign materials. Then, the prepared samples were processed as described by Woldemichael (1996).

3.5.1.1. Dry processing

Drying: Berries were dried by sun on drying bed made of mesh wire for about three weeks and one month at Teppi and Godare, respectively. The samples were covered by polyten sheet during rain and night time. The moisture content of the bean was measured using Electronic Rapid Moisture Tester (dick jone) and maintained between 10–12% for all samples uniformly.

Hulling: Fully dried coffee was dehulled by local mortars to produce the clean coffee beans and the dehulled beans were used both for cup quality and green bean physical character analysis.

3.5.1.2 Wet processing

Pulping: The fresh red ripen cherries, the yellow colored and the light green cherries were pulped using a disk pulper machine that squeezes the berries between fixed and moving surfaces and well washed by clean water to remove the pulp.

Fermentation: The wet parchment coffees were put in 27 different fermentation buckets to undergo fermentation from 28 to 40 hours at Teppi and Godare respectively to facilitate decomposition of the mucilage (Woelore, 1993). Hand fill texture method was employed to check for the removal of mucilage from the pulped coffee.

Washing: After fermentation the coffee samples were washed using four changes of clean water to remove all traces and decomposed products of the mucilage. Soacking was done for 24 hours with clean water (Woelore, 1993).

3.5.1.3 Semi-washed

With the semi-washed processing method, all the three maturity classes of 27 samples, red coffee cherries, yellow cherries and the light green stages of maturity were depulped and washed with the demucilager machine. The parchment coffee was not treated with fermentation, washing and soaking and directly dried on mesh wire. When the coffee bean reached the final drying, the parchment coffee was bagged with tags.

Drying: The wet parchment coffees were placed on drying table made of meshwire under sun for drying. During drying, the moisture content of the bean was measured by moisture tester (dicky jone) to check and maintain the moisture level between 10–12% for all samples uniformly. Then, the dry parchment coffee was put in sample bags and stored in a well ventilated coffee store at 60% relative humidity and 20 ^{0}C temperature for three months till cup testing.

Hulling: The dried parchment coffee was hulled and polished to get clean coffee beans for quality analysis. Both samples were assigned an arbitrary code (identity letters) in order to secure an unbiased judgment.

3.5.2 Labeling and packing

Each coffee sample was prepared from each sites as indicated during processing and separately labeled. The samples were packed and taken to Addis Ababa Coffee Quality Inspection and Grading Center for quality analysis.

3.6 Data collection

Data for seed moisture content, raw quality attributes of green bean (defect, above screen size, shape and make, color, odor and total raw quality) and cup quality attributes (cup cleaness ,acidity, body and flavor including total cup quality and total quality) were collected.

3.6.1 Quality analysis

Coffee quality analysis was undertaken under laboratory conditions using liquors taste evaluated for raw and cup quality factors. Representative samples were drawn and laboratory size samples were prepared from bulk samples. For further raw and cup quality analysis maximum of 350 gram green coffee sample with optimum moisture content (11.5%) was prepared following the procedure described by Ethiopian Commodity Exchange (2009).

Each sample was prepared and analyzed for their raw and cup quality based on the experimental procedure for their quality. The quality analysis was carried out from May 18 to June 30, 2012. Green bean raw and cup quality characteristics were evaluated by three certified professional coffee tasters (one is Q grader) at Addis Ababa liquoring unit of ECX. Each sample was coded according to the standard procedure used for washed and unwashed coffee raw and cup quality evaluation. Standard parameters and their respective values were used for washed and unwashed coffee raw quality evaluation and grading as per ECX (2009).

General Requirements ;-The moisture content of wet and dry coffee shall not be more than 11.5% and minimum 85% by weight of beans remain on top of screen 14 after sieving. Export green /raw analysis Screen size (>85% on top of screen No.14); Moisture content 9-11.5 % (ECX, 2009). In raw coffee evaluation defect count, overall appearance, color, shape & make and odor were seen. The raw quality for wet and dry coffee constitutes 40% (Defect=20% (primary defects=10% and secondary defects=10%) and Odor=5%and color=5% and shape and make=10%).The cup quality value scores 60 % (Cup Cleanness =15%, Acidity =15%. Body=15% and Flavor = 15 %) and for unwashed coffee constitute 40% (Defect=30% (primary defects=15% and secondary defects=15%) and Odor=10%).The cup quality value scores 60 % (Cup Cleanness =15%, Acidity =15%. Body=15% and Flavor = 15 %) of the overall coffee quality. The comparative sensorial tests describe a grading scale for washed and unwashed coffee as described in ECX procedure (ECX, 2009). The combined effect of green /raw and cup consider to account and using the grade ranges were classified accordingly.

Moisture content: The moisture content of each sample bean was measured with a standard moisture tester (dicky joy) certified and checked by Quality and Standard Authority of Ethiopia. When the moisture content of the dried cherry attained < 12%, it became to be stored until further processing/hulling.

3.6.1.1 Raw coffee quality evaluation (40%)

Physical characteristics of green coffee bean affect beverage quality to some extent. These include defect count, bean shape: round, long; bean size (screen size): small, medium or, bold or; bean uniformity, mixed, uniform; odour and bean color (Kathurima *et al.,* 2009).

Screen analysis: Screening can be done to make size assessment or grading. Based on the outcome, it is possible to easily know as to the sample size (large, bold, medium, and small or light. These were conducted manually by taking 300 gm of green sample from the bulk sample. Various screen size from screen number 10-20 and slotted screen is used to identify the different coffee bean size, so that it is possible to draw the raw quality in relation with largeness, boldness, medium and small bean size. Finally, raw and cup quality evaluations were considered for grading of coffee quality as per the standard procedures (ISO, 2000).

Defects count: It was done by counting different kinds of coffee defects: here black beans, fungus damaged, sever insect damaged, foreign matter out of bean origin were count and give value based on the standard grade indicated in Endale (2008). This analysis was also being undertaken on 300gm green bean sample in which sorting was made by hand picking.

Shape and make: The analysis can be undertaken by recording the attributes that determine the quality of the coffee beans. Shape uniformity and size of the beans i.e., if there is pea berry, round shape, broken bean, and shelled beans were evaluated.

Appearance/Color: The overall appearance (bluish, grayish, greenish faded, whitish etc.) was analyzed in comparisons to the standard. For better coffee (sample), the blue to grayish signifies the most desirable attribute of appearance. The color of the bean were evaluated by visual inspection method ranging from 1 to 10 where, 2=Brownish, 4=Faded, 6= Greenish, 8= Grayish, and 10= Bluish.

Odor: It approves whether the coffee is contaminated with bad odor of foreign material. And it ranges from 1 to 10 where, 1=Strong, 2= Moderate, 5=Light, 8=Trace, and 10=Clean (clean, trace, light, moderate, strong-accounts for (10%).

3.6.1.2 Cup quality evaluation (60%)

Roasting: Roasting was undertaken using 100 gm green coffee bean sample- roasting machine of model Probat Werke type Brz.6 at temperature of 150^{o}C-200^{o}C for 6-7 minutes. The art of roasting is to develop the bean to the exact, where the flavor is brought to its maximum. To attain such objective the degree of roasting matters a lot and as a standard a medium type /degree of roasted bean color light to medium is a desirable standard.

Grinding: Grinding is a physical change or in alternation in form with menaces of reducing the size by crushing, rubbing, grading, cutting tearing and any other process that can cause particle size reduction. This was carried out using a standard grinder of model and type Mahlkolig /Conumbia, WLLB in a set of cups (12 gm of powder /ground coffee per each cup with a capacity of 240 ml). 10gm of roasted bean (for each cup) grained using coffee grinder using fine to medium size.

Preparation for liquoring: Liquoring or cup tasting is an essential and most decisive in coffee quality control system. This quality assessment was done by cup tasting to be done by three panelists. For liquoring 3-5 cups were prepared by mixing 8 gm of coffee powder in each cup with boiled water to the half size of the cup and stirring the content to ensure the homogeneity of the mixture for aromatic stringent and quality and then filled to the brim with boiling water. After cup was left for about 3 minutes float to the top and then the floating grounds were skimmed.

Cup cleanness: it indicates freeness of the coffee from defects (Cup cleanness coffee was tasted from 0-15 defects. Where, 0= >3 cup defect, 3=3 cup defect, 6=2cup defect, 9=1 cup defect, 12=fair clean, 15=clean .If there is problem during roasting, trained panelists assessed the organoleptic quality. Tasting was carried out once the beverage cooled to around 60 ^{0}C (drinkable temperature). After all the above procedures completed tasting was carried out by 3 cuppers when the liquid (brew) had a palatable temperature.

Acidity: This is a desirable characteristic in coffee. It is the sensation of dryness that the Coffee produces under the edges of your tongue and on the back of your palate. cup acidity was evaluated as, pointed (15%), moderately pointed (12 %), medium (9 %), light (6 %) or lacking (3 %).

Body: 'Body' is the feeling that the coffee has in your mouth. It is the viscosity, heaviness, thickness, or richness that is perceived on the tongue. Cup body was evaluated as full (15 %), moderately full (12 %), medium (9 %), light (6 %), and thin (3 %).

Flavor: Flavor is the overall perception of the coffee in your mouth. Acidity, aroma and body are all components of flavor. It is the combination of body and acidity. The flavor, the overall test of the brew was evaluated and recorded as as good (15 %), fairly good (12 %), average (9 %), fair (6 %) and commonish (3 %).

Total cup quality: The sum total of sensory evaluation of each treatment.

Total quality: the sum total of both physical (40%) and organoleptic values (60%) of each treatment.

According to commercial coffee grading (ECX, 2009, 2010) total quality classification scores describe the range of coffee quality for the final score.

3.7. Statistical Analysis

The data were analyzed in randomized complete block design using SAS version 9.2 (SAS, 2008) computer package after the data were checked for meeting the various ANOVA assumptions. The following model was used for randomized complet block design:

Experimental design

The model

$$Yijkl = \mathcal{M} + r_i + m_j + l_k + p_l + (m*l)_{jk} + (m*p)_{jl} + (l * P)_{kl} + (m*l*p)_{jkl} + \varepsilon_{ijkl}$$

Where;

μ = is the overall mean effect

r_i = is the effect of i^{th} replication

m_j = the effect of j^{th} level of maturity

l_k = the effect of k^{th} level of altitude

p_l = the effect of l^{th} level of processing method

$(m*l)_{jk}$ = the effect of interaction between maturity and altitude

$(m*p)_{jl}$ = the effect of interaction between maturity and processing methods

$(l*p)_{kl}$ = the effect of interaction between altitude and processing methods

$(m*l*p)_{jkl}$ = the effect of the interaction among processing method, maturity and altitude

ε_{ijklm} = is a random error component for all factors

Least Significant Difference (LSD) at 0.05 and 0.01 probability level of significance were used to determine differences between treatment means whenever the treatment effects were found to be significant and the correlation between traits were also determined using the same software program.

4. RESULTS AND DISCUSSION

4.1. Raw Quality Analysis

4.1.1. Bean size

There was no significant variation among the three and two ways interaction effects on the proportion of percentage bean size. Similarly there was no significant difference among the three stages of maturity. But, significant ($P \leq 0.01$) variation was observed between altitudes (Appendix Table 5). The highest value was observed at Andiracha (1810m) with mean value of 97.67% and 96.07 % for Kabo (1415m). The smallest result was recorded at low land area of Baya (1095 masl) with a mean value of 93.44% (Table 2).

This variation could be attributed to altitudinal difference as altitude favored the production of beans of large size and weight, an indication of high accumulation of dry matter. Coffees of the highest altitude are more dense and larger in size than those produced at lower altitudes. At Andiracha, the low air temperature resulted in the slow rate of maturation of berries that probably favored better fruit growth and increased the size of beans.

The present findings agree with the reports of Vaast *et al.* (2006), indicating that coffee beans grown at higher elevations tend to be denser and larger. Similarly both genotypes and environments were found to affect beans size (Yonas, 2005; Tesfaye *et al.,* 2008; Alemseged and Tesfaye, 2012). This is as the result of the moisture amount received during bean growth is very critical to affect growths of coffee beans (Tesfaye *et al.,* 2008; Alemseged and Tesfaye, 2012).

Bean size (weight) highly depends on the type of environment where genotypes grow which is attributed to the favorable climate that coincides with the flowering time at the particular location especially the adequacy of the rain fall amount received is important for luxurious exocarb and endocarb expansion which are prerequisite, for complete development of endosperm to result in beans which are grown to their full genetic limits apart from the optimum edaphic factors present at the particular location (Yonas, 2014).

The percentage of bean retain on screen 14 had correlation (P≤0.05) with primary defect (r=30**), secondary defect (r=29**), with shape and make (r=24*), color (r=27*), flavor (r= 0.31**), 0dor (r=-0.10), total raw quality (r=0.17), cup cleanness (r=-0.11), acidity (r=0.13), body (r=0.18), total liquor quality (r=0.21), total quality (r=0.18). (Appendix Table 4).

Table 2. The effects of altitude on raw quality variables of 7454 variety at the three coffee farms

	Coffee farms					
Variables	Baya	Kabo	Andiracha	CV (%)	LSD(1%)	LSD(5%)
Bean size	93.44[c]	96.07[b]	97.67[a]	2.11	1.10	
Primary defect	8.29[b]	8.41[b]	9.18[a]	13.06	ns	0.61
Secondary defect	6.44[b]	6.74[b]	7.55[a]	16.32	0.61	
Odor	4.70[a]	4.55[a]	4.51[a]	10.13	ns	ns
Color	8.33[b]	8.77[b]	10.00[a]	24.70	ns	1.21

Means with the same letter(s) in the raw are not statistically different at 1% and 5% probability level

4.1.2. Primary defects

The three way interactions, the two ways as well as the main effects of maturity and processing method showed non significant differences. However, there was significant (P≤0.05) variation in the primery defect for different altitudes. The highest figure was recorded at Andirach with an average value of 9.18 which is with very small defective beans (Table 2). The lowest (8.29 and 8.44) was recorded at Kabo and Baya, indicating its highest defective coffee bean without statistical difference.

This could be attributed to climate variables that are suitable for insect pests kike antestia and leaf rusts at low land areas. Among defects observed in this study, the major ones are black bean and pest damaged beans which enhanced quality deterioration.

This result was in agreement with Eshetu *et al.* (2000) who reported the occurance of bean discoloration and berry rot with the highest record on bulk coffee beans followed by variety 7454, sampled from washing stations at Baya, Tepi Coffee Plantation Development Enterprise. Similarly, a brown eye spot disease cousing fungus which affects leaves and fruits flourishes under warm humid conditions (Merdassa, 1985; Eshetu *et al.,* 2000). Bigirimana *et al.* (2012) also revealed that high altitudes were associated with low disease and pest severity such as leaf rust. The negative correlation was also reported by Kushalappa and Eskes (1989) who found that higher altitudes were associated with lower disease severity. Rivera (1984) also observed a lower level of disease intensity at higher altitudes in Guatemala.

Primary defect of the cultivar showed significant and weak correlation at ($p<0.05$) for secondary defect (r=0.21*), shape and make (r=0.29*), color (r=0.28*), total raw quality (r=0.34*), acidity (r=0.28*), flavor (r=0.0.32*), total liquor quality (0.34*), total quality (r=0.29*) (Appendix Table 4).

4.1.3. Secondary defects

The three way interactions as well as the two way interaction effects are not significant. But the three main effects showed significant variations in the secondary defects (Appendix Table 5).

There was significant ($P \leq 0.01$) variation for different maturity stages. The highest was recorded for red and yellow stages of maturity, with an average value of 8.74 and 8.51 respectively (Table 3). The lowest (3.48) was scored for green maturity stage indicating its highest defective coffee beans.

This could be due to the fact that, the most intrinsic defective beans that considered the most relevant for physical quality are immature and black-immature. Immature beans originate mainly from immature fruits and are known to increase defect count (Adriana *et al.,* 2009). Among defects observed in this study, the major ones are partial black immature and floater which enhanced physical quality deterioration.

This result was in agreement with Bee *et al.* (2005) who indicated black-immature beans are derived from immature sour beans that have been exposed to high temperatures. If coffee is harvested at immature stage, the end product will show color defect (Anwar, 2010). Coffee beans from immature cherries contained black beans (Srirat *et al.,* 2007).

Table 3. Effects of fruit maturity stages on secondary defect of 7454 variety

Maturity stages	Secondery defect
Light Green stage	3.48[b]
Yellow stage	8.51[a]
Red stage	8.74[a]
CV (%)	16.32
LSD (1%)	0.61

Means with the same letter(s) are not statistically different at 1% probability level

There was also significant (P<0.01) variation among processing methods for secondary defects. The wet method processed beans had the highest mean defect score (8.00) point. However, sun dried recorded the lowest mean primary defect value (5.77) (Table 4). The lowest defects in washed coffee could be related to the fact that in wet processing, floaters and other defected beans are well washed away and minimizes defected beans and resulted in few defective beans as well as uniform beans. Wet processing machine has haggard pre-grader which grads the parchment coffee beans according to their size and density.

This result is in agreement with, Desse (2008), who stated coffee processed by wet method helps to preserve the intrinsic quality of the bean better, producing a green coffee, which is homogenous and has few defective beans. Hence, the coffee produced by this method is usually regarded as being of better quality and fetches higher prices. Further more, semi-washed method is also an alternative practice to produce few defective beans and better quality coffee. Desse (2008) added that the primary coffee quality draw backs particularly on sun dried coffee types consisted of beans which were damaged by insect pests, immature soiled, light, nipped, cracked, moldy and others.

Table 4. Effects of processing method on secondary defect of 7454 variety

Processing methods	Secondery defect
Wet	8.00[a]
Semi- washed	6.99[b]
Dry method	5.77[c]
CV (%)	16.32
LSD (1%)	0.61

Means with the same letter(s) are not statistically different at 1% probability level

Significant variation was observed ($P<0.05$) among altitudes for the raw quality of secondary defect. Accordingly, Baya and Kabo areas resulted in statistically the lowest mean primary defect scores. However, high land Andiracha coffee had the highest mean primary defect value, revealing the best physical quality (Table2).

This could be due to the strong correlation between the secondary defect of the samples and the altitude at which the coffee was grown. Further more, at low and mid altitude, lowest figure was recoreded as compare to the upper altitude. This might be related to high insect pest existence and multiplication at low lands to increase the over all secondary defect count at baya and kabo.

This result was supported by Prakash *et al.* (2004, 2005) who reported that alternating wet and dry conditions at low altitudes favor high disease build up and thus leads to high crop losses and high altitudes were associated with low disease severity with a negative correlation. Similarly, coffee berry borer is a serious pest of Arabica at low altitudes (Musoli *et. al*., 2001).

Secondary defect showed significant correlation ($p<0.05$) with primary defect ($r=0.21^*$), bean size ($r=0.29^*$), shape and make ($r=0.45^{**}$), color($r=0.36^*$), total raw quality (r=

0.42**), acidity (r=0.39*), flavor (r= 0.42**), total liquor quality (r=0.39*), total quality (r=0.40*) (Appendix Table 4).

4.1.4. Shape and make

There was significant ($P \leq 0.05$) variation among the three way interaction effects of processing methods, altitude and stages of maturity in shape and make (Appendix Table 5). The highest value was observed for red and yellow stages of maturity processed by wet method at Andiracha. Statistical similar result was recorded at Kabo and Andiracha for yellow and red stages processed by semi-washed and the lowest was recorded for green cherry stage at low lands of Baya (Table 5).

This variation could be attributed to the combined effect of differences in altitude of the locations, maturity of the cherry and the processing methods applied. At Anderacha, the conducieve rain fall and temperature favoured better fruit grouth and increased the formation of beans of yellow and red stages of maturity processed by wet method as a result of the type of processing method used.

The result of the present study agrees with the findings of Mekonnen (2009) who reported that the shape and make of coffee accessions was highly influenced by processing methods due to the fact that during wet processing small sized cherries and beans can be separated as floaters, which otherwise reduce the uniformity of the beans. Josephs & Kanampiu (2008) also revealed the formation of the bean can be corrugated by immaturity. On the other hand, Wintgens (2004) reported that beans produced at low altitudes have a negative effect on the shape and make of the beans due to accelerated maturation. He concluded that the shape and structure of beans (elephant, pea berry and empty beans) are the result of both genotype and environmental factors (Wintgens, 2004). The slowed-down ripening process of coffee berries at higher elevations (lower air temperatures) allows more time for complete bean filling (Vaast *et al.*, 2006). Moreover, botanical variety and environmental growth circumstances have a great impact on shape and make of coffee bean (Bertrand *et al.*, 2004).

Shape and make was highly significant ($P<0.01$) and strong positive association with primary defect (r=0.29**), secondary defect (r=45**), with color (r=0.50**), total raw quality(r=0.58**), acidity(r=0.56**), flavor(r=0.51**), total liquor quality (r=0.56**), total quality (r=0.60**).

Table 5. The interaction effect of altitude fruit maturity and processing methods on shape and make of Arabica coffee variety 7454

Maturity	Baya(1095 mts)			Kabbo(1415 mts)			Andiracha(1810 mts)		
	Dry	Semi-washed	Wet	Dry	Semi-washed	Wet	Dry	Semi-washed	Wet
Light Green	9.00^{f}	9.00^{f}	9.00^{f}	10.00^{ef}	9.00^{f}	9.00^{f}	10.00^{ef}	12.00^{cd}	12.00^{cd}
Yellow	12.00^{cd}	12.00^{cd}	11.00^{de}	12.00^{cd}	14.00^{ab}	12.00^{cd}	12.00^{cd}	13.00^{bc}	15.00^{a}
Red	11.00^{de}	12.00^{cd}	12.00^{cd}	12.00^{cd}	10.00^{ef}	13.00^{bc}	12.00^{cd}	14.00^{ab}	14.00^{ab}
CV (%)	10.27								
LSD (5%)	1.96								

Means with the same letter(s) along rows and columns are not different statistically at 5%

4.1.5. Bean color

There was significant variation ($P<0.01$) in bean color for the two way interaction of processing methods and stages of fruit maturity and for the main effect altitude (Appendix Table 5). As a result the red and yellow fruits prepered in wet processing had the highest bean color (12.33), with grayish to bluish color. Moreover, green fruit maturity processed in dry method scored the lowest mean color value (7.00) coated to greenish and was not different from semi-washed coffee of maturity stages (Table 6).

This could be due to the ways in which the coffee cherry was processed and the degree of maturity of coffee. The type of method used in coffee processing affects the appearance of the bean because of the under water fermentation and the drying of the bean inside pulp in wet and dry method respectively. Immature cherry is the source of color defect as the bean surface might be rough and greenish color.

The present finding supports the work done by Josephs & Kanampiu (2008). Washed green beans which reflect a brownish-gray-green to brown color are the coffees which usually have been picked either at stages of under ripe or over ripe. It has been confirmed that under-water soaking enhances the appearance of raw bean (Behailu *et al.,* 2008). The color of semi washed was inferior. This is supported by Velmourougane (2011) who reported that the main advantage of the soaking is to improve the raw and roast appearance by removing the browning of the coffees, which is presumed to originate from degraded sugars and poly-phenols .Moreover, Anon (2001), pointed out that the best color of the bean, green blue can be obtained by removing the mucilage under fermentation after removing the pulp in wet processing. According to Sutherland (1990), the beans with the poorest appearance have been observed when the red cherry harvested and dried with their skin under sun dried processing. Davids (2001) also confirmed that the green bean color was best where the mucilage had removed by fermentation under water in wet processing and the poorest color was obtained when the bean dried inside the fruit.

Table 6. The interaction effect of processing methods and stages of maturity on bean color of 7454 variety

Maturity stages	Processing methods		
	Dry	Semi-washed	Wet
Light Green	7.00[b]	9.00[b]	7.33[b]
Yellow	7.33[b]	8.00[b]	12.33[a]
Red	9.00[b]	9.00[b]	12.33[a]
CV(%)	24.70		
LSD(1%)	2.10		

Means followed by different letter(s) in the same column are significantly different at 1%

Significant ($P \leq 0.05$) variation was observed in the main effect of altitude for color of the variety under experiment. The highest value that is the best color was observed at high land of Andiracha with mean value of 10.00 and the lowest result coated to greenish color was scored at Baya with mean score value of 8.33 which were statistically different (Table 2).

This may be due to the fact that the production of good quality coffee bean in specific areas is characterized by their climatic condition clearly showing that the climate is an important factor in determining the physical and beverage quality of coffee. Under the optimal ecological conditions an appropriate agricultural management allows achieving high yield without resulting in competition for carbohydrates and nutrients between coffee berries yielding good bean color (Bosselmann *et al.,* 2009). In Baya farms the hot temperature during fruit grouth might be resulted in starved bean in which silver skin can not be removed from the bean and leading to coated bean.

This corroborates with Josephs & Kanampiu (2008) who reported that drought affected beans have a sticky silver skin. Bertrand *et.al.* (2004) pointed out similar variability due to botanical variety and environmental growth circumstances.

The bean color of 7454 variety showed significant correlation ($p<0.01$) with primery defect (r=28**), secondary defect (r=36**), shape and make(r=0.50**), total raw quality(r=0.33**), flavor (r=0.32**), total cup quality (r=0.31**), total quality (r=0.32**), and at ($P \leq 0.05$) for acidity (r=0.22*).

4.1.6. Total raw quality

The analysis of variance for the three way interactions among processing method, altitude and stages of maturity ($P \leq 0.05$) as well as the main effect of processing ($P \leq 0.05$), maturity and altitude ($P \leq 0.01$) showed significant variations for the total raw quality of coffee (Appendix Table 5). Accordingly, at Anderacha, red stages of maturity processed by wet method resulted in the highest mean total raw quality score (36.00) followed by washed processed yellow classes of maturity (35.67). However, the lowest was recorded for wet method of green maturity stage at Kabo (18.33) (Table 7).

This can be related to environmental, physiological, genetic and cultural factors, and their interactions, which are responsible for the authenticity of coffees, can only be expressed in the beverage if harvesting and post- harvest treatments are faultless. The starting point for producing a coffee is the physical environment; the intermediate stages are the plant, its functioning, the harvest, post-harvest treatments and roasting; the outcome is the beverage. Each stage gives the product a quality potential that is put to maximum use, or not, in the following stage depending on know-how (Avelino *et al*., 2005).

This agree with the report of Leroy *et al.* (2006) that explained though quality is an inherent factor environment and genetic diversity can play the major roles in determining coffee physical and other quality parameters. Similarly, physical quality like shape and make and size of the bean is affected by the environment where the coffee is growing (EAFCA, 2008; Endale, 2008; Mekonen, 2009), through temperature and availability of light and water during the ripening period (Decazy *et al.,* 2003). The methods of processing can also affect the raw quality or the physical appearance by affecting the formation and structure of the color, odor and the uniformity of the bean (Clark, 1985; Davids, 2001; Paulo *et al*., 2007; Endale, 2008). Maturation also has a strong influence on coffee quality (Bertrand *et al.*, 2006) and under ripe cherries can result in a brownish-gray-green to brown color of the bean and green beans that are shriveled, deformed beans, usually small, irregular or immature in formation; often with multiple center cuts (Josephs & Kanampiu, 2008). For *C. canephora,* yellow or light green cherries picked at the end of the picking season contain beans with a higher maturity level than red cherries picked at the start of the picking season (Leroy *et al.*, 2006).

The results also demonstrated its significant ($P \leq 0.01$) and positive correlations with secondary defect (r=0.42**), shape and make (0.58**), color (0.31*), acidity(r=0.56**), flavor(r=0.57**), total liquor quality(r=0.63**) and total quality(r=0.90**) (Appendix Table 4).

Table 7. Interactions effect among processing method, altitude and stages of maturity on total raw quality of Arabica coffee variety 7454

	Baya (1095 masl)			Kabo (1415 masl)			Andiracha (1810 masl)		
stages of maturity	Dry method	Semi-washed method	Wet method	Dry method	Semi-washed method	Wet method	Dry method	Semi-washed method	Wet method
Light Green	21.33^{hij}	22.33^{hij}	28.67^{efg}	20.67^{ij}	21.33^{hij}	18.33^{j}	24.00^{ghi}	26.00^{fgh}	30.33^{cdef}
Yellow	30.33^{cdef}	33.00^{abcde}	31.00^{bcde}	30.66^{abcd}	26.00^{fgh}	35.00^{abc}	33.00^{abcde}	34.00^{abcd}	35.67^{ab}
Red	30.00^{def}	31.00^{bcde}	32.00^{abcde}	30.66^{cdef}	31.00^{bcde}	32.00^{abcde}	33.33^{abcde}	35.00^{abc}	36.00^{a}
CV (%)	9.55								
LSD (5%)	4.83								

Means with the same letter(s) in the rows and columns are not statistically different at 5% probability level

4.2. Cup Quality Analysis

4.2.1. Acidity

The three way interactions among processing method, altitude and stages of maturity as well as the two way interaction between altitude and processing method, altitude and maturity, processing method and stages of maturity were non significant for cup acidity. However, the main effects showed significant variations for cup acidity for fruit maturity ($P \leq 0.01$), processing and altitude ($P \leq 0.05$) (Appendix Table 6).

Hence yellow and red maturity stages produced the highest mean acidity values confirming medium acidity, respectively. On the other hand, the light green stages of maturity resulted in the lowest acidity value (7.00) that reflects light to medium acidity (Table 8).

This result could be attributed to the composition of different stages of cherry because of the degree of maturity among the three stages of ripening. The quality of coffee is influenced mainly by the stage of fruit ripening at the harvesting process. The harvest should be done when the cherry reach the chemical composition that provides the highest quality fruits (Bertrand *et al.*, 2005; Mawardi *et al*., 2005).

This result was in agreement with Njoroge (2004) who reported that the coffee may give an astringent or impure cup, if harvested immature, reducing the acidity. Although low amounts of chlorogenic acids are important for flavor, high amounts may reduce cup quality, possibly due to the high levels of oxidation products generated before roasting (Fraha *et al.,* 2006b). The total chlorogenic acid (CGA) content of green coffee beans may vary according to degree of maturation (Clifford, 1985). Chlorogenic acids are known to be important determinants of coffee flavour. They contribute to the final acidity and confer astringency and bitterness to the beverage. As a result of maillard and strecker’s reactions bitterness increases during roasting due to release of caffeic acid and formations of lactones and other phenol derivatives responsible for flavoor and aroma (Farah and Donangelo, 2006). According to Farah *et al*. (2006a) the level of CGA has an inverse association with coffee quality with higher contents observed in lower quality coffee sample. Under ripe beans can generally produce a very light acidity in coffee (Josephs & Kanampiu, 2008) as opposed to the acidity observed in fruit crops (Watson *et al.,* 2000).

Acidity showed significant and positive correlation ($p<0.01$) with shape and make (r=0.56**), with primary defect (r=0.49**), size of the bean (r=0.56**), total raw quality (r=0.56**), flavor (r=0.57**), total liquor quality (r=0.81**), total quality (r=0.74**), and ($p<0.05$) secondary defect (r=0.39*),(Appendix Table 4).

Table 8. The effect fruit maturity on cup quality of 7454 variety

Stages of maturity	Acidity	Body	flavor	Total cup quality	Total quality
Light Green	7.00^{b}	8.88^{b}	6.67^{c}	36.15^{b}	60.85^{b}
Yellow	9.66^{a}	9.33^{a}	8.67^{b}	42.00^{a}	74.81^{a}
Red	9.55^{a}	9.44^{a}	9.67^{a}	43.11^{a}	76.85^{a}
CV (%)	14.92	7.56	17.24	6.58	5.82
LSD (1%)	0.71	--	0.77	1.45	2.25
(5%)		0.38			

Means with the same letter(s) in the column are not statistically different at 1% and 5% probability level

It was also observed that wet processed coffee resulted in significantly higher mean cup acidity that is medium acidity (Table 9). On the other hand, the lowest cup acidity (light to medium) was revealed on semi and dry processed coffee. This could be due to the fact that during the wet method the coffee bean stayes with water in fermentation tank and this increases acidity. In coffee processing, the soaking phase applied during the wet process may increase the cup acidity and decreases the bitterness (Knopp *et al.,* 2005).

These results concurred with the report of Clark (1985) who stated that the use of underwater fermentation instead of ‘dry’ accentuates the formation of acids. Jackels *et al.* (2006) also confirmed that fermentation in wet processed coffee can break the cellulose of the mucilage layer converting the parchment husk enclosing the bean and increases the acidity of the coffee. Clifford (1985) described that wet processed Arabica tends to be aromatic with a fine acidity, but some astringency while dry processed Arabica tends to be less aromatic but produce greater body. This can be largely due to the formation of acids under water fermentation. Acidity is a sharp and pleasing taste which may indicate signs of fermentation (Viani, 2000).

Table 9. The effect of processing methods on cup quality of 7454 variety

Processing methods	Acidity	Flavor	Total cup quality	Total quality
Dry	8.33[b]	8.00[b]	39.78[b]	69.00[b]
Semi-washed	8.55[b]	8.11[b]	39.85	70.07[b]
Wet	9.33[a]	8.89[a]	41.63[a]	73.44[a]
CV (%)	14.78	17.24	6.58	5.82
LSD (1%)				2.25
(5%)	0.71	0.77	1.45	

Means with the same letters with in a column are not statistically different at 1% and 5% probability level

Anderacha (1810 masl) showed significant higher mean cup acidity (Table 10), which was identified as medium acidity. But the fruits at Baya (1095 masl) scored, the lowest mean cup acidity values detected to be light to medium acidity.

This because of that altitude of the area affected the bio-chemical composition of bean and resulting in change in cup sweet caramelic character of the cup. Climate and altitude of Andiracha played important role through temperature and availability of light and water during the ripening period of cherry. The higher proteinase activity in fruits from high land of Andiracha breaks down proteins that are important for the development of coffee acidity (Silva *et al.,* 2005).

Avelino *et al.(*2005) also found the same findings in different altitudes of Costa Rica, Orosi low altitude of 1020-1250m and Santa Maria de dota(1550-1780 mts asl). Accordingly, it was proved that there was a positive altitude-acidity relation in both regions and the Santa Maria de dota coffee was slightly higher than those for the Orsi coffees, 3.42 and 2.60 respectively. More over, Abeyot *et al.* (2011) revealed that the caffeine content and acidity were directly correlated with elevation of collection areas of the coffee germ plasms in Ethiopia. Acidity was found to increase from 2.53-3.41 from respective elevation of 900-1450m above sea level according to the research done in central America using Sudanese- Ethiopian origin coffee varieties(Bertrand *et al.*, 2005).

Table 10. The effect of altitude on cup acidity of Arabica coffee variety 7454

Farms	Acidity	Flavor	Total cup quality	Total quality
Baya (1095)	8.11[b]	7.78[b]	38.85[c]	68.56[b]
Kaboo (1415)	8.77[ab]	8.22[b]	40.44[b]	68.89[b]
Anderacha (1810)	9.33[a]	9.00[a]	41.96[a]	75.07[a]
CV (%)	14.92	17.24	6.58	5.82
LSD (1%)		0.77	1.45	2.25
(5%)	0.71			

Means with the same letter(s) with in a column are not statistically different at 1% and 5% probability level

4.2.2. Body

The three ways interaction among factors was not significant. But, the two-way interaction between altitude and processing method was significant differences ($P \leq 0.05$) for cup body (Appendix Table 6). It was observed that at Anderacha (1810 masl) the dry method scored significantly higher cup body (Table 11), which was identified as moderately full body. On the other hand, the lowest cup body was revealed for wet and semi-washed at Baya (1095 masl) and semi-washed coffee at Andiracha, detected to be medium body.

This could be due to the cumulative effect of the climate and the type of processing method used. Dry processing is slow and may lead to translocation of chemical constituents from the pulp to inner bean as well as chemical transformation that depends on ambient condition such as location. As a reasult the dry-process may produce coffee that is heavy in body (Abrar *et al.*, 2014).

These results agree with Clark (2005) that naturally, dry, processed coffee has a better body due to the fact that the bean was in contact with its mucilage through a greater part of the processing phase. More over, Davids (2001) and Bacon (2005) also reported that dry processed (natural) have a full body and natural sweetness of the beans. In work carried out in Costa Rica, at Santa Mar´ıa de Dota by Avelino *et al.* (2005), altitude was also positively linked to body. A similar tendency was found at Orosi. Thus the altitude–body relation could vary depending on the nature of the heaviness. A high body score may also be perceived as a defect in some cases, notably for coffees from very-low-altitude plots, and as a quality in other cases (Avelino *et al.*, 2005).

The correlation effect revealed positive correlation ($P \leq 0.01$) between body and total cup quality(r=0.44**) and ($P \leq 0.05$) for flavor(r=0.24*) and total quality(r=0.34*) (Appendix Table 4).

Table11. Interaction effect of altitude and processing methods on body of 7454 variety

Altitude		Processing methods	
	Dry	Semi-washed	Wet
Baya (1095 masl)	9.00[b]	8.66[b]	8.66[b]
Kabbo (1415 masl)	9.00[b]	9.00[b]	9.00[b]
Andiracha (1810 masl)	12.00[a]	8.66[b]	9.33[b]
CV (%)	7.56		
LSD (5%)	0.71		

Means with the same letter(s) are not statistically different at 5% probability level

The main effect of maturity stage showed significant ($p<0.05$) variations for cup body (Appendix Table 6). Red and yellow maturity stages produced the highest mean body values of 9.44 and 9.33, respectively. But, light green stages of maturity had the lowest mean body value of 8.88 (Table 8).

This result could be attributed to the degree of cherry maturity among the three stages of ripening which resulted in different bio-chemical compositions which are precursors of body and contributors of light coffee (Leloup *et al.*, 1995).

Similarly, Montavon *et al.* (2003) depicted that immature berry has the higher amount of phenolic compounds such as chlorogenic acid. This was found in defffective immature beans and more amount of chlorogenic acid, resulting in lighter coffee (Yigizew, 2005).

4.2.3. Flavor

The three and two-way interactions were not significant but the main effects of processing method ($P=0.05$), altitude ($p<0.01$) and stages of maturity ($p<0.001$) showed significant differences in cup flavor (Appendix Table 6). Hence it was observed that red cherry resulted in significantly higher mean cup flavor (Table 8), which was identified as average flavor**.** However, yellow cherry stage scored the second highest cup flavor, ranging from fair to average or fair plus. On the other hand, the lowest cup flavor was determined for light green maturity, which refers to fair flavor.

This could be due to the bio-chemical content of the cherry at different stages of maturity. That is there are also flavor characteristics that are developed through the ripening process (Endale *et al.*, 2008). Larger molecules called macronutrients probably chopped up into smaller components to provide sustenance for the growing embryo. In this process, however, aroma compounds may also formed.

These results support with that of De Castro and Marraccini (2006) who pointed out some compounds that accumulated in mature coffee beans play an important role in the quality of the beverage and among these compounds such as sucrose is accumulated during latest stages of endosperm development from 231 to 260 days after flowering in full sun light and shade condition. Sucrose is important precursor of coffee flavor and aroma (Homma, 2001; Grosch, 2001) in which its degradation during roasting leads to a wide range of compounds (i.e. aliphatic acids) involved in coffee flavor (Ginz *et al.,* 2000).

Cup flavor was positively correlated ($P\leq0.01$) with primary defect ($r=0.51^{**}$), with secondary defect ($r=0.47^{**}$),bean shape and make ($r=0.51^{**}$), total raw quality ($r=0.57^{**}$), acidity ($r=0.61^{**}$), total cup quality ($r=0.82^{**}$), total quality ($r=0.71^{**}$) and ($P\leq0.05$) for bean size ($r=0.31^{*}$), color ($r=0.36^{*}$) and body ($r=0.24^{*}$).

Significant difference was observed for the different processing methods on flavor of 7454 variety at probability level of 5%. Accordingly, the wet processed samples scored the highest figure (8.89), nearly average flavor. The dry and semi washed coffee which was washed by the demucilager machine resulted in fair to average flavor which were not significantly different, 8.00 and 8.11 respectively (Table 9).

This could be due to the fact that in addition to the chemical composition of the coffee, post-harvest processing also influences the final quality and characteristics of the product. There fore the flavor of the brew can be affected probably as the result of the processing method used. The processing method used on a coffee is usually the single largest contributor to the flavor profile of a coffee (Clark, 1985).

This result was in agreement with the works of Mazzafera & Purcino (2004) and Arya & Rao (2007) in that the final quality of the beverage depends on several variables, such as the chemical composition of the beans. This composition may be affected when the color and the flavor attributes are changed within the beans during postharvest processing. According to Bytof *et al*. (2005, 2007), coffee produced by the wet method has less body and higher acidity; it is also more aromatic than coffee produced by the dry method, resulting in a higher acceptance by consumers. It is currently accepted that the metabolic reactions in the coffee fruits that occur during different types of processing can affect the chemical composition of beans and thereby affect beverage quality (Tarzia *et al*., 2010).

Anderacha (1810 masl) scored higher mean cup flavor (Table 10), which was identified as moderately full flavor was recorded. However, at Baya (1095 masl) and Kabo (1415 masl) statistically identical and the lowest cup flavor. This could be due to the fact that most of the flavor precursor biochemical compounds have strong relation with environment in which the coffee grows (Abreu *et al.,* 2012).

These results agree with Decazy *et al*. (2003) and environmental factors have been highlighted as contributing to the quality of the coffee beverage. This relationship was also noted by Avelino *et al.* (2005) who studied the effects of the exposure of the steeper slopes and different altitudes on the quality of the Costa Rica coffee terroirs. Rodrigues *et al.*

(2009) also noted a relationship between geographical location and the influence of altitude on coffee characteristics in 20 regions of the world. According to an experiment done in Costa Rica coffees from high lands of Santa Mar´ıa de Dota displayed a chocolate taste, which was more marked at high altitude.

4.2.4. Total cup quality

The analysis of variance for total liquor quality showed no significant variation for interaction effects. But, significant variation was observed at for main effects of altitude ($p<0.05$), processing method ($p<0.05$) and stages of maturity ($p<0.01$) (Appendix table 6). The red stages of maturity showed the highest score (43.11) compared to the yellow stages (42.00) and light green stage (36.15), but there was no significant difference between red and yellow stages. Accordingly, the light green colored samples showed the least and minimum cup quality values (Table 8).

This is due to the presence of higher levels of flavor compounds such as amino acids at maturation of cherry (Abreu *et al.,* 2012).

The current finding collaborates with the work of Van Der Vossen (2009) who stated only freshly harvested and fully ripe berries should be used in any of the three methods of primary processing and unripened coffee beans tend to produce astringent, bitter and “off” flavored beverages. The taste sensations experienced when drinking a coffee are the consequence of a specific balance between the concentration of the various aromatic and volatile compound present in coffee. An unbalance, or the excess of one compound over the other, can influence the taste of coffee especially in the case of acidic, sour and bittercompounds (Taba, 2012) and if a compound is below its taste threshold then it most likely will not affect the taste perceived by the coffee drinker. But, in immature coffee the amount of sucrose and trigonelline are very small and less than the ripe coffee (Srirat *et al.,* 2007). Green coffees do not contain sucrose. The chlorogenic acid (bitter taste) content of green coffee drops as it matures. On the otherhand sucrose and trigonelline act as aroma precursors, originating several substances (furans, pyrazines, pyrroles, pyridinines, etc.) that will affect both flavor and aroma in the beverage (De Maria *et al*., 1996; Ky *et al.,* 2001).

The simple correlation results depicted that the total cup quality was highly significant ($P \leq 0.001$) and positively correlated with primary defect (r=0.57**), secondary defect (r=0.47**), shape and make (r=0.56**), total raw quality (r=0.63**), acidity (r=0.81**), body (r=0.44**), flavor (r=0.82**) and total quality (r=0.85**) (Appendix Table 4).

Processing methods also showed significant variation ($p<0.05$) in total cup quality with the maximum value for wet method (41.63) and the semi-washed and the dry methods scored the least which were not different statistically (Table 9).

The final quality of the beverage depends on several variables, such as the chemical composition of the beans. This composition may be affected when the compositions are changed within the beans during postharvest processing (Mazzafera & Purcino, 2004; Musebe *et al.,* 2007; Abrar *et al.,* 2014).

Clifford (1985) reported that cup quality of coffee can be affected by processing methods. Coffee fruits are processed using several different steps for beverage production; these steps have a pronounced effect on the final quality of the resulting beverage (Mazzafera & Purcino, 2004; Bytof *et al*., 2005). It has been pointed out that beverages from coffees processed by different methods have significant differences (Selmar *et al.,* 2006; Leloup *et al.,* 2008). It is currently accepted that the metabolic reactions in the coffee fruits that occur during different types of processing can affect the chemical composition of beans and thereby affect beverage quality (Bytof *et al.*, 2005, 2007). Gonzales-Rios *et al. (*2006) stated that a comparison of green coffees from the different treatments (wet and dry processing) revealed the importance of mucilage removal in water to obtain coffees with better aroma quality. These wet processed coffees are in fact characterized by pleasant and fruity aroma characteristics whereas those obtained after a mechanical mucilage removal in a more “ecological” process were characterized by less pleasant aromatic notes.

Altitude showed significant *($P \leq 0.01$)* variations for total quality attributes of coffee beans. Accordingly, at Anderacha (1810 masl) the total cup quality resulted in the highest mean total score (41.96). In contrast, the least was recorded at Baya (1095 masl) scoring 38.85

total cup quality for this variety and significant variation was observed among the three areas (Table 8).

This could be due to the fact that organoleptic qualities of a coffee may depend on the area grown rather than the variety of coffee used. Temperature plays an important role in coffee quality by altering nitrogen compound composition (Abreu *et al.,* 2012). Therefore flavor potential cannot be realized under all possible environmental conditions. Therefore, elevation appears to have a significant effect on bean biochemical composition, with chlorogenic acid and fat concentrations increasing with increasing site elevation (Bertrand *et al.,* 2006).

In this regard, Avelino (2005) suggested that coffee quality depends on the terroir, ie mainly on the macroclimate, which determines sensory characteristics, including typicities, and chemical contents of the beans. Moreover environmental factors, such as altitude and rainfall, have been highlighted as contributing to the quality of the coffee beverage (Avelino *et al*., 2002; Decazy *et al.,* 2003; Rodrigues *et al*., 2009). Decazy *et al.,* 2003 found that Honduran coffees of superior quality came from high altitudes, above 1000m, where rainfall remains relatively low, that is to say below 1500mm per year. It was found that a strong inverse relation between rainfall and fat content exists and that this relation needs to be considered in relation to altitude because in the sampled regions in Honduras, rainfall and altitude were found to be inversely correlated. High altitude green coffee beans had a higher fat content than lower altitude beans and gave a better cup quality.

4.3. Total quality

The three-way and two way interactions showed non significant variations. But, the main effects of processing methods ($p<0.05$) altitude and stages of maturity ($p<0.01$) showed variation for total quality attributes of coffee beans (Appendix Table 6). Thus maturity stages showed highly significant difference and the red stage of maturity scored the highest mean value of total quality (76.5%) followed by yellow stage of maturity (74.81) which were not different. But, the minimum mean total quality value was scored by the light green maturity (60.85) and statiscally different from the two maturity stages (Table 8).

To produce a commercial standard quality of coffee beans, one should used ripe cherries and results the coffee beans that would contain low amount of defective bean and good cup quality. The content of green bean may be higher or lower depending on the maturity phase in which it was detected and finally affecting the quality of the brew (Van Der Vossen, 2009)

This result collaborates with the report of Bittenbender and Smith *(2008)* that the three types, or what might be called ripeness stages (green-ripe, or mature green), Mature coffee although not fully ripe and has a yellowish-green skin; hard-ripe, firm and red (or yellow); and soft-ripe, which is overripe, red to dark red, soft, and juicy), were noted as early as 1937 to have similar cupping qualities in tests conducted at Kona Research Station. However, a danger in picking the green-ripe cherries must be noted: at this stage, the beans are not sufficiently covered with mucilaginous coating to allow them to slide between pulping surfaces during the pulping process. Moreover according to Srirat *et al.,* 2007, ripe cherries (red and yellow) contained high content of trigonelline than the two high unripe (green) cherries treatments (Montavon *et al.,* 2003). During the last stage of development, the ripe stage, changes occur mostly in the pericarp, which increases in size and fresh and dry mass, and becomes red or yellow (Damatta *et al.,* 2008).

The simple correlation analysis showed that total quality has highly significant at ($P \leq 0.01$) and positive correlation with primary defect (r=0.59**), secondary defect (r=0.59**), shape and make (r=0.61**), total raw quality (r=0.90**),acidity (0.74**), body (r=0.34**), flavor (r=0.71**) and total cup (liquor) qualiy (r=0.85**).

The processing methods showed significant variation for total cup quality. Accordingly, the wet method of processing scored the highest value of total cup quality (73.44%). The least was observed for dry method (69.00) and did not vary statistically from semi washed.

This could be due to the fact that the processing method used on a coffee usually creates significant differences in the beans, because the two main processing methods have a measurably different effect on the sugars and flavor precursors present, which in turn play a role in improving the physical and cup quality of coffee (Daniels, 2009).

This is in agreement with Velmourougane (2011) and Mburu (1999) who described that under-water soaking of washed wet parchment for specified period was reported to improve raw and cup quality of coffee by way of leaching some of the chemical compounds (diterpenes, poly phenols, tannins etc.) responsible for bitterness and browning of coffee beans. On contrary, Coffee processed by machine wash alone recorded, fair to good body, fair to good acidity and slight bitter/harsh taste. In similar way, Bytof *et al.* (2005) proved that the processing method affects complex metabolic processes that the bean undergoes during processing and drying. This result was also supported by Bahilu *et al.* (2008) and Mekonin (2009) in Ethiopia.

Total coffee quality was highly significant different due to location effect. Accordingly, Andiracha high land (1810 masl) scored the maximum (75.07), but the least total cup quality was observed at Baya low lands (68.56). The medium altitude area kabo scored the second value (68.89) though not different from the low land coffee farm.

This is due to that beverage quality appears to be highly dependent on the climate conditions in which the quality precursors probably affected. As altitude decrease the mean temperature increases and at low lands, acceleratrd development and ripening of fruits, often leading to loss of quality (Vaast *et al.,* 2006).

According to Abreu *et al.* (2012), environmental factors have a strong infl uence on coffee beverage quality by changing the amino acid and protein profi le, which is an important factor in coffee quality. Lara (2005) also reported that the coffee quality was also discriminated according to geographic origin. Altitude influenced to the greatest extent the determination of coffee physical quality (larger, heavier beans, and lower percentage of imperfect beans), organoleptic quality (aroma, body, acidity, flavor and biochemical compounds (caffeine, trigonelline, sucrose, chlorogenic acids and sucrose) (Avelino *et al.,* 2002; Decazy *et al.*, 2003; Avelino *et al.*, 2005; Rodrigues *et al.*, 2009). Accordingly, coffees from altitude less than 1000m gave small bean size, large concentration in trigonelline and sucrose, and low organoleptic quality. On contrary, altitudes higher than

1290 m presented the highest fat and chlorogenic acids content. The compounds that contributed the most to the geographic discrimination were trigonelline, sucrose, fat and chlorogenic acids. Generally, climate and altitude play important roles through temperature and availability of light and water during the ripening period (Cannell 1974, Clifford and Wilson 1985; Guyot *et al*., 1996; Carr, 2001; Decazy *et al*., 2003; Barbosa, 2012). Damatta *et al.* (2008) concluded that the search for good quality beverage has spread the cultivation of coffee to higher altitudes.

5. SUMMARY AND CONCLUSIONS

Coffee is the most important crop in the national economy of Ethiopia and still the leading export commodity. Over 25% of the populations of Ethiopia are dependent on coffee for their livelihoods. In recent years, different coffee producing countries have tremendously expanded their production and their export volume. Thus providing good quality coffee is the only way out and viable option to get in to the world market and to remain competitive.

The findings indicate variability among the stages of maturity of 7454 variety especially between the light green and the rest of stages, the yellow and the red stages, for most of physical and all cup qualityattributes, except odor and cup cleanness. Accordingly, the two maturity stages, yellow and red stages of cherry showed statistical similarity for all attributes, except the flavor in which the red cherry scored different result from the yellow even though both of them are at acceptable and exportable quality range. Moreover, the total quality of yellow and red stages of maturity was nearly similar and did not show variation. But, the light green stage of maturity was less than the exportable standard and harvesting of the green cherry deteriorates the final quality of coffee. The result revealed that the red and yellow stages of maturity have equal effects and yellow cherry can be harvested for the processing purpose, indicating its genetic characterstics.

The processing methods showed statistically significant result in most physical and cup quality attributes. There were also statistically significant variations in coffee quality due to the processing methods for body, acidity, bean color and total quality as well as total liquor quality, flavor and total raw quality.

Variety 7454 processed with wet method was found to be superior in terms of most coffee quality parameters considered in this study. But, the semi-washed coffee did not show variations from dry method almost in all attributes. Therefore, the experiment is a clue whether to use the semi-washed method for commercial plantation because of the additional installation cost and the quality gain as mentioned above.

Generally, altitude revealed significant differences in all of the quality attributes, except odor with quality increasing from low to high altitudes. Though the unique characteristics of the variety for all altitudes in case of productivity cannot be ignored, the best quality was achieved at the high land Andiracha farm. Therefore, the effects of environments were also obvious on the quality of this variety, demonstrating the importance to consider altitude for the production of high quality product. However, from the present findings, it can be possible to suggest the followings high priority research areas, among others.

1. Assessment of nutrional packages, response of the variety to moisture condition at different stages of cherry development, shade condition and tree management and pest controlfor high yielder 7454 variety and other adaptable coffees.

2. Analysis of other biochemical constitutes of coffee quality for light green, yellow and red maturity stages of the 7454 and other CBD resistant varieties showing similar maturity behavior for the washed technique.

3. Gross monetary values from the present studied treatments over seasons and locations under Teppi and Godere condtions.

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7. APPENDIX

Appendix Table 1. Quality status of released coffee varieties from Jimma Research Center

Selection	Raw quality	Cup quality	Commercial acceptance
741	Fair/Good	Average	Acceptable
744	Average /Good	Average	Acceptable
7440	Fair/Good	FAQ	Acceptable
7454	Fair/Good	Fair/Good	Acceptable
7487	Fair/Good	Average	Hardly Acceptable
74110	Average/ Good	Good	Acceptable
74112	Good	Good	Good & Acceptable
74140	Average	Average	Hardly Acceptable
74148	Average	Average	Hardly Acceptable
74158	Good	Fair/Good	Acceptable
74165	Good	Fair/Good	Acceptable
754	Good	Fair/Good	Acceptable
75225	FAQ	FAQ	Acceptable
Dessu (F-59)	Good	Average/good	Good & Acceptable
Catimor J-19	FAQ	Average	Hardly Acceptable
Catimor J-21	FAQ	Average	Hardly Acceptable
Geeisha	Average	Average	Hardly Acceptable
Me'oftu (F-35)	Average	Average	Acceptable
Angafa (1377)	Good	Good	Good & Acceptable
Bunowashi (7416)	Average/ Good	Average +	Acceptable
Merdacherico (8136)	Very good	Average	Acceptance
Wushwush (7514)	Good	Average +	Acceptable
Yachi (7576)	Average Good	Good	Acceptable
Ababuna*	Average	Average	Average
Melko CH2*	Average/Good	Average	Acceptance
Gawe*	Average/ Good	Average	Acceptable

**Hybrid coffee varieties*

Source: CLU report (1996-2004)

Appendix Table 2. Summary of important input data used in coffee spatial suitability modeling

Input data	Highly suitable	Moderately suitable	Marginally suitable	Not suitable	Weight of the parameter (%)
Elevation (m)	1500-1800	1200-1500	900-1200	0-900	25
Soil (types)	Nitosols	Acrisols	Luvisols	All others	20
Annual rainfall (mm)	>1300	1100-1300	800-1100	0-800	40
Temperature (^{o}C)	22-25	18-22 & 25-28	15-18 & 28-30	0-15	15

Source: proceeding of coffee diversity and knowledge, 2008.

Appendix Table 3. Yield performance of CBD resistant varieties (kg ha) planted at the enterprise farms.

Selection	Plantation			
	Bebeka	Tepi	Kabo	Limu
7332 *	120	-	-	-
741 *a	241	-	-	-
744 *	345	330	530	-
7440	383	-	-	-
7454	695	410	560	-
7487 š	-	-	-	-
74110 *	286	290	550	-
74112 *	237	220	470	-
74140 *	302	250	450	-
74158 *a	314	-	-	-
74165 *a	219	-	-	-
754 *	230	-	-	-
75188 *	55	-	-	-
75227 *	303	-	450	-
Mixed	-	-	-	583

**, š, and *a represents coffee varieties withdrawn from production at Bebeka, Limu, and both Tepi and Bebeka, respectively.*

Source: CPDE, unpublished, 2005.

Appendix Table 4. Person Correlation coefficient of raw and cup quality parameters

	Ros	Prdf	Scdf	Shm	Col	Od	Trq	Cuc	Ac	Bo	Fl	Tcq	Tq
Ros	1	0.30**	0.29**	0.24*	0.27**	-0.10^{ns}	0.17ns	-0.11^{ns}	0.14^{ns}	0.18^{ns}	0.31**	0.21^{ns}	0.18
Prdf		1	0.21*	0.48**	0.28**	-0.04^{ns}	0.20^{ns}	-0.15^{ns}	0.49**	0.19^{ns}	0.51**	0.57**	0.54**
Scdf			1	0.61**	0.36**	-0.08^{ns}	0.42**	0.07^{ns}	0.39*	-0.04^{ns}	0.47**	0.46**	0.53**
Shm				1	0.50**	-0.16^{ns}	0.57**	0.10^{ns}	0.56**	0.0^{ns}	0.50**	0.56**	0.61**
Col					1	-0.10^{ns}	0.31*	0.13^{ns}	0.24*	-0.00^{ns}	0.36**	0.31*	0.24*
Od						1	0.14^{ns}	-0.08^{ns}	-0.01^{ns}	0.15^{ns}	-0.01^{ns}	0.02^{ns}	0.11^{ns}
Trq							1	0.08^{ns}	0.57**	0.16^{ns}	0.57**	0.63**	0.82**
Cuc								1	0.02^{ns}	-0.26*	0.04^{ns}	0.23*	0.16^{ns}
Ac									1	0.16^{ns}	0.61**	0.63**	0.75**
Bo										1	0.24*	0.23*	0.33*
Fl											1	0.82**	0.67**
Tcq												1	0.85**
Tq													1

*** and * = Correlation significant at 1% and 5% level of significance, respectively; ns=non significant; ros=percentage percentage of retain on screen; prdf=primary defect; scdf= secondary defect shm=shape and make ofbean; col=color of bean; OD=odor; TRQ=total raw quality;cuc=cup cleaness AC=acidity; BO=body; FL= flavor; TlQ=total cup quality and TQ=total quality.*

Appendix Table 5 Mean squares of altitude, maturity, processing method and their interactions for physical quality attributes.

Source	rep	matu	pm	L	matu*pm	mat*l	pm*l	mat*pm*l oc	error	CV (%)
DF	2	2	2	2	4	4	4	8	52	
Physical attributes										
Bean size	0.75^{ns}	5.3^{ns}	15.19^{ns}	18.73^{**}	2.89^{ns}	3.34^{ns}	4.49^{ns}	1.55^{ns}	3.56	2.11
Primary defect	6.86*	1.53^{ns}	0.7^{ns}	6.12^{*}	3.16^{ns}	0.27^{ns}	1.75^{ns}	1.12^{ns}	1.27	13.06
Secondary defect	1.53^{ns}	238.66^{**}	33.38**	8.93^{*}	0.86^{ns}	0.86^{ns}	0.93^{ns}	0.75^{ns}	1.27	16.32
Shape and make	^{ns}	57^{**}	4.33ns	26.33**	1.33^{ns}	1.33^{ns}	4.67*	3.16*	1.41	10.27
Odour	1.37^{*}	0.44^{ns}	0.11ns	0.25^{ns}	0.27^{ns}	0.09^{ns}	0.20^{ns}	0.20^{ns}	0.21	10.17
Color	11.44^{ns}	37.4*	59.11**	20.11*	25.44*	6.44^{ns}	1.11^{ns}	1.19^{ns}	5.22	24.7
Total raw quality	31.19*	656.38**	57.27*	149.86**	3.82^{ns}	12.41^{ns}	7.25^{ns}	22.19^{*}	7.87	9.55

Ns,, ** indicates non significant (p>0.05), significant (p<0.05) and highly significant (p<0.01) respectively. Matu=maturity stages, PM=processing methods, l= altitude*

Appendix Table 6 Mean squares of altiude, maturity, processing method for cup quality attributes.

Source	rep	matu	pm	L	matu*pm	mat*l	pm*l	mat*pm*l	error	CV (%)
DF	2	2	2	2	4	4	4	8	52	
Physical attributes										
Acidity	0.77^{ns}	61.44**	7.44*	10.11*	2.44^{ns}	0.6^{ns}	4.11^{ns}	1.86^{ns}	1.66	14.92
Body	2.33*	2.33*	12.33**	9.33**	0.66^{ns}	0.66^{ns}	9.16*	0.25^{ns}	0.55	7.56
Flavor	0.33^{ns}	63.00**	6.33*	10.30*	2.33^{ns}	2.33^{ns}	2.66^{ns}	1.16^{ns}	2.00	17.24
Total liquor quality	18.6^{ns}	377.82**	29.67*	65.34*	2.90^{ns}	2.06^{ns}	9.03^{ns}	7.91^{ns}	7.49	6.56
Total quality	80.08*	2048.0**	145.19*	363.86**	36.45^{ns}	22.73^{ns}	24.41^{ns}	25.62^{ns}	19.35	5.82

Ns,, ** indicates non significant (p>0.05), significant (p<0.05) and highly significant (p<0.01) respectively. Matu=maturity stages, PM=processing methods, l= altitude*

Appendix Table7. Land holding of 7454 variety at different farms of TGC

Name of the farms	Total area of farms	Total area of 7454 variety	% of 7454 variety
Komi	268.78	64.00	23.81
Shosha	238.60	35.28	14.79
Farm 02	1380.78	292.06	21.15
Farms 03	1563.18	212.39	13.59
Farms 04	1391.42	441.81	31.75
Farms 05	1594.70	302.57	18.97
total	6449.42	1348.11	20.90

Source: TCPD, 2012

Appendix Table 8 Current coffee standards

	Washed	Unwashed
Green/Raw analysis	▪ Screen Size (≥ 80%, Screen no 14) ▪ Moisture Content (≤11.5.0%) ▪ Shape & make (V. good, good, F/good, FAQ) accounts-15% ▪ Odor (clean, trace, light, moderate, strong) accounts 10% ▪ Color (bluish, grayish, greenish, faded) accounts 15% ▪ Overall raw quality ((V. good, good, F/good, FAQ) (c+d+e)	▪ Screen Size (≥ 80%, screen No 14) ▪ Moisture content (≤11.5%) ▪ Defect point analysis (V. good, good, F/good, FAQ, fair) accounts for 30% ▪ Odor (clean, trace, light, moderate, strong) accounts for 10% ▪ Overall raw quality (V. good, Good, F/good, FAQ, fair) (c+d)
Cup quality	▪ Acidity (pointed M/pointed, medium, light, lacking) accounts 15% ▪ Body (full, M/full, medium light, thin) accounts 15% ▪ Flavor/ character (V. good, good, F/good, FAQ, fair) accounts 15% ▪ Cup- cleanliness (1-5 cups defects) ▪ Overall cup quality (a+b+c+d)	▪ Acidity (pointed, M/pointed, medium, fair) accounts 15% ▪ Body (full, M/full, medium, fair) accounts 15% ▪ Flavor (V. good, good, F/good, FAQ, Fair) accounts 15% ▪ Cup cleanliness (1-5 defects) ▪ Overall cup quality (a +b +c +d)
Overall grading	The combined effect of green & cup considered and there are ranges, which goes from Grade 1 to 5 that are used for ultimate classification.	The combined effect of green/raw and cup considered to account and using the grade ranges (Grade 1- 5) the quality will be classified accordingly.

source: Endale, 2008