EFFECT OF PROCESSING METHODS AND DRYING MATERIALS ON BEAN PHYSICAL AND SENSORIAL QUALITY ATTRIBUTES OF COFFEE (*Coffea arabica* L.) VARIETIES AT GERA AND JIMMA

M.Sc. Thesis

Beza Teklu Eshete

March, 2011

Jimma University

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M.Sc. Thesis

Submitted to School of Graduate Studies

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

By

Beza Teklu Eshete

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As Thesis Research advisor, I hereby certify that I have read and evaluated this thesis prepared, under my guidance, by Beza Teklu, entitled '**Effect of processing methods and Drying Materials on Bean physical and sensorial Quality attributes of coffee (*Coffea arabica* L.) Varieties at Gera and Jimma'** and recommend that to be submitted as fulfilling the thesis requirement.

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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 Beza Teklu, entitled '**Effect of Processing Methods and Drying Materials on Bean Physical and Sensorial Quality Attributes of Coffee (*Coffea arabica* L.) Varieties at Gera and Jimma'** 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 mom, Genet Alemu, to my grand mother Etagegn Shiferaw and my uncle Birhanu T/Micheal

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

Beza Teklu Eshete was born on December 15, 1987 in Jimma town. She completed her elementary school at St. Peter and Paul Catholic Elementary school from 1993 to 2000 and secondary education at Jimma Senior Secondary School from 2001 to 2004. In 2006, she joined Jimma University College of Agriculture and Veterinary Medicine and graduated in 2008 with B.Sc. degree in Horticulture.

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LIST OF ABBREVIATIONS

CBD	Coffee Berry Disease
CLU	Coffee Liquoring Unit
CRI	Coffee Research Institute
ECX	Ethiopian Commodity Exchange
FAO	Food and Agriculture Organization of the United Nations
FAQ	Fairly acceptable quality
IAR	Institute of Agricultural Research
ICO	International Coffee Organization
IMF	International Monetary Fund
IPGRI	International Plant Genetic Resource Institute
ISO	International Standard Organization
ITC	International Trade Center
JARC	Jimma Agricultural Research Center
JZARDO	Jimma Zone Agricultural and Rural Development Office
LMC	Livelihood Coffee Market
OTA	Ochratoxin A
SAS	Statistical Analysis System

Effect of Processing Methods and Drying Materials on Bean Physical and Sensorial Quality Attributes of Coffee (*Coffea arabica* L.) Varieties at Gera and Jimma

By
Beza Teklu

Major advisor: Ali Mohammed (Ph.D)
Co-advisor: Taye Kufa (Ph.D)

ABSTRACT

Arabica coffee belongs to the family Rubiaceae and to the genus Coffea. It is also the backbone of Ethiopia's economy, contributing the highest of all exports revenues. The quality of coffee is influenced by several factors of which post-harvest handling is one. Coffee in Ethiopia is processed in two different methods on different drying materials including bare soil uniformly across locations. However, lack of information on the effects of post harvest processing and drying on quality necessitates a comprehensive study. Thus, the objectives of this experiment was to evaluate the influence of processing methods and drying materials on the physical and organoleptic quality attributes of known coffee varieties under Gera and Jimma conditions, and to estimate the economic advantages of coffee processing and drying practices under each agro-ecology. Accordingly, the experiment was conducted at Jimma agricultural research center and Gera agricultural research sub center from October 2009 up to June 2010 using a 2×6×3 factorial experiment arranged in split-split plot, using randomized complete block design (RCBD) with three replications. Days to drying, physical and cup quality parameters were recorded and analyzed using SAS version 9.2 computer package. As a result, variation among the varieties were highly significant (P<0.01) for bean size and hundred bean weight at both sites. Body and bean size showed significant variation (P<0.05) at Gera and highly significant variation (P<0.01) at Jimma for body and shape and make due to the processing methods. The maximum value for odor (10) was obtained from drying material mesh wire, bamboo, palm leaves mat and jute mesh at Gera while at Jimma the maximum value was obtained only from mesh wire. With regard to aromatic quality, drying material bamboo demonstrated significantly the highest value (3.31) at Jimma. Wet processing significantly (P<0.01) increased the value for body from 2.88 to 3.74 at Gera and 3.25 to 3.89 at Jimma. A highly significant (P<0.01) interaction was also noticed between drying material and variety on acidity wherein 74110 dried on mesh wire resulted in the highest (3.39) at Jimma. As to flavor, mesh wire recorded the highest 2.90 at Jimma. Thus from the study the wet processed coffee dried on bamboo, mesh wire, palm leaves mat, and jute mesh had good cup quality. With reference to days to drying, at both locations and using both processing methods, the use of bamboo resulted in earlier drying as compared to the other coffee drying materials. Differently, either wet or dry processed coffee dried on soil was found to be strongly discouraging because of its bad quality. Thus from the study the variety 74110 processed with wet processing method is superior in terms of most of the Quality parameters considered in this study and can be recommended for Jimma Zone specially for Melko. 7440 and 75227 processed with wet processing method had acceptable physical and cup quality at JARC and best at Gera; consequently, can be recommended for Gera. However further researches including biochemical analysis and environmental factors should be conducted to give concrete recommendations

Keywords: *coffee, cup quality, shape and make, body, drying material, and processing*

1. INTRODUCTION

Arabica coffee belongs to the family *Rubiaceae* and to the genus *Coffea* (Coste, 1992; Illy, 2002). *Rubiaceae* has some 500 genera and over 6000 species (Wrigley, 1988). Of these, the most economically important genus is *Coffea* (Wellman, 1961), comprising about 100 species (Pearl *et al*., 2004; Davies *et al*., 2006).

Coffee is one of the world’s principal commodities (ICO, 2001). Commercially, only two out of more than 100 coffee species are cultivated: the *Coffea arabica* L. and *Coffea canephora* Pierre (robusta coffee) (Raina *et al*., 1998; Anthony *et al*., 2002; Herrera *et al*., 2002; Prakash *et al*., 2002; Steiger *et al*., 2002; Pearl *et al.*, 2004). *Coffea arabica* is cultivated at higher altitudes, which is responsible for about 75% of the commercial world coffee (Cambrony, 1992; Carneriro, 1997; Damatta and Ramalho, 2006). It is the only tetraploid (2n = 4x = 44) and self-fertile (over 95%) species in the genus *Coffea* (Anthony *et al.*, 2001; Prakash *et al.*, 2002; Pearl *et al.*, 2004; Silvarolla *et al.*, 2004; Fassio and Silva, 2007) as well as the most widely cultivated and the longest known coffee species (Coste, 1992; Moncada and McCouch, 2004). The other species are diploid and self-incompatible (Charrier and Berthaud, 1985; Lashermes *et al*., 1996). Presently, arabica coffee accounts for about 64% of coffee produced, and robusta coffee for the rest (Fassio and Silva, 2007).

Coffee is one of the principal agricultural products in international trade in volume, having a market value of almost US$19.5 billion per year; most of it is grown and exported by more than 50 developing countries, about half of them are in Africa, but industrialized countries are the most significant consumers (Gillison *et al*., 2004). Coffee, therefore, plays a vital role in the trade and monetary exchanges between developed and developing countries, enabling the latter to earn the valuable foreign exchange they require to import capital and consumer goods from the former (ICO, 2001). The coffee sector, because of its great capacity for income distribution, causes a substantial social impact especially through the employment opportunities it generates which represent a major incentive against migration from the rural areas (Amaya *et al*., 1999).

Coffee is the backbone of Ethiopia's economy (Nicolas, 2007), contributing the highest of all exports revenues (ITC, 2002) and accounted for about 35% of total exports of Ethiopia (IMF, 2007). It ranks first amongst tree crops in terms of area coverage, which account 600,000 ha, the average annual production amounts to about 200,000 tones (FAO, 2006). Coffee production showed an increasing trend from 3,693,000 bags in 2002 to 5,733,000 bags in 2007 (ICO, 2008). However, this is still below the country's potential, since Ethiopia has the largest highland plateau suitable for arabica coffee production in the world (Tadesse and Feyera, 2008).

More than 90 % of the coffee is produced by small-scale subsistent farmers with an average farm-size of 0.5ha (Tadesse and Feyera, 2008), while the remaining comes from private and government owned large-scale farmers (MoARD, 2008). Coffee contributes to 25% of the employment opportunity in the country. The country's coffee production system is classified as forest, semi-forest, garden and plantation coffee production systems (Workafes and Kassu, 2000). Diversity of arabica coffee for different important traits is expected within these systems (Teketay and Tigneh, 1994; Gole *et al.*, 2001; Gole, 2003). Moreover, Anthony *et al.* (2002) indicated the presence of high genetic diversity in southwest wild coffee population as compared to cultivated crops abroad.

There are three major methods in processing of coffee: dry, wet, and semi-washed. However, in Ethiopia only the dry and wet processing methods are predominantly in use (Solomon *et al.*, 2008). Wet processed arabica is aromatic with fine acidity and some astringency, while dry processed arabica is less aromatic but with greater body and natural sweetness of the beans (Clifford, 1985; Bacon, 2005).

Coffee quality is of critical importance to the quality industry (Abdessa *et al.*, 2008). Quality coffee is a product that has desirable clean raw and roasted appearance, attractive aroma, and good cup taste.

In principle, there is no inherently bad coffee by nature. If a coffee presents poor quality, the cause usually is traced to pre-and post- harvest activities, like processing, drying, storage, handling, and transportation. It is essential to maintain stringent standards of cleanliness at all steps, especially in wet processing. If this is done, almost any coffee has the potential to show a presentable green with at least a passable cup or liquor (Endale, 2008). However, it is beyond dispute that in Ethiopia the quality of coffee produced by farmers has been deteriorating from time to time (Dessie, 2008). The factors that determine coffee quality are numerous, involving genotype, climate conditions and soil characteristics of the area in which coffee is grown, agricultural practices, harvesting methods and timing, post harvest processing techniques, grading, packing, storage condition and transporting, all contribute either to exaltation or deterioration of coffee quality (Leroy *et al.*, 2006). However, of this various factors, some of the human controlled ones such as pre-and post-harvest processing techniques, grading, packing and transporting are believed largely to contribute to the decline in coffee quality as the country is believed to possess diverse genetic base and other natural factors that favor both quality and productivity (Dessie, 2008).

To this end, there were some works done by Anuwar (2010) on assessment of coffee quality and its related problems in Jimma zone of Oromia Regional State. But, still there are gaps such as lack of profound assessment works to identify the specific coffee quality problems in Jimma zone and lack of information on the effects of post harvest processing, drying and handling techniques. Though research on coffee has been conducted at the national level for more than four decades by JARC, its target was to develop CBD resistant, high yielding and wide adapting varieties for major coffee growing areas of the country (Getu, 2009). However, recently studies are focusing on post harvest handling and quality aspects of coffee. Anwar (2010) assessed coffee quality and its related problems in Jimma zone while, Getu (2009) and Yigzaw (2005) worked on organoleptic quality traits variation with respect to genotype by environment interaction but, coffee drying material related to quality has been not done so far. Consequently, this study was conducted to examine the influence of coffee processing methods and drying materials on the quality of arabica coffee varieties under varying agro-ecologies in Jimma zone, coffee growing weredas who have big problems in coffee drying. The economic benefits of the various post-harvest management practices was considered to provide baseline information on alternative options, largely targeted to the smallholding farmers and processors for enhanced coffee quality improvement in the area. Therefore, the study has the following objectives:

1. To evaluate the influence of processing methods and drying materials on the physical and organoleptic quality attributes of known coffee varieties under Gera and Jimma conditions.

2. To estimate the economic advantages of coffee processing and drying practices under each agro-ecology.

2. LITERATURE REVIEW

2.1. Botanical Classification and Characteristics of Coffea arabica L.

Coffea arabica L. performed over all 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 western montane rainforests of Ethiopia (Feyera, 2006).

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 reproduced 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 (5.2-6.3pH); 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 (Sylvian, 1958; Meyer, 1965; Wondimu, 1998; Bellachew *et al*., 2000; Anthony *et al*., 2002; Steiger *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 orange leaf rust (*Hemileia vastatrix* Berk and Br.) (Eskes, 1983; Wondimu, 1998), nematodes (*Meloidogyne incognita*) (Anzueto *et al*., 2001), coffee berry disease (*Colletotrichum kahawae* Waller and Bridge) (Bayetta *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 (Wondimu, 1998).

2.2. Economic Importance and Uses of Coffee in Ethiopia

Historically, Ethiopia is the oldest exporter of coffee in the world and it is the largest coffee producer and exporter in Africa (ITC, 2002; Nicolas, 2007). 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 sixth largest coffee producer worldwide (FAO, 2010). 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).

In Jimma zone of Oromia Regional State, about eight woredas are producing coffee and 105,140 ha of land is devoted to coffee production with the annual production of 40,000-55,000 tons (JZARDO, 2008). Of which, about 28,000 to 35,000 tons are supplied to the central market, while the remaining is locally consumed (Alemayehu *et al*., 2008). The washed and sun dried coffees account for 46 % and 54 %, respectively. Currently, Jimma Zone covers 21% of the total export the country (JZARDO, 2008). According to the report from the same source, 30-45% of the people in Jimma zone are directly or indirectly benefited from the coffee industry.

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. Similarly, Berhanu (1998) reported the importance of coffee as a remedy against intermittent fevers and as antidote against narcotic poisoning. The most common medicinal use of caffeine is as part of headache preparations and other pain relievers.

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.

The world’s best quality coffees such as Harar, Limu and Yirgacheffe are produced from the eastern and southwestern parts of Ethiopia (ITC, 2002). However, it is beyond dispute that in Ethiopia the quality of coffee produced by farmers has been deteriorating from time to time. At different forum, serious complaints have been raised about the declining quality of coffee produced in different parts of the country (Dessie, 2008).

Except Wellega coffee, traditionally all the sun dried coffees produced around Illubabor, Jimma, Gemadro and, South Western Ethiopia lowland such as Tepi, Bebeka, Gambella areas are considered as Jimma coffee. And this sun dried Jimma coffee is one of the lowest priced coffees in the international market due to inappropriate processing as opposed to Limmu washed grade 2 fetches better premium price thought it is produced in the same agro-ecological zone (Dessie, 2008). Limmu coffee is characterized as having excellent balanced flavor with good acidity and medium body. It shares the winy characteristics of

Harar (Getu, 2009). Furthermore, Dessie (2008) reported that although the inherent flavor of Jimma coffee is pleasantly winy, some of the common cup defects are earthy, musty with secondary cup defects of the taints on the liquor, which are mainly due to post harvest management problems.

2.3.1. Quality insurance

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, chemical), 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).

In this regard, Agwanda (1999) compared four traits (acidity, body, flavour and overall standard) for their suitability as selection criteria for the genetic improvement of overall liquor quality. Based on correlation, repeatability and sensitivity analysis, flavour rating was recommended as the best selection criterion for genetic improvement of cup quality in Arabica coffee. The trait showed high genetic correlation with preference, was easy to determine organoleptically and had relatively high sensitivity in discriminating different coffee genotypes (Agwanda, 1999). On the other hand, Walyaro (1983) and Van der Vossen (1985) observed fairly high heritability for the overall standard of cup quality and indicated the possibility of good selection progress. Carvalho (1988) reported the dominant nature of good cup quality in Arabica coffee. These are the most important criterion of evaluation of green coffee, as their presences alter the final cup quality by generating off flavor.

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 (46% AA) 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, Roche (1995) and Agwanda *et al.* (2003) 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 (Puerta, 2000; 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 (Wondimu, 1998). 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 (Srinivasen, 1978; EAFCA, 2008).

2.4.2. Environmental factor

The environmental factors most frequently mentioned are altitude (positive effect on coffee quality) and rainfall (negative effect) (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 (Sivetz, 1979).

Higher altitude favors better aroma and flavor formation. Environment, genetic, and the interaction of both factors influence “typicity” of coffee cup quality (Mawardi, 2005). In addition, physical quality like shape and make and size of the bean is affected by the environment where the coffee is growing (Yigzawu, 2005; 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). 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). 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). 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).

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).

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 sub-optimal (low altitude) coffee production zones, by promoting slower and balanced filling and uniform ripening of berries. Likewise, Yemaneberhan (1998) reported that shade increased sugar concentration, which is an important factor for creating the aroma of coffee.

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, 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.

2.4.4. Harvesting and post-harvest handling

Among local techniques, the varieties cultivated, harvesting time and postharvest processing play a predominant role in obtaining a quality coffee (Avelino *et al*., 2005).

i. 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). 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).

ii. Coffee processing

There are three major methods in use for processing of coffee: dry, wet, and semi-washed. However in Ethiopia only the dry and wet processing are widely used. Processing methods had been known to be important for coffee quality (Jackels *et al*., 2006). 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. Due to the weather conditions in Vietnam (GTZ, 2002), most coffee drying is done mechanically; only a small amount of sun-drying is possible, removing coffee parchment and quality grading (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, 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, 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).

In general, washed coffee carefully prepared and handled, is clean in flavor and free from undesirable element (Sivetz and Desrosier, 1979). 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). A rapid and more controllable fermentation is necessary in order to avoid congestion at the factor, when over-burdened with coffee to be processed, and eliminate the possibility of occurrence of deleterious off-flavors and taints, such as 'sourness', 'stinkers', and 'onion flavor', the results of aspects of the concomitant microbial and/or bean physiological and biochemical activities. Natural coffee, since it is always dried in contact with its mucilage, has a better body and due to this fact under ideal condition natural coffee may be of excellent quality, clean testing and full bodied and, while different, as desirable as washed coffee (Bacon, 2005). The way of coffee processing affects coffee bean odor (Endale, 2008) and color (Davids, 2001). Consequently, a coffee with a better attention/management in terms of harvesting, processing, storage, and transportation turns out to have a better odor (Endale, 2008). Jackelers and Jackels (2005) 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.

Coffee drying is always a delicate operation which should be carried out carefully. It is a step in coffee processing that is required and quality can easily be lost by drying (Paulo *et al.,* 2007). Therefore, drying is assumed to be the major factor affecting the final coffee quality (Mulato and Muhlbauer, 2003).

During the drying process, variations in the structure of the beans (color, aspect, defects and flavor, etc) can occur, affecting the quality of the beverage (Paulo *et al*., 2007); and if the mucilage remains present during drying, there is the risk of undesirable fermentation, which is detrimental for the quality of the coffee (Clark, 1985).

Coffee drying by using cemented floor, bricks floor and raised bed with mesh wire, wooden and bamboo bed has better quality than coffee drying on the ground. It is expected that drying material correlated positively with quality and vice versa (Anwar, 2010).

Weather conditions, drying depth and other logistic constraints cause delays between harvesting and drying. This could adversely affect the cup quality of coffee produced. The non-volatile components of the green coffee beans as affected by pre-drying storage conditions and their effect on the final quality of the dried beans is limited in the literature (Lowor and Amoah, 2008). In addition, depth and suitable exposure (covering) period that correlates with above average cup quality of coffee. The covering period during drying and depth of parchment layer affects the total time required to dry (Solomon and Behailu, 2006; Behailu *et al*., 2008).

The coffee during the drying period, which lasts 8-10 days in favorable conditions, solar drying is subject to the vagaries of atmospheric conditions, together with the possibilities of growth of both desirable and undesirable microorganisms generating substances from the drying pulp, affecting subsequent flavor of the coffee brew made from the coffee after roasting (Clarke, 1987). Silva *et al*. (2000) reported that the microbial population associated with dry processed Arabica coffee includes 32 species of bacteria, 24 species of yeasts, and 8 species of filamentous fungi. The time which the coffee is maintained at a given temperature during drying process is just as important in its effect on quality. Over drying produces sour or cooked flavors in the brewed coffee (Sivetz, 1979).

iii. Moisture content

Moisture in coffee beans is frequently a last minute item of concern. However, it is a significant factor in the quality and cost attributes of coffee. Beginning at the time of harvest, moisture is a key determinant of the maturity of the bean for harvest. This maturity has a continuing influence on the quality of the coffee at each of the next steps. It determines the amount of drying needed to stand the rigors of shipping. It is a principal economic factor due to weight loss of the green beans during storage and roasting (Robin, 2009).

Moisture is an important attribute and indicator of quality. Green coffee with low moisture contents tend to roast faster than those with high moisture content (Leroy *et al*., 2006). The ICO resolution 407 recommends that coffee should not be exported when outside of these limits (10 to 12% MC) as assessed by the ISO 6673 method (ISO, 2000).

After wet processing parchment coffee needs to be dried quickly to prevent the development of microbial activities (moulds, yeasts, etc.), which can result in severe cup defects as well as create toxins which can pose health risks to consumers. Coffee must be dried so that it has a moisture content of at least 11- 12%. At this level, coffee beans will preserve their inherent quality, mould development is limited and minimal breakage will occur during hulling, grading and exporting (Kamau, 1980). At < 9% the coffee looses flavor, while at > 13% there is an increasing risk of OTA contamination (Magan and Aldred, 2005).

However, in case of Vietnam's Arabica growing areas are rather low altitude, beans expand quickly resulting in a more open or "spongy" structure compared to beans growing in altitudes above 1,000 meters. As a result of this open structure, beans are more subject to rewetting. Therefore, final moisture content after drying 10 to 11% is recommended for Vietnamese coffee processors, thus ensuring that moisture content on arrival overseas will not exceed 12% (GTZ, 2002). Uniform drying will be achieved, if temperature and relative humidity of the air are correct and coffee is regularly turned.

Growers need to constantly monitor moisture content in order to determine the best drying time and procedures. For example, green beans in Indonesia will typically be higher in moisture content than green beans in Columbia because of the higher humidity in Indonesia. Consequently, different drying schedules and techniques may improve the drying results (Robin, 2009).

According to Robin (2009), frequently, two loads of green beans from the same region have different moisture contents. This may be the result of different drying method or varying weather conditions. For example, three different growers advertise that they use the gentle drying process. However, the grower in Kenya uses a concrete patio, the grower from Ethiopia uses netting and the grower from Ghana uses the drying table approach. If the process is not monitored by measuring the beans' moisture, wide variations in the resulting moisture content can be expected. The variations in the methods used and the differences in weather condition each of the countries would affect drying times. Without a means to measure the changing moisture, wide differences would be expected.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study was carried out in 2009/2010 at Jimma Agricultural Research Center (JARC,) and Gera Agricultural Research Sub-Center, representing the medium and high altitude coffee growing agro-ecologies in the southwestern Ethiopia, respectively.

JARC is geographically located at 7^{0}46' N latitude and 36^{0} E longitude at an elevation of 1753m.a.s.l, in south western Ethiopia in Jimma zone. It is 363 km away from Addis Ababa. The mean maximum and minimum temperature of the center are 26.2^{0}C and 11.3^{o}C, respectively. The annual rainfall is about 1529.5 mm. JARC has both upland and bottom land soil. The dominant soil types in the uplands are chromic Nitosols and Cambisels where as Fluisol is the dominant soil type in the bottom land. The center represents the tepid to cool sub-humid low to high altitude coffee growing zones of the country. The research center specializes in agricultural research, which serves as National coordinating center for coffee (EIAR, 2004). Gera Agricultural Research Sub-center is located at 7^{0} 7' N latitude and 36^{0} E longitude at elevation of 1940m.a.s.l. It is 435 km away from Addis Ababa. The mean maximum and minimum air temperatures of the center are 24.5^{0} C and 10.4^{0} C, respectively. The annual rainfall is about 1880 mm (EIAR, 2006).

3.2. Experimental Materials

The study locations were representatives of coffee growing areas having big problems in coffee drying and the selected three CBD (Coffee Berry Disease) resistant coffee varieties were recommended for the two locations (highland and mid land). The three CBD resistant coffee varieties which have been released and recommended for the study areas (Table 1) were evaluated for their organoleptic and physical quality attributes.

For this, the handpicked red ripe coffee cherries were processed with the two processing methods (the dry and wet processing) and dried on six different drying materials; the locally used drying materials including soil, bamboo, palm leaves mat, jute mesh, cement floor and, the recommended drying material mesh wire were used for the study. Four uniform drying bed sizes (1m x 0.6 m) were constructed at a height of one meter above the ground. Similarly, equal bed sizes were also included on the ground using cemented floor and bare soil surface. The coffee samples of each treatment were divided into equal halves, prepared and dried on each drying bed.

Arabica coffee varieties that have been established at JARC and Gera Agricultural Research Sub-center were planted in July 2001 using a spacing of 1.7 m between plants and 1.8 m between rows for variety 74110, 1.8 m between plants and 2 m between rows for 7440 and 1.9 m between plants and 2.2 m between rows for 75227. In order to control variation, the varieties were planted with shade of 50% and all agronomic practices such as chemical fertilization, applications of pesticide and herbicide were uniformly applied during the first year of transplanting at each location for successful establishment. But, manual weeding was practiced at both locations to maintain the field as clean as possible using the recommended post-planting operations.

3.3. Experimental Design and Treatments

The experiments were laid out in a 2×6×3 factorial split-split-plot arrangement in a randomized complete block design with three replications at each study location. The processing methods were assigned as main plots, drying materials as sub plots and varieties as sub-sub plot treatments.

Therefore, a total of 216 coffee samples were prepared for both processing method at JARC and Gera Sub-center. The samples were kept free from rain during the day and night time. The treatment combinations are presented in Table 2.

Table 1. Description of coffee varieties used in the study

Variety	Area of collection	Released year	Canopy nature	Yield (Q/ha)		Quality		Growing altitude	Spacing (m)	Recommended areas	Resistance
				On-farm	On-station	Raw	Cup				
74110	Metu	1978/79	Compact	9-10	19.1	Average/good	Good	1500-1750	1.7 × 1.8	Highland and midland	CBD
7440	Gimbo	1979/80	Intermediate	8-9	16.2	Fair/good	FAQ	1550-1750	1.85×2.0	Highland	CBD
75227	Gera	1980/81	Open	8-9	17.9	FAQ	FAQ	1750-2100	1.9 × 2.2	Highland and midland	CBD

Source: IAR (1996); Behailu *et al.* (2008)

Table 2. Details of treatment combinations

Treatment	Treatment combination	Symbol
T_1	Wet processing + 74110 drying on mesh wire	WV_1Dm_1
T_2	Wet processing + 7440 drying on mesh wire	WV_2Dm_1
T_3	Wet processing + 75227 drying on mesh wire	WV_3Dm_1
T_4	Wet processing + 74110 drying on bamboo	WV_1Dm_2
T_5	Wet processing + 7440 drying on bamboo	WV_2Dm_2
T_6	Wet processing + 75227 drying on bamboo	WV_3Dm_2
T_7	Wet processing + 74110 drying on palm leaves mat	WV_1Dm_3
T_8	Wet processing + 7440 drying on palm leaves mat	WV_2Dm_3
T_9	Wet processing + 75227 drying on palm leaves mat	WV_3Dm_3
T_{10}	Wet processing + 74110 drying on jute mesh	WV_1Dm_4
T_{11}	Wet processing + 7440 drying on jute mesh	WV_2Dm_4
T_{12}	Wet processing + 75227 drying on jute mesh	WV_3Dm_4
T_{13}	Wet processing + 74110 drying on cement floor	WV_1Dm_5
T_{14}	Wet processing + 7440 drying on cement floor	WV_2Dm_5
T_{15}	Wet processing + 75227 drying on cement floor	WV_3Dm_5
T_{16}	Wet processing + 74110 drying on soil floor	WV_1Dm_6
T_{17}	Wet processing + 7440 drying on soil floor	WV_2Dm_6
T_{18}	Wet processing + 75227 drying on soil floor	WV_3Dm_6
T_{19}	Dry processing + 74110 drying on mesh wire	DV_1Dm_1
T_{20}	Dry processing + 7440 drying on mesh wire	DV_2Dm_1
T_{21}	Dry processing + 75227 drying on mesh wire	DV_3Dm_1
T_{22}	Dry processing + 74110 drying on bamboo	DV_1Dm_2
T_{23}	Dry processing + 7440 drying on bamboo	DV_2Dm_2
T_{24}	Dry processing + 75227 drying on bamboo	DV_3Dm_2
T_{25}	Dry processing + 74110 drying on palm leaves mat	DV_1Dm_3
T_{26}	Dry processing + 7440 drying on palm leaves mat	DV_2Dm_3
T_{27}	Dry processing + 75227 drying on palm leaves mat	DV_3Dm_3
T_{28}	Dry processing + 74110 drying on jute mesh	DV_1Dm_4
T_{29}	Dry processing + 7440 drying on jute mesh	DV_2Dm_4
T_{30}	Dry processing + 75227 drying on jute mesh	DV_3Dm_4
T_{31}	Dry processing + 74110 drying on cement floor	DV_1Dm_5
T_{32}	Dry processing + 7440 drying on cement floor	DV_2Dm_5
T_{33}	Dry processing + 75227 drying on cement floor	DV_3Dm_5
T_{34}	Dry processing + 74110 drying on soil floor	DV_1Dm_6
T_{35}	Dry processing + 7440 drying on soil floor	DV_2Dm_6
T_{36}	Dry processing + 75227 drying on soil floor	DV_3Dm_6

3.4. Experimental Procedures

For each sample, 6kg of cherries was processed by the wet method to obtain approximately 1.2 kg of green coffee beans and 3kg of cherries for dry method to get approximately 0.6 kg of green coffee beans (Bertrand *et al*., 2006). A total of 216 samples were used for the study at the two study locations for the two processing methods.

The required amount of red fresh cherries were handpicked and prepared from representative coffee tree at peak harvest period in November, 2009 and bulked together. Then, the samples were carefully divided into equal parts and processed accordingly.

3.4.1. Harvesting and processing

For both wet and dry processing, red fully ripen cherries were manually picked as recommended and separated from foreign materials and unripe green cherries. Then, the prepared samples were processed as described by Woldemichael (1996).

Dry processing

Drying: Cherries were dried in the sun on their respective drying materials for about two to three weeks depending on the climate, variety and drying material. In all the treatments, coffee was spread at 5 cm drying depth and covered with polyethylene plastic sheet during hot hours of the days (12:00 to 10:00PM) for parchment coffee and throughout the night for both processing methods. The moisture content of the bean was measured using Electronic Rapid Moisture Tester (HOH-Express, HE 50 Germany) and maintained between 10–12% for all samples uniformly.

*Hulling***:** Fully dried coffee was dehulled by lab-scale hulling machine to produce the clean coffee beans and undamaged beans were used both for cup quality and green bean physical character analyses.

Wet processing

*Pulping***:** The fresh red ripen cherries were pulped using a hand pulper 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 a fermentation tank to undergo fermentation for 40 hours to facilitate decomposition of the mucilage. Under Jimma condition, mucilage normally takes 24 to 40 hours to become completely removed from the bean (Woelore, 1993; Anwar, 2010). Hand fill texture method was employed to check for the removal of mucilage from the pulped coffee.

*Washing***:** After fermentation, the beans were washed using three to four changes of clean water to remove all traces and decomposed products of the mucilage. Socking takes 24 hours with clean water. At this stage, the coffee is referred as "parchment coffee".

*Drying***:** The wet parchments coffees were placed on those different drying materials under sun for drying. Beans with some defects are avoided at this stage. During drying, Parchment coffee dried at 2 cm drying depth, the moisture content of the bean was measured by moisture tester (H-E50, Germany) 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 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.

3.4.2. Quality analysis

About 300g of green coffee bean sample were prepared from each treatment for organoleptic and raw quality characteristic analysis. To obtain homogenous bean size and healthy beans, samples were screened through a mesh sieve size 14. Then, samples on screen 14 and above were used for analysis.

Roasting

The roaster machine (Probat BRZ6, Germany) was first heated at about 160-200 ^{0}C. About 100 g of green coffee bean sample per treatment was used for roasting. When the roasted beans started to crackle (burst), the gas was turned down and when the coffee was considered medium roasted (7 minutes on average), it was tipped out into the cooling tray. Immediately, cold air was blown though the coffee to produce rapid cooling off. When the roasted beans were cool enough (4 minutes on average), it was blown to remove the loose silver skins before grinding. Variability in roasting was controlled by measuring weight loss. The weight losses found were between 8-10 % and these matches with medium to dark roasting degree reported in Clarke (1987).

Grinding

Of the roasted coffee, about 8g medium sized ground coffee was prepared using electrical grinder (Mahlkonig, Germany) with middle adjustment.

Brewing

Soon after grinding, about 8g coffee powder was placed in a 180ml cup (ISO, 6668:1991). Then, boiling water was poured onto the ground coffee up to about half way in the cup. Soon after, volatile aromatic quality and intensity parameters were recorded by sniffing; carried out by the trained panelists of JARC. Then, the contents of the cup were stirred to ensure an infusion of all coffee grounds. The cup was then filled to the brim with boiled water. The brew was left for 3 minutes and then the foam was skimmed off with spoon. Finally, the brew was made ready for panelists within 8 minutes.

Cup tasting

This was made at JARC coffee liquoring laboratory using the standard procedures (Table 3). Once the beverage was cooled to around 60°C (drinkable temperature), then cup tasting was carried out by the five trained panelists certified by ministry of agriculture coffee liquoring unit, Addis Ababa, Ethiopia. Three cups per sample was prepared for a tasting session arranged randomly. To end with, means of each variable by the panel was used for statistical analysis (Getu, 2009).

Table 3. Standard parameters and their respective values used for unwashed and washed coffee raw and cup quality evaluation as per JARC (2010)

Character	Sample code
Shape and make	
Color	
Odor	
Moisture content	
Over screen 14	
Aromatic intensity	
Aromatic quality	
Acidity	
Astringency	
Bitterness	
Body	
Flavor	
Typicity	
Overall standard	
Defects	
Remark	

Notes:
Shape and make (15) where 15= V. good, 12=Good, 8=Average, 5=Mixed, 2=Small
Color (15) where 15=Bluish, 12= Greyish, 8=Greenish, 5=Faded, 2=Brownish
Odour (10) where 10= clean, 8=Trace, 5=Light, 2=Moderate, 1=Strong
Scale ranging from 0-5 where 0=nil, 1= very light, 2=light, 3=medium, 4=Strong, 5=very strong
**Typicity is an after taste aromatic quality that could be winey, citrus, mocha fruity, spicy*
Overall standard is evaluated based on the other attributes (aromatic quality, acidity, body, flavor and typicity).
For overall standard, scale ranging from 0-5 where, 0 = unacceptable, 1 = bad, 2 = regular, 3=good, 4 = very good, 5 = Excellent.

3.5. Data Collected

Data for seed moisture content, physical quality attributes of green bean (above screen size, shape and make, color, odor and hundred bean weight) and cup quality attributes (aromatic intensity, aromatic quality, acidity, astringency, body, flavor and overall standard) were collected by combining the different coffee cupping techniques followed at French Agricultural Research Center for International Development (CIRAD), Jimma Agricultural Research Center (JARC) and Coffee liquoring Unit of Ethiopia (CLU).

3.5.1. Days to drying

During drying, the moisture content of the bean was measured daily by using Electronic Rapid Moisture Tester (HOH-Express, HE 50 Germany) to know and maintain the moisture level between 10–12%.

It is a standard quality evaluating parameter to know whether the coffee can continue for further steps of quality evaluation and check if it is suitable (conducive) to the effect of microbial action particularly Ochratoxin A (Eshetu and Girma, 2008). Hence, days to drying was recorded as the number of days taken from the date of washing (for wet processing) and harvesting (for dry processing) to when the moisture content of the bean was 10- 12%.

3.5.2. Physical quality attributes

i. Defects count

A 300 g of each clean coffee sample was taken using digital balance. Internationally a standard is fixed for these green defects (over-ripe, foxy, under ripe, immature, blacks, whites, stones, soil, earthy, broken, etc) (Endale, 2008). Beans were separated from each sample according to Ethiopia Commodity Exchange (2010) (Table 4 and 5). It is the principle of counting different kinds of coffee defects using a set of standards developed, taking their rate of effect on the overall quality of coffee. The defect handpicking and sorting is done by the hand pickers whereas the analysis task is carried out by the experts (Endale, 2008).

Table 4. Raw defect type and evaluation system of SCAA and Ethiopia unwashed green coffee bean

Raw defects												
SCAA primary defects		Secondary defects observations										
Type	Bean grade	SCAA	0	1	2	3	Ethiopia	0	1	2	3
Full black		Partial black					Foxy				
Full sour		Partial sour					Under dried				
Fungus		Floater					Over dried				
Foreign matter		Immature					Mixed				
Insect damaged		Withered					Stinkers				
Pod/Husk		Shell					Faded				
		Serious insect damaged					Coated				
		Broken					Light				
		Soiled					Starved				
Total (Transfer to grade table)		Total									

Source: ECX (2010)

Table 5. Dry processed coffee green bean raw evaluation parameters for defect count rating system

Defects type	Rate	Defect point
Immature	5	1
Pest damaged	5	1
Foxy	5	1
Broken	10	1
Black	1	1
White	1	1
Pod	1	1
Husk	Depends on size	1
Stick	Big	10
	Medium	5
	Small	3
Stone	Big	10
	Medium	5
	Small	3
Wanza	1	10
Earth (soil)	Big	10
	Medium	5
	Small	3
Soil beans	5	1

Source: ECX (2010)

ii. Bean size

The beans were graded by size using standard screens that have different screen size, with round holes as defined in the International Organization for Standards (ISO, 1991). To obtain uniform bean size for bean physical and organoleptic quality analysis, samples were screened through mesh sieve size. 14. Then samples on screen No.14 and above, which are defined in the International Organization for Standards (ISO) (1991) so that it is possible to draw the raw quality in relation with largeness, boldness, medium and small bean size. Bean size distribution was carried out by means of rounded perforated plate called screen. The size of the screen holes was specified in 1/64 In.

iii. Shape and make

This attribute is an interchangeably used term, which usually refers to the structure or make up of the beans (Endale, 2008). Evaluated as 15=very good, 12=good, 8=Average, 5=Mixed and 2=small and, weighted accordingly.

iv. Color

Evaluated as 15= bluish, 12=Grayish, 8=Greenish, 5=faded and 2=Brownish and, weighted accordingly.

v. Odor

Olfaction evaluated as 10=clean, 8=Trace, 5=Light, 2=Moderate, and 1=strong.

vi. Hundred Bean weight

Hundred beans weight of each sample was recorded using digital bean balance by oven drying at 103^0C temperature for 24 hours to 0 % moisture content and was converted by 0.89 at 11% moisture content (bean weight at 0% moisture*100)/(bean number*0.89=bean weight at 11% moisture content) (IPGRI, 1996).

3.5.3. Organoleptic quality attributes

i. Aromatic intensity

Aromatic intensity is the magnitude of the aroma and it is evaluated on the basis of 0 to 5 scale where, 0=nil, 1=very light, 2=light, 3=medium, 4=strong, 5=very strong.

ii. Aromatic quality

This is a sensation that is hard to separate from flavor. The aroma contributes to the flavors we discern on our palates. Subtle nuances, such as 'floral' or 'winy' characteristics, are derived from the aroma of brewed coffee. Scale ranges from 0 to 5 where, 0=unacceptable, 1=bad, 2=regular, 3=good, 4=very good, 5=excellent. The result recorded accordingly.

iii. Acidity

It is the sensation of dryness that the coffee produces under the edges of the tongue and on the back of the palate. Acidity should not be confused with sour. Cup acidity was evaluated as 0= unacceptable, 1=bad, 2=regular, 3= good, 4= very good, 5= excellent and the result accordingly recorded

iv. Astringency

Describes complex sensation accompanied by shrinking, drawing or puckering mucosal surface in the mouth, produced by substances like tannins and sloe tannins. Evaluated using a scale ranging from 0 to 5 where, 0 =nil, 1=very light, 2=light, 3=medium, 4= strong, 5=very strong.

v. Body

Body is the feeling that the coffee has in the mouth. It is the viscosity, heaviness, thickness, or richness that is perceived on the tongue. Cup body was evaluated using a scale ranges from 0-5 where 0=unacceptable, 1=bad, 2=regular, 3=good, 4=very good, 5=excellent. The result recorded accordingly.

vi. Cup Cleanness

It indicates freeness of the coffee from defects, if there is problem during roasting and it ranged from 0 to 15 where, 0 = > 3 cups defect, 3 =3 cups defect, 6 =2 cups defects, 9 =1 cups defect, 12=fair clean, and 15 =clean.

vii. Flavor

Flavor is the overall perception of the coffee in the mouth. Acidity, aroma and body are all components of flavor, the scale ranging from 0 to 5 where, 0 = unacceptable, 1 = bad, 2 = regular, 3 = good, 4 = very good, 5 = excellent.

viii. Overall standard

The overall test of the brew evaluated and recorded as 0 = unacceptable, 1= bad, 2= regular, 3= good, 4 = very good, 5 = excellent.

3.6. Grading

Coffee grading evaluation for both raw (40%) and liquor (60%) quality was carried out for 72 samples following the procedures of (Appendix Table 9 and 10) (ECX, 2009).

3.7. Partial budget analysis

A quality of coffee is the principal component of economic benefit to the producer. The simple calculation was show that the total cost (Appendix Table 8) is the sum of the total fixed cost (TFC) and the total variable cost (TVC). The gross benefit gets from (ECX, 2010) according to the current price per kg of coffee by their grade. Finally, Net benefit obtained by subtracting total cost (TC) from gross benefit (revenue).

TC = TFC + TVC

Net Benefit = R - TC

3.8. Statistical Analysis

The data were analyzed in a split-split plot design according to Montgomery (2005) 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 a split-split plot design:

$$Y_{ijlk} = \mu + \sigma_k + \eta_i + \beta_j + \alpha_l + (\eta\beta)_{ij} + (\eta\alpha)_{il} + (\beta\alpha)_{jl} + (\eta\beta\alpha)_{ijl} + \varepsilon i_{jlk}$$

$$\begin{cases} i = 1, 2, ..., a \\ j = 1, 2, ..., b \\ l = 1, 2, ..., c \\ k = 1, 2, ..., n \end{cases}$$

Where,

μ = the overall mean effect

η_i = the effects of the i^{th} level of factor A

β_j = the effects of the j^{th} level of factor B

αl = the effect of the l^{th} level of factor C

$(\eta\beta)_{ij}$ = the effects of the interaction between τ_i and β_j

$(\eta\alpha)il$ = the effect of the interaction between τ_i and αl

$(\beta\alpha)jl$ = the effect of the interaction between βj and αl

$(\eta\beta\alpha)ijl$ = the effect of the interaction among $\tau_{i,}$ βj and αl

σ = effect of Blocking

ε_{ijlk} = is a random error component

Least square means (LSMEANS) and LSD procedures at 0.05 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.

Table 6. ANOVA model including the factors processing, drying method and variety estimation of variance components, in a split-split plot Arrangement, RCBD design

Source of variation	Df	SSQ	MS	F
Blocks (*B*)	b-1	SSQ_B	SSQ_B/(b-1)	MS_B/MS_{Em}
Treatments (*Tr*)	t-1	SSQ_{Tr}	SSQ_{Tr}/(t-1)	MS_{Tr}/MS_{Em}
Error-main plots (*Em*)	(t-1)*(b-1)	SSQ_{Em}	SSQ_{Em}/((t-1)*(b-1))	
Subplots (*S*)	s-1	SSQ_S	SSQ_S/(s-1)	MS_S/MS_{Es}
Subplots x Treatments (*SxT*)	(t-1)*(s-1)	SSQ_{SxT}	SSQ_{SxT}/(t-1)*(s-1)	MS_{SxT}/MS_{Es}
Error-subplots (*Es*)	t*(b-1)*(s-1)	SSQ_{Es}	SSQ_{Es}/(t*(b-1)*(s-1))	
Split-subplots (*U*)	u-1	SSQ_U	SSQ_U/(u-1)	MS_U/MS_{Eu}
Split-subplots x Treatments (*UxT*)	(t-1)*(u-1)	SSQ_{UxT}	SSQ_{UxT}/(t-1)*(u-1)	MS_{UxT}/MS_{Eu}
Split-subplots x Subplots (*UxS*)	(s-1)*(u-1)	SSQ_{UxS}	SSQ_{UxS}/(s-1)*(u-1)	MS_{UxS}/MS_{Eu}
Split-subplots x Subplots x Treatments (*UxSxT*)	(t-1)*(s-1)*(u-1)	SSQ_{UxSxT}	SSQ_{UxSxT}/((t-1)(s-1)*(u-1))	MS_{UxSxT}/MS_{Eu}
Error-split-subplots (*Eu*)	t*s*(b-1)*(u-1)	SSQ_{Eu}	SSQ_{Eu}/(t*s*(b-1)*(u-1))	
Total (*Tot*)	t*b*s*u-1	SSQ_{Tot}		

Where, t=number of main treatments, b=number of blocks, s=number of subplot and u=number of sub-sub plot

4. RESULTS AND DISCUSSION

4.1. Analysis of Variance

Results obtained from test of homogeneity for error of variance showed that the computed F-calculated value exceeds the corresponding tabulated (χ^2) value at 5% level of significance for all of the traits. The hypothesis that the two error variances are homogeneous was rejected as described by Gomez and Gomez, (1984); Mandefro, (2005). As a result, the analysis of variance and other statistical analysis were run for the two locations separately.

4.1.1. Days to drying

The results in Appendix Table 1 showed that a highly significant ($P<0.01$) variation was observed among the two way interaction effects of processing methods and drying materials, drying materials and varieties as well as processing methods and varieties with respect to days to drying at Gera. On the other hand, a significant variation could not be observed from the three way interaction effect of processing methods, drying materials and varieties.

At JARC, a significant ($P<0.05$) variation was observed among the three way interaction effect of processing methods, drying materials and varieties (Appendix Table 1).

Highly significant variations were found due to the interaction effect between processing method and drying material at Gera (Fig 1). Wet processed coffee dried on mesh wire dried earlier (7.44 days) but it was not significantly different from wet processing and drying on bamboo bed (7.67 days). On the other hand, dry processed coffee dried on a mesh wire bed took significantly longest time (21 days) to dry. This might be due to the fact that wet processed parchment coffee dried quickly than coffee cherry dried without removing the outer pulp and mucilage. This result is in line with the report of GTZ (2002).

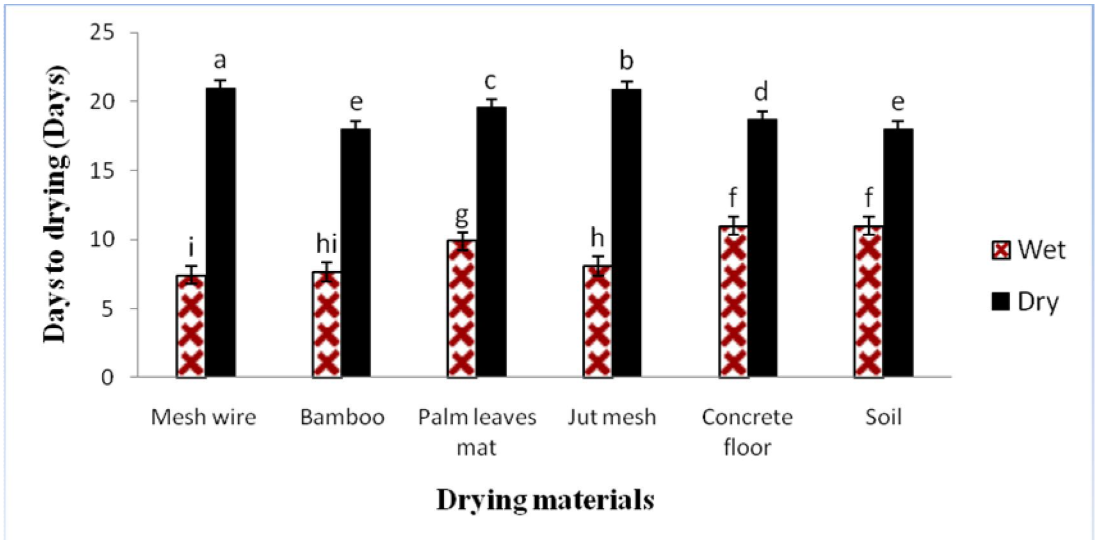

Figure 1. Interaction effect between processing methods and drying materials on days to drying at Gera

The interaction effect between processing methods and varieties at Gera was significantly different (Appendix Table 1). Wet processing of variety 74110 (8.56 days) dried significantly earlier than others. Dry processing of variety 7440 (19.83 days) and variety 75227 (19.78 days) took significantly much longer time (Fig. 2). The reason for this could be due to the fact that the coffee cheery dried with its intact outer pulp and mucilage may require longer time to dry. In addition, varietal difference in terms of bean size and amount of mucilage might have contributed to the observed discrepancies.

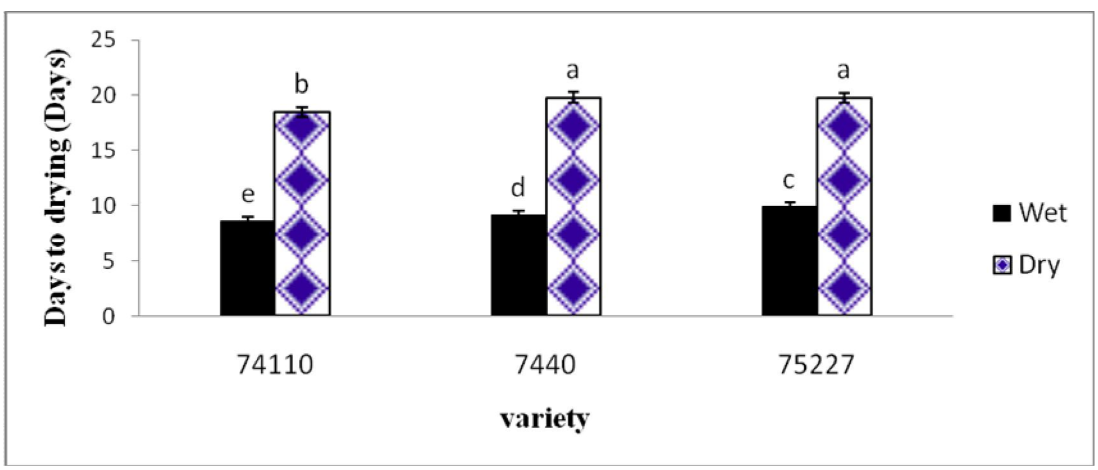

Figure 2. Interaction effect between processing methods and varieties on days to drying under Gera conditions

Variety 74110 and 7440 dried on bamboo dried equally earlier (12.50 days) than others, nonetheless they were not significantly different from variety 74110 dried on mesh wire (12.67 days) (Fig. 3). Variety 7440 and variety 75227 dried on soil took identically much longer time (15.67 days) than the others, which however, were not significantly different from variety 75227 dried on jute mesh (15.33 days), variety 75227 dried on palm leaves mat (15.00 days), variety 7440 dried on cement floor (15.00 days) and variety 75227 dried on cement floor (15.00 days). Variety 7440 and 75227 required a prolonged drying period probably due to the amount of mucilage that the coffee fruit developed in these varieties as compared with 74110. Coffee drying on a raised drying bed might facilitate better aeration and drainage which again speed up the drying process. In general, coffee drying at Gera, which is cooler than Jimma, took much longer time with a difference of only 3 days between the maximum and minimum. This result shows that there is genetic difference among the varieties used for the study site Gera.

With regard to the three way-interactions at JARC, the wet processing and drying on mesh wire of variety 74110, 7440, and 75227 all required significantly the least number of days to dry (5 days), which was equivalent with the time taken by wet processing and drying on bamboo of variety 74110, 7440, 75227 and wet processing of variety 74110 and drying on palm leaves mat and jut mesh (5 days), wet processing of variety 7440 and 75227 and drying on jut mesh (5 days). Dry processing of variety 7440 and 75227 followed by drying on mesh wire took equally and significantly much longer time (18.33 days) than the others (Fig. 4). It is vivid that there was a difference of about 13 days between the fastest and slowest drying treatments. In a nut shell, drying coffee at JARC was much faster owing to the warm condition associated with the medium altitude.

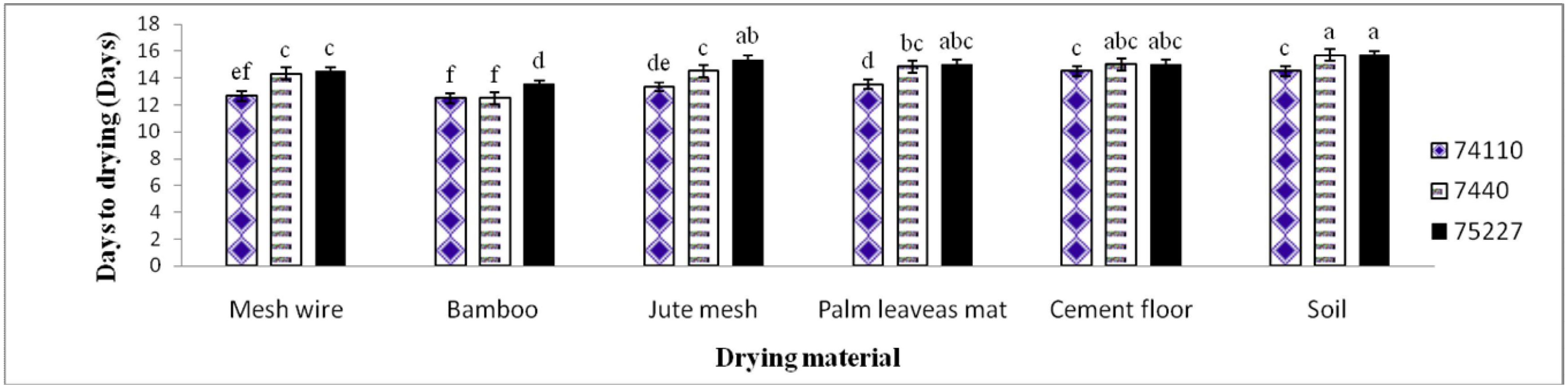

Figure 3. Interaction effect between drying materials and varieties on days to drying at Gera highland

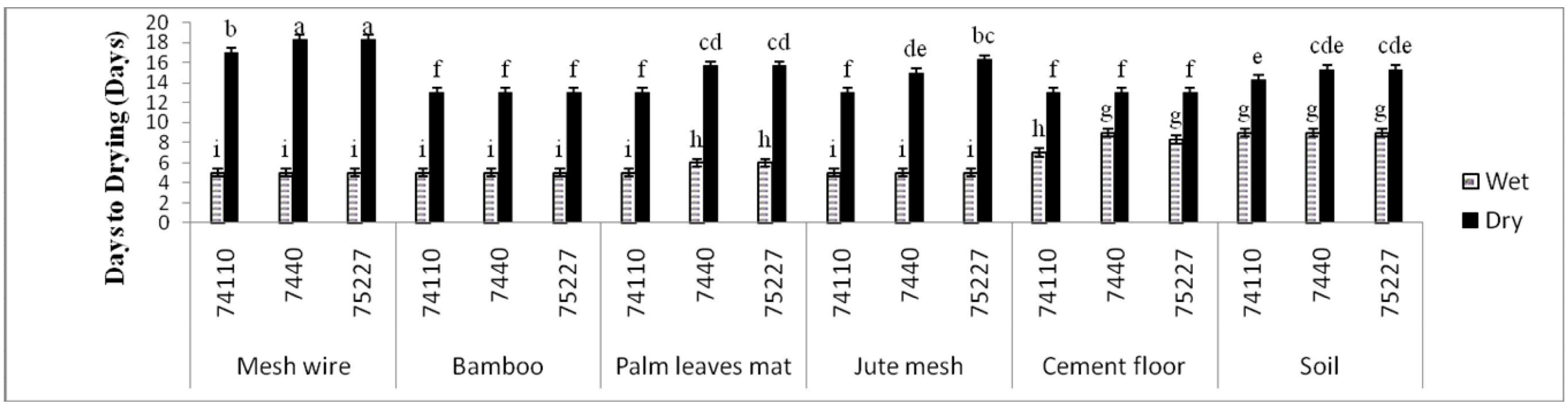

Figure 4. Interaction effect among processing methods, drying materials and varieties on days to drying at JARC

4.1.2. Physical quality attribute

i. Bean Size

With regard to bean size, 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) at Gera. A highly significant ($P<0.01$) variation was observed among the varieties and significant ($P<0.05$) variation between processing methods were revealed for bean size (Appendix Table 2). However, non-significant results were obtained among the different drying materials and for the interaction effects between processing methods and drying materials; processing methods and varieties; drying materials and varieties as well as processing methods, drying materials and varieties.

At JARC, a significant ($P<0.05$) variation was observed between the interaction effect of drying material and variety. However, processing methods and the interaction effect between processing methods and drying material; processing methods and varieties; and processing method with drying material and variety were found to be non significant (Appendix Table 3).

At Gera, the variety 7440 had significantly the maximum proportion of bold and large sized beans in which 96.12 % of the beans were retained above screen size 14. However, it was not statistically different from variety 75227 for which 95.12% of the beans were above screen (Table 7). On the other hand, variety 74110 had statistically the smallest bean size with percent above screen value of 91.95%. There was a difference of 4.07% between the maximum and minimum bean sizes of coffee at Gera. The probable reason could be due to the nature of the botanical varieties. The result obtained in this study is in conformity with the findings reported by Yigzaw (2006) and EAFCA (2008).

Pertaining to processing methods at Gera, wet processing has the highest above screen size (95.54%), 2.20% higher, than the dry processed coffee (93.24%) that resulted in statistically the lowest mean value (Table 7). This could be due to the fact that, during wet processing small sized cherries and beans are separated as floaters, which otherwise reduce the proportion of the beans. The result is inconformity with Mekonen (2009).

Table 7. Effect of varieties and processing methods on bean size of Arabica coffee at Gera

Variable	Bean size (%)
Variety	
74110	91.95b
7440	96.12a
75227	95.12a
LSD (0.05)	1.18
SE(±)	0.42
Processing methods	
Wet	95.54a
Dry	93.24b
LSD (0.05)	0.97
SE(±)	0.34
CV (%)	2.64

Means followed by different letters in the same column are significantly different

More or less bean size, expressed as above screen size, the interaction effects between processing methods and varieties in respect of above screen size were significantly different at JARC. Wet processing of 75227 had bold and large sized beans which as a result registered the highest mean value for above screen size (96.85%) even though it was not significantly different from wet processing of 7440 that had 95.60% of its beans retained above screen size. In contrast, the smallest bean size was recorded from 74110 under both natural sun drying and wet processing methods with a value of 92.68 and 91.21%, respectively, which of course is 5.64% lower than the maximum value (Table 8). Some varieties are known to have bold and large size coffee beans than the others. At Gera and Jimma was very similar (More than 95%) which is very good by standard. This result agreed with Yigzaw (2005) and Mekonen (2009) who reported that bean size is determined by botanical variety and method of processing that has a particular importance to roasters since uniform bean size would produce uniform roast.

Table 8. Interaction effect between processing methods and varieties on coffee bean size at JARC

Processing method	Variety	Bean size
Wet	74110	91.21c
	7440	95.60ab
	75227	96.85a
Dry	74110	92.68c
	7440	95.02b
	75227	94.85b
LSD (0.05)		1.64
SE(±)		0.58
CV (%)		2.59

Means followed by different letters in the same column are significantly different

ii. Shape and Make

At Gera, a significant (P<0.05) variation was noticed in the shape and make of coffee beans for processing methods (Appendix Table 2). On the other hand, non-significant results were obtained among the different drying materials, varieties and for the interaction effects between processing methods and drying materials, processing methods and varieties, drying materials and varieties as well as processing methods with drying materials and varieties.

The results pertaining to shape and make revealed that there was highly significant variation (P<0.01) between processing methods at JARC. Similarly, significant variation (P<0.05) was found among the different types of drying materials and for the interaction effect between processing methods and varieties (Appendix Table 3). However, varieties and the interaction effect between processing methods and drying materials, drying materials and varieties and, processing methods with drying materials and varieties had no significant impact on the shape and make of coffee.

At Gera the maximum value of shape and make (12.67), which is a very good shape and make with more uniform appearance, was observed when coffee was wet processed (Table 9). In contrast the coffee processed with dry processing method recorded the lowest value for shape and make (11.84) which is less by 0.83 from the maximum. This could be due to the fact that, during wet processing small sized cherries and beans are separated as floaters, which otherwise reduce the uniformity of the beans. This result is similar with the findings of Mekonen (2009).

Table 9. Effect of processing methods on shape and make of Arabica coffee at Gera

Processing methods	Shape and make
Wet	12.67a
Dry	11.84b
LSD (0.05)	0.50
SE(±)	0.18
CV (%)	10.91

Means followed by different letters in the same column are significantly different

At JARC, drying materials had a significant effect on the shape and make of coffee samples. Drying on mesh wire bed had the highest mean value (13.00), but was not significantly different from drying on bamboo (12.56), palm leaves mat (12.33) and, jute mesh (12.83); drying on soil floor had the lowest mean value (11.88) which of course was not significantly different from the value obtained from drying on bamboo (12.56), palm leaves mat (12.33) and, cement floor (12.22) (Table 10). Unlike at Gera, shape and make of coffee from JARC showed a discrepancy of 2.12 between the maximum and minimum values. Even though they are statically different, they are in the same range having very good shape and make with more uniform appearance. This could be due to the fact that, shape and make of the bean is not uniform if the drying coffee takes mach time, which finally the beans shrink. Similar results were reported by Endale (2008).

Table 10. Effect of drying materials on shape and make of Arabica coffee at JARC

Drying material	Shape and make
Mesh wire	13.00a
Bamboo	12.56abc
Palm leaves mat	12.33abc
Jute mesh	12.83ab
Cement floor	12.22bc
Soil floor	11.89c
LSD (0.05)	0.69
SE (±)	0.24
CV (%)	8.29

Means followed by different letters in the same column are significantly different

Interaction effect between processing method and variety on shape and make were significant at JARC. Wet processed variety 74110 exhibited the highest value (13.67) which was at par with wet processed variety 7440 (13.00). To the contrary, dry processing of variety 74110 had the lowest value (11.78) and that was statically equivalent to the shape and make rated for dry processing of variety 7440 (11.89) and dry processing of variety 75227 (12.00) (Table 11). Even though they are statically different, they are in the same range having very good shape and make with more uniform appearance. This result shows that there is genetical difference among the varieties used for the study and during wet processing small sized cherries and beans are separated as floaters, which otherwise reduce the uniformity of the beans. This result corroborates with reports of Mekonen (2009) and Yigzawu (2005).

Table 11. Interaction effect between processing methods and varieties on shape and make of Arabica coffee at JARC

Processing method	Variety	Shape and make
Wet	74110	13.67a
	7440	13.00ab
	75227	12.50bc
Dry	74110	11.78d
	7440	11.89cd
	75227	12.00cd
LSD (0.05)		0.69
SE (±)		0.24
CV (%)		8.29

Means followed by different letters in the same column are significantly different

iii. Odor

At Gera, highly significant ($P<0.01$) variation was observed among the different drying materials with regard to coffee bean odor (Appendix Table 2). However, non-significant results were obtained among different coffee varieties, between processing methods and for the interaction effects of between processing methods and drying materials, processing methods and varieties, drying materials and varieties as well as processing method with drying materials and varieties.

At JARC, there was a highly significant (P<0.01) interaction effect between processing methods and varieties (Appendix Table 3). In addition, the use of different types of drying materials highly significantly affected (P<0.01) the coffee bean odor. However, the effects of variety and the interaction between processing methods and drying materials, drying materials and varieties and, processing method with drying material and variety were found to be non significant.

The mean comparison (Table 12) of odor of coffee samples from Gera revealed that, the coffee dried on palm leaves mat, mesh wire, jute mesh, and bamboo received significantly the highest value (10.00) for odor. However, these treatments were as good as cement floor (9.77) which also produced clean bean odor. Unlike the rest of the treatments, soil as a drying material (8.77) resulted in significantly the lowest value for odor. As coffee is hygroscopic by its nature, it might have picked earthy flavor from the soil. Endale (2008) reported that coffee with a better attention/management turn out to have a better odor.

Table 12. Effect of drying materials on odor of Arabica coffee at Gera

Drying material	Odor
Mesh wire	10.00a
Bamboo	10.00a
Palm leaves mat	10.00a
Jute mesh	10.00a
Cement floor	9.77a
Soil floor	8.77b
LSD (0.05)	0.31
SE (±)	0.11
CV (%)	4.83

Means followed by different letters in the same column are significantly different

Similarly, a significant variation was also observed at JARC among the evaluated drying materials as far as odor is concerned (Table 13). Drying material palm leaves mat (10.00) and mesh wire (10.00) had the highest when compared to the other drying materials but it was not significantly different from jute mesh (9.88) and bamboo (9.77). Coffee samples dried on soil (9.27) produced the lowest odor value but it was not significantly different from cement floor (9.44). A more traditional way of drying coffee on the grounds obviously produces bad and unwanted odors; this could be due to contamination with dirt which not only produce earthy odor but also bring about a large microbial load including, in many cases, OTA-producers (Eshetu and Girma, 2008). Given the potential problems associated with drying on soil surface and its negative image, the practice of direct drying of coffee on soil is strongly discouraged. Endale (2008) similarly reported that coffee with a better attention/management turn out to have a better odor.

Table 13. Effect of drying materials on the odor of Arabica coffee at JARC

Drying material	Odor
Mesh wire	10.00a
Bamboo	9.77ab
Palm leaves mat	10.00a
Jute mesh	9.88ab
Cement floor	9.44bc
Soil floor	9.27c
LSD (0.05)	0.48
SE(±)	0.17
CV (%)	7.39

Means followed by different letters in the same column are significantly different

As far as the mean comparisons of the studied varieties with the two processing methods at JARC are concerned (Table 14), highest odor was noticed in variety 7440 with wet processing (10.00), which was more or less same as the value registered from variety 74110 with dry processing (9.89), variety 74110 with wet processing (9.89), variety 75227 with dry processing (9.78) and variety 75227 with wet processing (9.78) whereas the lowest mean value was recorded from variety 7440 with dry processing (9.06). This could be due to the fact that coffee processing affects coffee bean odor. This finding is similar with that of Endale (2008).

Table 14. Interaction effect of processing methods and varieties on coffee bean odor at JARC

Processing method	Variety	Odor
Wet	74110	9.89a
	7440	10.00a
	75227	9.78a
Dry	74110	9.89a
	7440	9.06b
	75227	9.78a
LSD (0.05)		0.48
SE(±)		0.17
CV (%)		7.39

Means followed by different letters in the same column are significantly different

iv. Bean color

At Gera, there was highly significant variation ($P<0.01$) in bean color among the three way interaction of processing methods, drying materials and varieties (Appendix Table 2).

The interaction of processing method and drying material showed a highly significant variation ($P<0.01$) on bean color at JARC (Appendix Table 3). However, varieties and the interaction effect between processing methods and varieties, drying materials and varieties and, processing methods with drying materials and varieties were found to be non significant.

In line with the observed results from the three way interaction at Gera (Fig. 5), 74110 processed in wet processing and dried on mesh wire (14.00) and, 7440 processed in wet processing and dried on jute mesh (14.00) had the highest bean color, with grayish to bluish color but it was not significantly different from 7440 and 75227 processed in wet processing and dried on mesh wire (13.00), 74110, 7440 and 75227 processed in wet processing and dried on bamboo (12.00), 74110 and 75227 processed in wet processing and dried on palm leaves mat (12.00), 74110 and 7440 processed in wet processing and dried on jute mesh (12.00), wet processing with jute mesh and 75227 (13.00), wet processing with cement floor and 75227 (12.00), dry processing with mesh wire and 74110 (12.00), dry processing with mesh wire and 75227 (12.00) and dry processing with jute mesh and 74110 (12.00).

Moreover, wet processing with soil and 74110 (5.00) and, wet processing with soil and 7440 (5.00) were the lowest, with faded color but it was not significantly different from wet processing with cement floor and 7440 (6.00) and, dry processing with soil and 74110 (6.67). This could be due to the green bean color was best where the mucilage was removed by fermentation under water in wet processing and the poorest color was obtained when the bean dried inside the fruit. The present finding support Anon (2001), who 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. Walyaro (1983) reported the presence of large inherent differences among genotypes for bean and cup quality attributes.

Interaction of processing method and drying material at JARC in relation to color was significantly different. Wet processing with mesh wire (13.00) was significantly the highest and dry processing with soil floor (10.44) was significantly the lowest (Table 15). Davids (2001) also confirmed that the green bean color was best where the mucilage had been removed by fermentation under water in wet processing and the poorest color was obtained when the bean dried inside the fruit.

Table 15. Interaction effect between processing methods and drying material on bean color at JARC

Drying material	Processing method	
	Wet	Dry
Mesh wire	13.00a	12.00bc
Bamboo	12.33b	12.00bc
Jute mesh	12.00bc	12.00bc
Palm leaves mat	12.00bc	12.00bc
Cement floor	12.00bc	11.33d
Soil floor	11.56cd	10.44e
LSD (0.05)	0.58	0.58
SE (±)	0.21	0.21
CV (%)	5.18	5.18

Means followed by different letters in the same column are significantly different

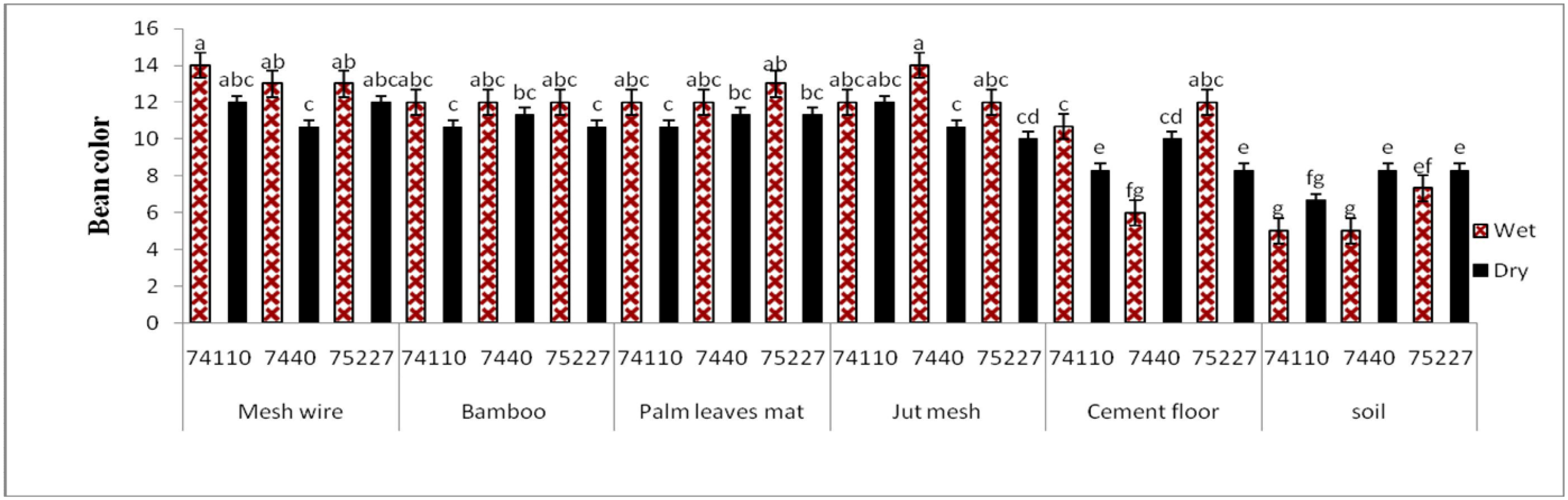

Figure 5. Interaction effect of processing methods, drying materials and varieties on bean color at Gera

v. Hundred bean weight

Highly significant (P<0.01) variation was observed between the interaction effect between processing methods and varieties, with respect to coffee bean weight at Gera (Appendix Table 2). However, non-significant results were obtained among the drying materials and for the interaction effects of processing method and varieties, drying materials and varieties as well as the three way interaction.

At JARC, highly significant (P<0.01) variation was observed between the interaction effect between processing methods and varieties, drying materials and varieties as well as processing methods with drying materials and varieties for hundred bean weight (Appendix Table 3). Similarly, significant (P<0.05) variation was observed between the interaction effect of processing methods and drying materials.

The combined results at Gera (Fig. 6) showed that, significantly the highest hundred bean weight was recorded from the dry processed intermediate variety 7440 (14.98g). Besides this, the wet processed compact variety 74110 (12.86g) was statistically different with the lowest mean value. The apparent variation in terms of variety could be attributed to the fact that 7440 and 75227 has big size bean. This corroborates with other authors who reported that Arabica varieties (genotypes) were diverse in respect of average bean weight with values ranging between 18.2g and 9.2g (Wintegens, 2004; Yigzaw, 2006). In agreement with the findings of the present study, bean weight of coffee was highly influenced by both coffee genotype and processing methods (Mekonen, 2009).

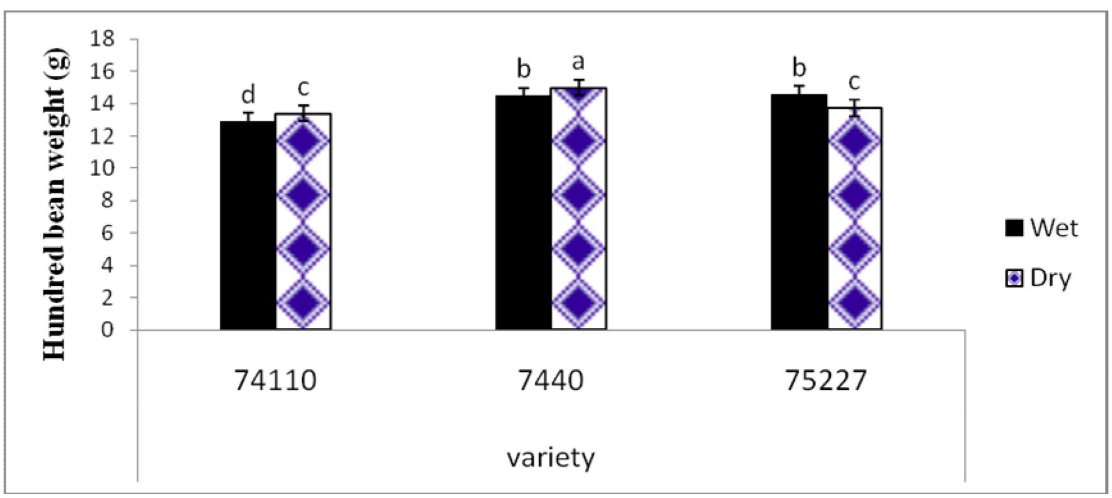

Figure 6. Interaction effect between processing methods and varieties on hundred bean weight at Gera

The three way interaction in relation to hundred bean weight was significantly different at JARC. Wet processed 75227 dried on cement floor (16.10g) had the highest mean value for bean weight but it was not significantly different from wet processed 75227 dried on bamboo (15.73g), wet processed 7440 dried on mesh wire (15.50g), wet processed 7440 dried on palm leaves mat (15.07g), wet processed 75227 dried on palm leaves mat (15.54g), wet processed 75227 dried directly on soil (15.20g), jute mesh (15.04g), wet processed 7440 dried on palm leaves mat (15.43g) and dry processed 74110 dried on soil (15.13g). Dry processed 7440 dried on jute mesh registered significantly the lowest bean weight (10.00g) (Table 16).

Table 16. Influence of interaction among processing methods, drying materials and varieties on hundred bean weight (g) of Arabica coffee at JARC

Drying material	Variety	Processing method	
		Wet	Dry
Mesh wire	74110	12.13m	13.37jkl
	7440	15.5abcd	14.03hijk
	75227	15.30abcde	14.77bcdefgh
Bamboo	74110	12m	13.27kl
	7440	14.37efghij	14.2fhijk
	75227	15.73ab	14.97bcdefgh
Jute mesh	74110	12.17m	13.27kl
	7440	14.93bcdefgh	10n
	75227	14.73bcdefgh	15.04abcde
Palm leaves mat	74110	11.67m	13.33jkl
	7440	15.07abcdefgh	15.43abcde
	75227	15.57abc	15.03bcdefgh
Cement floor	74110	11.83m	13.27kl
	7440	14.77bcdefgh	14.53cdefgh
	75227	16.1a	14.1ghijk
Soil floor	74110	12.17m	15.13abcdefg
	7440	14.77bcdefgh	14.53defghi
	75227	15.20abcdef	14.03ijkl
LSD (0.05)		1.07	1.07
SE (±)		0.38	0.38
CV (%)		4.63	4.63

Means followed by different letters in the same column are significantly different

4.1.3. Organoleptic quality attributes

i. Aromatic intensity

The analysis of variance for aromatic intensity showed no significant variation at Gera between the different processing methods, among drying materials and varieties. Likewise, there was no significant interaction effect between processing methods and drying materials, processing methods and varieties, drying materials and varieties as well as the three way interaction effect (Appendix Table 2). However, as indicated in Appendix Table 3, there were significant ($P<0.05$) variation observed between the interaction effect of processing methods and drying materials at JARC. On the other hand, varieties and the interaction effect between processing methods and varieties, drying materials and varieties and, the three way interaction were found to be non significant.

The mean comparison between the interaction effect of processing method and drying material at JARC revealed that the wet processing combined with drying on bamboo (3.61) had the highest aromatic intensity although it was not statistically different from wet processing coupled with palm leaves mat as a drying material (3.40), wet processing and drying on jute mesh (3.41) and soil floor (3.46), dry processing and drying on mesh wire (3.43), bamboo (3.35), palm leaves mat (3.46) and cement floor (3.31) (Table 17). Of all the treatments, dry processing combined with drying on soil floor had the lowest mean value (3.06) with respect to aromatic intensity but it was not statistically different from wet processed coffee dried on mesh wire (3.21), cement floor (3.17), as well as dry processing and drying on bamboo (3.35), jute mesh (3.13) and cement floor (3.31). Wet processed arabica is aromatic with fine acidity and some astringency, while dry processed arabica is less aromatic and less acidic but with greater body (Clifford, 1985).

Table 17. Influence of interaction between processing methods and drying materials on aromatic intensity of Arabica coffee under JARC condition

Processing method	Drying material	Aromatic intensity
Wet	Mesh wire	3.21 ± 0.12bcd
	Bamboo	3.61 ± 0.12a
	Palm leaves mat	3.40 ± 0.12abc
	Jute mesh	3.41 ± 0.12abc
	Cement floor	3.17 ± 0.13bcd
	Soil floor	3.46 ± 0.12ab
Dry	Mesh wire	3.43 ± 0.12abc
	Bamboo	3.35 ± 0.12abcd
	Palm leaves mat	3.46 ± 0.12ab
	Jute mesh	3.13 ± 0.12cd
	Cement floor	3.31 ± 0.12abcd
	Soil floor	3.06 ± 0.12d
LSD (0.05)		0.33
CV (%)		10.38

Means followed by different letters in the same column are significantly different

ii. Aromatic quality

Aroma is the most important parameter in the appreciation of quality and it is the organoleptic quality of the cup, mainly due to the volatile compounds present in roasted coffee. A highly significant (P<0.01) variation was observed among the varieties for aromatic quality at Gera. However, non-significant results were obtained from the different drying materials, between processing methods and the interaction effects between processing methods and drying materials, processing methods and varieties, drying materials and varieties as well as the three way interaction effect (Appendix Table 2).

At JARC, there was a significant (P<0.05) variation among the drying materials for aromatic quality. However, processing methods, varieties and the interaction effect between processing methods and drying materials, processing methods and varieties, drying materials and varieties and, the three way interaction were found to be non significant (Appendix Table 3).

Coffee varieties evaluated at Gera demonstrated a significant variation for the aromatic quality (Table 15). Variety 74110 (3.33) and 7440 (3.13) were significantly the highest, with good aromatic quality. Furthermore, variety 75227 (2.87) produced significantly the lowest value, with regular aromatic quality. The probable reason for this could be due to the inherent quality of the varieties; and the varietal variation in terms of aromatic quality could be attributed to the fact that 74110 had good cup quality, 7440 and 75227 had FAQ. Similar results were reported by Behailu *et al*. (2008).

Aromatic quality of coffee samples dried on Bamboo (3.31) was significantly the highest, which however was more or less identical with the result registered from palm leaves mat (3.29), mesh wire (3.20), jute mesh (3.19) and cement floor (3.14) while the aromatic quality value of coffee dried directly on soil floor (2.69) was significantly the lowest of all at JARC (Table 24). Anwar (2010) reported that coffee drying by using cemented floor and raised bed with mesh wire, wooden and bamboo bed has better quality than coffee drying on the ground.

iii. Body

There were highly significant variations ($P<0.01$) among the varieties, and in the interaction effect between processing methods and drying materials in relation to body at Gera. However, non-significant results were obtained for the interaction effects of between processing methods and drying materials, processing methods and varieties, drying materials and varieties as well as the three way interaction effect (Appendix Table 2).

Highly significant ($P<0.01$) variations were observed between the interaction effect of processing methods and drying materials. However, varieties and the interaction effect between processing methods and varieties, drying materials and varieties as well as the three way interaction were found to be non significant at JARC (Appendix Table 3).

The maximum value for body (3.44) was recorded from the variety 74110 with very good body while, the least (3.20) was obtained from the variety 75227 that was not significantly different from 7440 (3.21) (Table 18). This result possibly occurred due to the inherent variability that exists in the respective varieties, suggesting suitability of acidity and body as selection criteria for the genetic improvement of overall liquor quality and there was a reported variation in the body among genotypes of *Coffea arabica* (Yigzawu, 2006). Similar findings on the inherent variations among varieties were reported by Benoit *et al*. (2006).

Table 18. Effect of varieties on aromatic quality and body at Gera

Variety	AQ	BO
74110	3.33 ± 0.08a	3.44 ± 0.06a
7440	3.13 ± 0.08a	3.21 ± 0.06b
75227	2.87 ± 0.09b	3.20 ± 0.07b
LSD (0.05)	0.23	0.16
CV (%)	15.35	10.28

Means followed by different letters in the same column are significantly different; AQ = Aromatic Quality; BO= Body

Dry processed coffee dried on mesh wire, bamboo and jute mesh were equally rated as best (3.74), with very good body whereas the least value were obtained from wet processed coffee dried on mesh wire (2.88) with good body (Table 19). The observed result might be due to the typical characteristic of natural coffee that, owing drying of beans still in contact with the mucilage, has a better body. Hence, under ideal condition natural coffee may be of excellent quality, clean testing and full bodied and, while different, fully as desirable as washed coffee. Anwar (2010) reported that coffee drying by using cemented floor and raised bed with mesh wire, wooden and bamboo bed has better quality than coffee drying on the ground. This result is in line with Davids (2001), Selmar *et al*. (2001) and Bacon (2005).

Table 19. Interaction effect between processing methods and drying materials on body of Arabica coffee at Gera

Drying material	Processing method	
	Wet	Dry
Mesh wire	2.88 ± 0.13d	3.74 ±0.11a
Bamboo	3.17 ± 0.11cd	3.74 ±0.11a
Jute mesh	3.13 ± 0.11cd	3.74 ±0.11a
Palm leaves mat	3.09 ± 0.11cd	3.52 ± 0.11ab
Cement floor	3.09 ± 0.11cd	3.00 ± 0.13cd
Soil floor	3 .00 ± 0.11cd	3.25 ± 0.13bc
LSD (0.05)	0.32	0.32
CV (%)	10.28	10.28

Means followed by different letters in the same column are significantly different

Interaction between processing method and drying material produced significantly different body coffee at JARC. Dry processing combined with drying on mesh wire (3.89) significantly the highest value for body, which of course was at par with values obtained from dry processing and using drying material made of bamboo (3.96), palm leaves mat (3.76) and jute mesh (3.69). On the other hand, wet processing and subsequent drying of coffee on palm leaves mat (3.03) recorded significantly the lowest value (Table 21), which again was statistically at par with dry processing and drying on soil (3.15), cement (3.09), and mesh wire (3.25) as well as wet processing coupled with drying on bamboo (3.21), jute mesh (3.22), cement floor (3.25) and soil (3.04). The observed result might be attributed to the full body and natural sweetness of the dry processed beans. This result is similar with Davids (2001), Selmar *et al.* (2001) and Bacon (2005).

iv. Acidity

At JARC, interaction effect of drying materials and varieties showed highly significant variation ($P<0.01$) for acidity. Similarly, a significant ($P<0.05$) variation was observed between the interaction effect of processing methods and drying materials for acidity. However, the interaction effect between processing methods and varieties, drying materials and varieties as well as the three way interaction were found to be non significant (Appendix Table 3).

At Gera, ANOVA indicate that there was no significant difference between all treatments and their interaction (Appendix Table 2).

Pertaining to the interaction effect between drying materials and varieties at JARC, drying material mesh wire with 74110 (3.39) had the highest acidity although it was not statistically different from drying material mesh wire with 7440 (3.17), bamboo with 74110 (3.31), bamboo with 75227 (3.01), palm leaves mat with 74110 (3.17), palm leaves mat with 75227 (3.28), jute mesh with 74110 (3.28), jute mesh with 7440 (3.14), jute mesh with 75227 (3.31), cement floor with 74110 (3.07), cement floor with 75227 (3.03) and soil with 75227 (3.28). Variety 74110 dried on soil (2.42) had the lowest mean value but it was not statistically different from drying material mesh wire with 75227 (2.72), bamboo with 7440 (2.64) and palm leaves mat with 7440 (2.83) (Table 20). This could be due to the inherent quality of the variety and the drying material that typically better aeration and drainage.

Table 20. Influence of interaction effect between drying materials and varieties on acidity of Arabica coffee at JARC

Drying material	Variety	Acidity ± SE
Mesh wire	74110	3.39 ± 0.16a
	7440	3.17 ± 0.16abc
	75227	2.72 ± 0.16def
Bamboo	74110	3.31 ± 0.16ab
	7440	2.64 ± 0.16ef
	75227	3.01 ± 0.16abcde
Palm leaves mat	74110	3.17 ± 0.16abc
	7440	2.83 ± 0.16cdef
	75227	3.28 ± 0.16ab
Jute mesh	74110	3.28 ± 0.16ab
	7440	3.14 ± 0.16abcd
	75227	3.31 ± 0.16ab
Cement floor	74110	3.07 ± 0.18abcde
	7440	2.94 ± 0.16bcde
	75227	3.03 ± 0.16abcde
Soil floor	74110	2.42 ± 0.16f
	7440	3.11 ± 0.16abcd
	75227	2.92 ± 0.16bcde
LSD (0.05)		0.45
CV (%)		12.76

Means followed by different letters in the same column are significantly different

Interaction between processing method and drying material at JARC in relation to acidity were significantly different. Wet processing with mesh wire (3.31) resulted in significantly the highest value of acidity nonetheless it was statistically equal with effect of dry processing and subsequent drying on jut mesh (3.26). Wet processing with drying material soil (2.74) imparted significantly the lowest value for acidity (Table 21). Jackelers and Jackels (2005) confirmed that fermentation in wet processed coffee can break the cellulose of the mucilage layer and increases the acidity of the coffee.

Table 21. Interaction effect of processing methods and drying materials on acidity and body Arabica coffee under JARC conditions

Processing method	Drying material	AC	BO
Wet	Mesh wire	3.31 ± 0.13a	3.25 ± 0.11b
	Bamboo	2.82 ± 0.13cd	3.21 ± 0.11b
	Palm leaves mat	3.19 ± 0.13ab	3.30 ± 0.11b
	Jute mesh	3.22 ± 0.13ab	3.22 ± 0.11b
	Cement floor	2.96 ± 14abcd	3.25 ± 0.12b
	Soil floor	2.74 ± 0.13d	3.04 ± 0.11b
Dry	Mesh wire	2.81 ± 0.13cd	3.89 ± 0.11a
	Bamboo	3.15 ± 0.13abc	3.96 ± 0.11a
	Palm leaves mat	3.00 ± 0.13abcd	3.76 ± 0.11a
	Jute mesh	3.26 ± 0.13a	3.69 ± 0.11a
	Cement floor	3.06 ± 0.13abcd	3.09 ± 0.11b
	Soil floor	2.89 ± 0.13bcd	3.15 ± 0.11b
LSD (0.05)		0.35	0.33
CV (%)		12.76	9.64

Means followed by different letters in the same column are significantly different; AC= Acidity; BO = Body.

v. Astringency

Significant (P<0.05) variation was observed from the interaction effect between processing methods and drying materials as well as processing methods and drying materials at Gera with respect to astringency. On the contrary, the interaction effect between drying materials and varieties and, processing methods with drying materials and varieties were found to be non significant (Appendix Table 2). Nevertheless, as indicated in Appendix Table 3, there was no significant variation between the different processing methods, among drying materials and varieties. Similarly, there was no significant interaction effect between processing methods and drying materials, processing methods and varieties, drying materials and varieties as well as the three way interaction effect at JARC.

At Gera (Table 22), dry processed variety 7440 gave the highest (0.48) with very light astringency but it was not significantly different from wet processed variety 75227 (0.44), wet processed variety 74110 (0.31), dry processed variety 74110 (0.30). And wet processed variety 7440 (0.26) and dry processed variety 75227 (0.26) were equally the lowest but not significantly different from the rest except dry processing combined 7440

(0.48). Even though they were statically different, they are in the same range having very light astringency. This may be substantiated by the fact that varietal differences do exist, indicating the presence of genetically diverse materials. The result obtained in this study is in conformity with what has been reported by Getu (2009).

Table 22. Interaction effect of processing methods and varieties on astringency of Arabica coffee at Gera

Processing methods	Variety	Astringency ± SE
Wet	74110	0.31 ± 0.07ab
	7440	0.26 ± 0.07b
	75227	0.44 ± 0.07ab
Dry	74110	0.30 ± 0.07ab
	7440	0.48 ± 0.07a
	75227	0.26 ± 0.08b
LSD (0.05)		0.20
CV (%)		88.73

Means followed by different letters in the same column are significantly different

With regard to the observed interaction effect between processing method and drying material at Gera, it was significantly different. Dry processing coupled with drying on bamboo and soil produced equally the highest astringency (0.54), a result which is more or less identical with what was obtained from dry processing combined with mesh wire (0.46) as well as wet processing followed by drying on cement floor (0.46) and mesh wire (0.42) Beside this, dry processing with drying material cement floor (0.08) was the lowest but it was not significantly different from wet processing with drying material bamboo (0.26), wet processing with drying material jute mesh (0.31), wet processing with drying palm leaves mat (0.30), wet processing with drying material soil floor (0.30), dry processing with drying material jute mesh (0.26) and dry processing with drying material palm leaves mat (0.26). Even though they are statistically difference, they are in the same range having very light astringency (Table 23).

Table 23. Interaction effect between processing methods and drying materials on astringency of Arabica coffee at Gera

Drying material	Processing method	
	Wet	Dry
Mesh wire	0.42 ± 0.11a	0.46 ± 0.10a
Bamboo	0.26 ± 0.10ab	0.54 ± 0.10a
Jute mesh	0.31 ± 0.10ab	0.26 ± 0.10ab
Palm leaves mat	0.30 ± 0.10ab	0.26 ± 0.10ab
Cement floor	0.46 ± 0.10a	0.08 ± 0.11b
Soil floor	0.30 ± 0.11ab	0.54 ± 0.11a
LSD (0.05)	0.29	0.29
CV (%)	88.73	88.73

Means followed by different letters in the same column are significantly different

vi. Flavor

Flavor indicates fragrance of the liquor either by direct inhaling of the vapours arising from the cup or nasal perception of the volatile substance evolving in the mouth. At Gera, there was no significant variation between the different processing methods, among drying materials and varieties. Similarly, there was no significant interaction effect between processing methods and drying materials, processing methods and varieties, drying materials and varieties as well as the three way interaction effect (Appendix Table 2).

At JARC, there was significant variation ($P<0.05$) among the drying materials in relation to flavor. However, processing methods, varieties and the interaction effect between processing methods and drying materials, processing methods and varieties, drying materials and varieties and, processing methods with drying materials and varieties were found to be non significant (Appendix Table 3).

The coffee flavor obtained from drying material mesh wire (2.90) registered the highest mean value, which still was statistically similar with the rest except the value obtained from drying on soil floor (2.19) that resulted in the lowest value and yet not statistically different from cement floor (2.63) at JARC (Table 24). This could be due to the fact that all raised bed materials circulates air though the mass of the coffee while in the case of cement floor and soil floor, the dried coffee couldn’t get proper aeration as a result of which the coffee begin to develop bad flavor. Endale (2008) reported that coffee with a better attention/management turn out to have a better flavor.

vii. Over all standard

At Gera, there was no significant variation between the different processing methods, among drying materials and varieties with respect to overall standard (Appendix Table 2). Likewise, there was no significant interaction effect between processing methods and drying materials, processing methods and varieties, drying materials and varieties as well as the three way interaction effect.

However, processing methods, varieties and the interaction effect between processing methods and drying materials, processing methods and varieties, drying materials and varieties and, processing methods with drying materials and varieties were found to be non significant for overall standard at JARC (Appendix Table 3). While, variation among the drying material was significant ($P<0.05$).

Drying material jute mesh scored good overall standard with a mean value of (3.08), mesh wire (2.99), palm leaves mat (2.98), bamboo (2.97) and cement floor (2.87) were significantly the highest when compared to the other drying material. Soil floor (2.48) was significantly the lowest (Table 24). This could be due to the drying period is very long when coffee is dried on soil therefore when the time of drying take too much time with high moisture content it is hard to determine which steps are risky to OTA contaminations. Anwar (2010) reported that coffee drying by using cemented floor and raised bed with mesh wire, wooden and bamboo bed has better quality than coffee drying on the ground.

Table 24. Effect of drying materials on some organoleptic coffee quality traits at JARC

Drying material	AQ	FL	OVS
Mesh wire	3.20 ± 0.10a	2.90 ± 0.15a	2.99 ± 0.95a
Bamboo	3.31 ± 0.10a	2.67 ± 0.15a	2.97 ± 0.95a
Palm leaves mat	3.29 ± 0.10a	2.86 ± 0.15a	2.98 ± 0.95a
Jute mesh	3.19 ± 0.10a	2.85 ± 0.15a	3.08 ± 0.95a
Cement floor	3.14 ± 0.11a	2.63 ± 0.16ab	2.87 ± 0.10a
Soil floor	2.69 ± 0.10b	2.19 ± 0.15b	2.48 ± 0.95b
LSD (0.05)	0.29	0.44	0.27
CV (%)	14.05	24.02	13.98

Means followed by different letters in the same column are significantly different ; AQ = Aromatic Quality; FL= Flavor; OVS = Overall Standard

4.2. Correlation studies

4.2.1. Gera

Aromatic intensity was significant (P<0.01) and strong positive correlation with aromatic quality (r=0.93) and shape and make (r=0.93). This might be due to the fact that when the intensity of the aroma is strong, obviously require strong aromatic quality. Moreover, it has been found significant (P<0.05) and positively correlated with bean color (r=0.90). It had weak and negative correlation with bean size (r=-0.51). Agwanda *et al*. (2003) and Roche (1995) reported that unlike the popular belief, bean size was not a good indicator of cup quality. Aromatic quality was highly significant (P<0.01) and strong positive association with shape and make (r=0.94) and bean color (r=0.94). It has been found significant (P<0.05) and positively correlated with body (r=0.88) and odor (r=0.83). It had weak and negative correlation with astringency (r=-0.09), bean size (r=-0.44) (Table 25).

Astringency had weak and negative correlation with flavor (r=-0.57), astringency (r=-0.56), overall standard (r=-0.53), shape and make (r=-0.02), color (r=-0.20) and odor (r=-0.41). Bean size had weak and negative correlation with flavor (r=-0.48), shape and make(r=-0.33), bean color (r=-0.32), odor (r=-0.40), hundred bean weight (r=-0.29) and body (r=-0.12) (Table 25).

Shape and make was highly significant (P<0.01) and strong positive association with bean color (r=0.97). It has been found significant (P<0.05) and positively correlated with odor (r=0.84). Similarly, Color was highly significant (P<0.01) and strong positive association with odor (r=0.93) (Table 22).

Hundred bean weight had weak and negative correlation with acidity (r=-0.06). Days to drying had weak and negative correlation with aromatic intensity (r=-0.61), aromatic quality (r=-0.44), astringency (r=-0.57), body (r=-0.61), flavor (r=-0.04), over all standard (r=-0.04), shape and make (r=-0.30), bean color (r=-0.27), odor (r=-0.23) and hundred bean weight (r=-0.31) (Table 25).

4.2.2. JARC

Aromatic quality was significant (P<0.01) and strong positive association with overall standard (r = 0.94). It has been found significant (P<0.05) and positively correlated with body (r=0.83), flavor (r=0.89) and bean color (r=0.87). This result may suggest the existence of strong link between good cup qualities attributes in influencing the lasting ability of coffee quality. It had weak and negative correlation with astringency (r=-0.64) and hundred bean weight (r=-0.41) (Table 26).

Acidity were significant (P<0.05) and positively correlated with flavor (r=0.87) and overall standard (r=0.90) High acidity and good flavor gives better quality and more intense aroma to the beverage (Clifford, 1985; EAFCA, 2008). It had weak and negative correlation with astringency (r=-0.51) and hundred bean weight (r=-0.10) (Table 26).

Astringency had weak and negative correlation with body (r=-0.62), flavor (r=-0.57), overall standard (r=-0.50), shape and make (r=-0.46), and odor (r=-0.53). Body is significant (P<0.05) and positively correlated with bean color (r=0.91) and odor (r=0.89). It has weak and negative correlation with above hundred bean weight (r=-0.31) flavor (r=0.81), overall standard (r=0.80) (Table 26).

Flavor was highly significant (P<0.01) and strong positive association with overall standard (r=0.95). The trait showed high genetic correlation with preference, was easy to determine organoleptically and had relatively high sensitivity in discriminating different coffee genotypes (Agwanda, 1999). It has been found significant (P<0.05) and positively correlated with shape and make (r=0.83) and bean color (r=0.91). It had weak and negative correlation with bean size (r=-0.20), hundred bean weight (r=-0.33) and days to drying (r=-0.45) (Table 26).

Overall standard is significant (P<0.05) and positively correlated with shape and make (r=0.82) and bean color (r=0.88). It had weak and negative correlation with hundred bean weight (r=-0.20). Bean size had weak and negative correlation with shape and make (r=-0.16), bean color (r=-0.24), odor (r=-0.05), hundred bean weight (r=-0.17) (Table 26).

Shape and make is significant (P<0.05) and positively correlated with bean color (r=0.90). It had weak and negative correlation with days to drying (r=-0.32). Similarly, odor had weak and negative correlation with hundred bean weight (r=-0.34) and days to drying (r=-0.25) (Table 26).

Table 25. Bi-variate correlation coefficients among response variables for Gera

Character	AI	AQ	AC	AS	BO	FL	OVS	BS	SM	BC	OD	HBW
AQ	0.93**											
AC	0.35^{ns}	0.42^{ns}										
AS	0.18^{ns}	-0.09^{ns}	-0.56^{ns}									
BO	0.81^{ns}	0.88*	0.34^{ns}	0.09^{ns}								
FL	0.32^{ns}	0.60^{ns}	0.09^{ns}	-0.57^{ns}	0.46^{ns}							
OVS	0.42^{ns}	0.70^{ns}	0.58^{ns}	-0.53^{ns}	0.76^{ns}	0.70^{ns}						
BS	-0.51^{ns}	-0.44^{ns}	0.22^{ns}	0.01^{ns}	-0.12^{ns}	-0.48^{ns}	0.10^{ns}					
SM	0.93**	0.94**	0.55^{ns}	-0.02^{ns}	0.78^{ns}	0.37^{ns}	0.58^{ns}	-0.33^{ns}				
BC	0.90*	0.94**	0.68^{ns}	-0.20^{ns}	0.78^{ns}	0.44^{ns}	0.67^{ns}	-0.32^{ns}	0.97**			
OD	0.79^{ns}	0.83*	0.76^{ns}	-0.41^{ns}	0.62^{ns}	0.45^{ns}	0.62^{ns}	-0.40^{ns}	0.84*	0.93**		
HBW	0.71^{ns}	0.66^{ns}	-0.06^{ns}	0.49^{ns}	0.57^{ns}	0.12^{ns}	0.17^{ns}	-0.29^{ns}	0.74^{ns}	0.56^{ns}	0.26^{ns}	
DTD	-0.61^{ns}	-0.44^{ns}	0.21^{ns}	-0.57^{ns}	-0.61^{ns}	-0.04^{ns}	-0.04^{ns}	0.36^{ns}	-0.30^{ns}	-0.27^{ns}	-0.23^{ns}	-0.31^{ns}

**, **= statistically significant difference at 5 %, 1 % probability level respectively; ns = non-significant difference; AI=aromatic intensity, AQ=aromatic quality, AC=acidity, AS=astringency, BO = body, FL= flavor, OVS = overall standard, BS = bean size, SM=shape and make, BC=bean color, OD=odor, HBW = hundred bean weight, DTD = Days to drying.*

Table 26. Bi-variate correlation coefficients among response variables for JARC

Character	AI	AQ	AC	AS	BO	FL	OVS	BS	SM	BC	OD	HBW
AQ	0.60^{ns}											
AC	0.05^{ns}	0.71^{ns}										
AS	-0.46^{ns}	-0.64^{ns}	-0.23^{ns}									
BO	0.73^{ns}	0.83*	0.58^{ns}	-0.62^{ns}								
FL	0.33^{ns}	0.89*	0.87*	-0.67^{ns}	0.81^{ns}							
OVS	0.36^{ns}	0.94**	0.90*	-0.50^{ns}	0.80^{ns}	0.95**						
BS	0.25^{ns}	0.03^{ns}	0.12^{ns}	0.68^{ns}	0.03^{ns}	-0.20^{ns}	0.04^{ns}					
SM	0.16^{ns}	0.67^{ns}	0.74^{ns}	-0.46^{ns}	0.78^{ns}	0.83*	0.82*	-0.16^{ns}				
BC	0.48^{ns}	0.87*	0.66^{ns}	-0.74^{ns}	0.91*	0.91*	0.88*	-0.24^{ns}	0.90*			
OD	0.54^{ns}	0.59^{ns}	0.60^{ns}	-0.53^{ns}	0.89*	0.75^{ns}	0.65^{ns}	-0.05^{ns}	0.72^{ns}	0.75^{ns}		
HBW	-0.57^{ns}	-0.41^{ns}	-0.10^{ns}	0.57^{ns}	-0.31^{ns}	-0.33^{ns}	-0.20^{ns}	0.17^{ns}	0.19^{ns}	-0.17^{ns}	-0.34^{ns}	
DTD	-0.62^{ns}	-0.75^{ns}	-0.49^{ns}	0.04^{ns}	-0.56^{ns}	-0.45^{ns}	-0.67^{ns}	-0.64^{ns}	-0.32^{ns}	-0.46^{ns}	-0.25^{ns}	0.16^{ns}

**, **= statistically significant difference at 5 %, 1 % probability level respectively; ns = non-significant difference; AI=aromatic intensity, AQ=aromatic quality, AC=acidity, AS=astringency, BO = body, FL= flavor, OVS = overall standard, BS = bean size, SM=shape and make, BC=bean color, OD=odor, HBW = hundred bean weight, DTD =Days to drying*

4.3. Coffee grading

With respect to processing methods, drying materials and varieties indicated that wet processed variety 74110 dried on mesh wire, bamboo, palm leaves mat and jute mesh were profiled under grade 2 for both Gera and Jimma areas. Whereas under grade 4 and 8 for cement floor and soil for Gera and, under grade 3 and 7 for cement floor and soil respectively for JARC. Furthermore, wet processed variety 7440 and 75227 dried on mesh wire, palm leaves mat and jute mesh were profiled under grade 3 at Gera, while on the same processing method the same sampled dried on cement and soil under grade 4 and 8, respectively (Appendix Table 4).

Wet processed variety 7440 and 75227 dried on bamboo, palm leaves mat and jute mesh were profiled under grade 3 for JARC location. Nevertheless, the three varieties processed with wet processing and dried on soil were profiled under grade 7 at JARC. Wet processed coffee dried on cement floor had grade 3 for the variety 74110, grade 4 for the 7440 and grade 5 for 75227 at JARC (Appendix Table 4).

Dry processed variety 74110 dried on mesh wire was found grade 1 for Gera. This could be due to the inherent quality of the variety. This result is in line with the report of Yigzaw (2005), who indicated that, if other factors are kept constant, better quality coffee can be found at higher altitude, while lowland coffees are somewhat bland, with considerable body. On the same processing method the variety 74110, 7440 and 75227 dried on bamboo, palm leaves mat, jute mesh and cement floor were under grade 2 for location Gera except 7440 dried on palm leaves mat score grade 3 and, 75227 and 7440 dried on cement floor scored grade 3. In addition, 7440 and 75227 dried on mesh wire were also obtained grade 2 for Gera location (Appendix Table 5).

As Appendix Table 5 shows that the dry processed variety 74110, 7440 and 75227 dried on soil obtained the same result grade 7 for both locations. In addition to this, dry processed variety 74110 dried on mesh wire, palm leaves mat and bamboo were profiled under grade 2 at JARC. Moreover, dry processed variety 7440 and 75227 dried on mesh wire, jute mesh, palm leaves mat and bamboo were profiled under grade 3 at Jimma except 7440 and 75227 on palm leaves mat and mesh wire respectively. Lastly, the three varieties

74110, 7440 and 75227 processed on dry processing method and dried on cement floor and jute mesh were profiled under grade 3 at Jimma.

4.4. Partial Budget Analysis

Quality of coffee is the principal component of economic benefit to the producer. A simple calculation showed that the total cost is the sum of the (Total Fixed Cost) TFC and the Total Variable Cost (TVC). The gross benefit obtained from ECX (2010) based on the current price per kg of coffee by grade (it is not clear for still) . Finally, net benefit was obtained by subtracting the total cost (TC) from the gross benefit (Revenue).

The cost of coffee processing using different drying materials for both processing methods is shown in Table 24. The main costs involved in coffee processing were the installation cost of the material and the labor cost. Some of the materials used are durable and can be used for at least five years consecutively while most of the materials are used only for one year. In addition, most of the materials have almost the same cost of processing except soil which had the least processing cost while mesh wire was the most expensive in its cost though it is can be used for at least 5 years once established.

The revenue from coffee processing greatly depends on the quality of the drying material used. However, the revenue was found to be almost the same for all coffee drying materials except for soil which depicted very low revenue because of the low quality of coffee obtained from dry processing at both sites.

At Gera, the wet processed coffee dried on drying material mesh wire gave better net income (29.49) followed by jute mesh and bamboo with a net return of 22.41 and 21.19 birr/1.2kg respectively. On the other hand, the coffee dried on soil resulted in a net loss of 11.73 birr/1.2kg. Correspondingly, the wet processed coffee dried on drying material mesh wire was found to be better for net income generation (20.18) followed by jute mesh and bamboo with a net return of 20.09 and 19.02 birr/1.2kg respectively. Differently, the coffee dried on soil floor imparted a net loss of 8.62 birr/1.2kg at Jimma.

With respect to dry processed coffee dried on cement floor gave better net income 12.13 at Gera and 10.57 at Jimma. The coffee processed with the same processing methods dried on soil floor resulted in a net loss of 6.96 and 7.58 at Gera and Jimma respectively.

Table 27. Partial budget analysis

Location	Processing methods	Drying material	Installation cost for the first year	Total cost	Revenue	Net benefit
Gera	Wet	Mesh	3.19	43.94	73.43	29.49
		Bamboo	10.6	51.64	72.84	21.19
		Palm leaves mat	10.6	53.03	72.43	19.40
		Jute mesh	8.6	50.02	72.43	22.41
		Cement floor	2.4	45.57	65.00	19.43
		Soil floor	0.6	43.77	32.24	-11.53
	Dry	Mesh	3.19	28.02	39.75	11.73
		Bamboo	10.6	34.60	39.05	4.45
		Palm leaves mat	10.6	35.47	38.90	3.43
		Jute mesh	8.6	34.97	39.05	3.93
		Cement floor	2.4	26.77	38.90	12.13
		Soil floor	0.6	24.60	17.64	-6.96
Jimma	Wet	Mesh	3.00	52.47	72.64	20.18
		Bamboo	9.93	53.43	72.45	19.02
		Palm leaves mat	9.93	53.93	72.45	18.52
		Jute mesh	8.26	51.76	71.85	20.09
		Cement floor	2	46.57	62.35	15.78
		Soil floor	0.6	46.85	38.23	-8.62
	Dry	Mesh	3.00	39.53	39.90	10.37
		Bamboo	9.93	34.18	39.05	4.87
		Palm leaves mat	9.93	34.55	38.97	4.42
		Jute mesh	8.26	32.88	38.82	5.94
		Cement floor	2	28.25	38.82	10.57
		Soil floor	0.6	25.22	17.64	-7.58

5. SUMMARY AND CONCLUSIONS

The findings indicate variability among the coffee variety for physical and cup quality, and days to drying. As a result, in both processing methods coffee dried earlier at JARC than at Gera. This might be due to the temperature difference between the two locations. In addition, wet processed coffee dried on bamboo and mesh wire dried earlier. On the other hand, drying materials soil and cement floor took much longer time. In contrast, dry processed coffee drying on mesh wire took much longer time and coffee drying on bamboo and cement floor dried earlier. The study also proved that there was varietal difference. 7440 took much longer time to dry but was not statistically different from 75227 where as 74110 was the earliest one.

The selected coffee varieties showed statistically significant result in most physical and cup quality attributes which had a significant effect on the total quality. There were also statistically highly significant ($P<0.01$) variations in coffee quality due to the processing methods for body, and shape and make as well as varied significantly ($P<0.05$) for color and acidity.

Hence, based on the interest of consumers and specialty market, variety 74110 processed with wet processing method is superior in terms of most of the Quality parameters considered in this study and can be recommended for Jimma Zone specially for Melko. 7440 and 75227 processed with wet processing method had acceptable physical and cup quality at JARC and best at Gera; consequently, can be recommended for Gera.

However, notwithstanding poor processing of sun dried coffee. Dry processed 74110, dried on mesh wire gives better quality and ranked as grade one. It can be recommended for Gera.

All raised bed drying material bamboo, mesh wire, palm leaves mat, jut mesh had great aromatic quality, flavor, overall standard and body. In addition, regard to days to drying at both locations and processing methods drying material bamboo dried earlier compared to the other coffee drying materials at both sites. In contrary, potential problems associated with drying & quality, and its negative image, the practice of drying of coffee on soil is strongly discouraged. From economic point of view wet processed coffee dried on mesh wire and dry processed coffee dried on cement recommended for both location.

Associations among cup quality attributes (acidity, body, flavor and overall standard of liquor) were positive and statistically significant. Correlations between cup quality attributes and green bean physical characters were positive but mostly statistically not significant. Therefore, green bean physical characters are not good indicators for cup quality improvement. Both desirable cup quality and green bean physical characters can be simultaneously selected due to positive correlation. In general, it can be concluded that coffee varieties were location specific for quality attributes. On top of this, drying period is location, drying material and processing method specific. The results show that the wet and dry processing methods resulted in higher acidity and body, respectively. Therefore, coffee quality can be best improved through wet and dry processing if using the proper harvesting methods, drying material and other quality affecting factors. From the present findings, it is possible to suggest the followings as high priority research areas:

☼ Both processing methods were affected by drying material. Thus, special attention should be given to the drying material through refinement of the method itself. Furthermore, research on post-harvest management practices and identification of related factors in more replicated areas would help to come up with more conclusive recommendations.

☼ It is also known that high volume of dry coffee is arriving at national auction center from Jimma zone. Therefore, special attention should be give to dry processing approach

☼ Multivariate analysis of environmental factors and quality attributes under the diverse coffee production systems in the region should be considered.

☼ Analyses of other biochemical constitutes of coffee quality should be done.

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7. APPENDICES

Appendix Table 1. ANOVA Mean Square Values for Days to drying

Source of Variation	Df	Gera	JARC
Block	2	3.45**	0.26^{ns}
PM	1	2790.75**	1908.48**
E-PM	2	0.19	4.93
DM	5	9.70**	20.84**
DM *PM	5	31.37**	36.48**
E-DM	20	1.52	4.37
Variety	2	17.12**	9.51**
Variety*PM	2	2.08**	2.06*
Variety*DM	10	2.56**	1.13^{ns}
Variety*DM*PM	10	0.64^{ns}	1.20*
E-variety	4	0.39	0.57
CV (%)		4.39	7.19

**, **= statistically significant difference at 5 % and 1 % probability level respectively; ns = non-significant difference; DF=Degrees of freedom; PM=processing method, E-PM =error of processing method, DM= drying material, E-DM=error of drying material, E-Variety=error of variety; CV=Coefficient of variation.*

Appendix Table 2. ANOVA Mean Square Values for Parameters at Gera

Source of Variation	**Df**	**AI**	**AQ**	**AC**	**AS**	**BO**	**FL**	**OVS**	**BS**	**SM**	**BC**	**OD**	**HBW**
Block	2	0.02^{ns}	0.83*	1.16**	0.01^{ns}	0.06^{ns}	1.02^{ns}	1.09*	4.58^{ns}	3.23^{ns}	1.95^{ns}	0.26ns	1.04ns
PM	1	0.08^{ns}	0.39^{ns}	0.23^{ns}	0.002^{ns}	**4.74***	0.61^{ns}	0.41^{ns}	**142.60***	**67.15***	6.75^{ns}	0.93ns	0.17ns
E-PM	2	0.05	0.13	0.07	0.07	0.05	0.92	0.30	5.38	0.56	1.58	0.48	0.98
DM	5	0.38^{ns}	0.21^{ns}	0.19^{ns}	0.11^{ns}	**0.46****	0.17^{ns}	0.28^{ns}	4.85^{ns}	1.55^{ns}	**83.74****	**4.30****	1.15ns
DM *PM	5	0.16^{ns}	0.48^{ns}	0.20^{ns}	**0.25***	**0.42****	0.44^{ns}	0.48^{ns}	5.97^{ns}	1.21^{ns}	**11.11****	3.39ns	0.29ns
E-DM	20	0.18	0.20	0.27	0.11	0.09	0.53	0.28	8.18	3.72	4.26	0.33	0.56
Variety	2	0.09^{ns}	**1.87****	0.38^{ns}	0.02^{ns}	**0.61****	0.59^{ns}	0.87^{ns}	**170.58****	2.40^{ns}	2.12^{ns}	0.04ns	**23.31****
Variety*PM	2	0.01^{ns}	0.27^{ns}	0.07^{ns}	**0.39***	0.05^{ns}	0.18^{ns}	0.03^{ns}	12.48^{ns}	3.40^{ns}	6.08^{ns}	0.04ns	**5.36****
Variety*DM	10	0.14^{ns}	0.15^{ns}	0.14^{ns}	0.12^{ns}	0.07^{ns}	0.72^{ns}	0.15^{ns}	11.16^{ns}	2.42^{ns}	3.51^{ns}	0.21ns	0.21ns
Variety*DM*PM	10	0.09^{ns}	0.36^{ns}	0.26^{ns}	0.13^{ns}	0.15^{ns}	0.18^{ns}	0.19^{ns}	4.00^{ns}	2.75^{ns}	**5.21****	0.04ns	0.73 ns
E-variety	4	0.11	0.23	0.22	0.09	0.11	0.36	0.29	6.22	1.74	1.91	0.22	0.58
CV (%)		9.95	15.35	15.50	88.73	10.28	22.86	18.71	2.64	10.91	13.08	4.83	5.43

**, **= statistically significant difference at 5 % and 1 % probability level respectively; ^{ns} = non-significant difference; DF=Degrees of freedom; AI=aromatic intensity, AQ=aromatic quality, AC=acidity, AS=astringency, BO = body, FL= flavor, OVS = overall standard, BS = bean size, SM=shape and make, BC=bean color, OD=odor, HBW = hundred bean weight, PM=processing method, E-PM =error of processing method, DM= drying material, E-DM=error of drying material, E-Variety=error of variety; CV=Coefficient of variation.*

Appendix Table 3. ANOVA Mean Square Values for Parameters at JARC

Source of Variation	**Df**	**AI**	**AQ**	**AC**	**AS**	**BO**	**FL**	**OVS**	**BS**	**SM**	**BC**	**OD**	**HBW**
Block	2	0.29^{ns}	0.24^{ns}	0.29^{ns}	0.09^{ns}	0.09^{ns}	0.32^{ns}	0.17^{ns}	2.65^{ns}	0.03^{ns}	0.58^{ns}	0.29ns	0.68^{ns}
PM	1	0.20^{ns}	0.04^{ns}	0.006^{ns}	0.08^{ns}	**3.60****	0.51^{ns}	0.52^{ns}	3.70^{ns}	36.75**	7.26^{ns}	**2.68***	0.55^{ns}
E-PM	2	0.04	0.29	0.04	0.04	0.01	0.86	0.05	3.85	0.36	3.18	0.06	0.41
DM	5	0.18^{ns}	**0.93***	0.35^{ns}	0.05^{ns}	**0.77****	**1.25***	**0.84***	6.28^{ns}	**3.02***	4.73^{ns}	**1.65****	**2.01****
DM *PM	5	**0.30***	0.24^{ns}	**0.38***	0.08^{ns}	**0.54****	0.11^{ns}	0.31^{ns}	7.30^{ns}	2.08^{ns}	**1.06***	0.63^{ns}	**1.27***
E-DM	20	0.10	0.23	0.24	0.08	0.11	0.31	0.27	4.88	0.79	1.78	0.22	0.42
Variety	2	0.08^{ns}	0.18^{ns}	0.15^{ns}	0.16^{ns}	0.17^{ns}	0.44^{ns}	0.26^{ns}	**161.42****	2.03^{ns}	0.86^{ns}	1.23^{ns}	**55.05****
Variety*PM	2	0.02^{ns}	0.20^{ns}	0.43^{ns}	0.12^{ns}	0.02^{ns}	0.007^{ns}	0.004^{ns}	**27.43***	**4.36***	0.12^{ns}	**2.68****	**13.17****
Variety*DM	10	0.14^{ns}	0.37^{ns}	**0.15****	0.10^{ns}	0.13^{ns}	0.25^{ns}	0.31^{ns}	12.16^{ns}	0.83^{ns}	0.46^{ns}	0.43^{ns}	**2.20****
Variety*DM*PM	10	0.19^{ns}	0.21^{ns}	0.15^{ns}	0.06^{ns}	0.10^{ns}	0.32^{ns}	0.15^{ns}	4.09^{ns}	0.76^{ns}	0.25^{ns}	0.90^{ns}	**3.10****
E-variety	4	0.12	0.19	0.15	0.06	0.11	0.42	0.16	6.00	1.07	0.38	0.52	0.42
CV (%)		10.38	14.06	12.76	110.75	9.64	24.03	13.99	2.60	8.29	5.18	7.39	4.63

**, **= statistically significant difference at 5 % and 1 % probability level respectively; ^{ns} = non-significant difference; DF=Degrees of freedom; AI=aromatic intensity, AQ=aromatic quality, AC=acidity, AS=astringency, BO = body, FL= flavor, OVS = overall standard, BS =bean size, SM=shape and make, BC=Bean color, OD=odor, HBW = hundred bean weight, PM=processing method, E-PM =error of processing method, DM= drying material, E-DM=error of drying material, E-Variety=error of variety; CV=Coefficient of variation.*

Appendix Table 4. Cup quality and green bean physical characteristics evaluation of the coffee samples for wet processed coffee for both location grading

Location	Drying material	variety	Raw quality				Cup quality				OVQ
			DC(20)	SM(10)	CL(5)	OD(5)	CC(15)	AC(15)	BO(15)	FL(15)	
Gera	Mesh wire	74110	20	10	4	5	15	12	12	9	2nd
Gera	Mesh wire	7440	20	8	4	5	12	9	9	9	3rd
Gera	Mesh wire	75227	20	8	4	5	12	9	9	9	3rd
Gera	Bamboo	74110	20	10	4	5	15	12	12	12	2nd
Gera	Bamboo	7440	20	8	4	5	15	12	9	12	2nd
Gera	Bamboo	75227	20	8	4	5	15	9	9	9	3rd
Gera	Palm leaves mat	74110	18	10	4	5	12	9	9	9	2nd
Gera	Palm leaves mat	7440	18	8	4	5	12	9	9	9	3rd
Gera	Palm leaves mat	75227	18	8	4	5	12	9	9	9	3rd
Gera	Jute mesh	74110	20	10	4	5	12	9	12	12	2nd
Gera	Jute mesh	7440	20	8	5	5	12	9	9	9	3rd
Gera	Jute mesh	75227	20	8	4	5	12	9	9	9	3rd
Gera	Cement floor	74110	18	10	4	5	9	9	9	6	4th
Gera	Cement floor	7440	18	8	4	5	9	9	9	6	4th
Gera	Cement floor	75227	18	8	4	5	9	9	9	6	4th
Gera	Soil	74110	5	10	1	2	6	9	9	3	8th
Gera	Soil	7440	5	8	1	2	6	9	9	3	8th
Gera	Soil	75227	5	8	1	2	6	9	9	3	8th
JARC	Mesh wire	74110	20	10	4	5	15	12	9	9	2nd
JARC	Mesh wire	7440	20	8	4	5	15	9	9	9	2nd
JARC	Mesh wire	75227	20	8	4	3	12	9	9	9	3rd
JARC	Bamboo	74110	20	10	4	5	15	12	9	9	2rd
JARC	Bamboo	7440	20	10	4	5	15	9	9	9	3rd
JARC	Bamboo	75227	20	10	4	5	15	9	9	9	3rd
JARC	Palm leaves mat	74110	20	8	4	5	15	12	6	9	2nd
JARC	Palm leaves mat	7440	20	8	4	5	12	9	9	9	3rd
JARC	Palm leaves mat	75227	20	8	4	5	12	9	9	9	3rd
JARC	Jute mesh	74110	20	10	4	5	15	12	9	9	2nd
JARC	Jute mesh	7440	20	10	4	5	12	9	9	9	3rd

Appendix Table 4. Continued

JARC	Jute mesh	75227	20	8	4	5	12	9	9	9	3rd
JARC	Cement floor	74110	18	10	4	5	12	12	9	9	3rd
JARC	Cement floor	7440	14	8	4	5	9	6	9	9	4th
JARC	Cement floor	75227	14	8	4	3	9	6	9	9	5th
JARC	Bare soil	74110	5	8	3	3	6	6	9	6	7th
JARC	Bare soil	7440	5	8	3	3	6	6	9	6	7th
JARC	Bare soil	75227	5	8	3	3	6	6	9	6	7th

DC= defects count; SM= shape and make; OD= odor; CL= color; AC= acidity; BO= body; FL= flavor; CC= cup cleanness; OVQ= overall quality

Appendix Table 5. Cup quality and green bean physical characteristics evaluation of the coffee samples for dry processed coffee for both location grading

Location	Drying material	Variety	Raw quality		Cup quality				
			DC(30)	OD(10)	CC(15)	AC(15)	BO(15)	FL(15)	OVQ
Gera	Mesh wire	74110	30	10	15	12	15	12	1st
Gera	Mesh wire	7440	30	10	12	9	12	9	2nd
Gera	Mesh wire	75227	30	10	12	9	12	9	2nd
Gera	Bamboo	74110	30	10	12	12	12	12	2nd
Gera	Bamboo	7440	30	10	12	9	12	9	2nd
Gera	Bamboo	75227	30	10	12	9	12	9	2nd
Gera	Palm leaves mat	74110	27	10	12	9	12	9	2nd
Gera	Palm leaves mat	7440	27	10	12	9	9	9	3rd
Gera	Palm leaves mat	75227	27	10	12	6	12	9	3rd
Gera	Jute mesh	74110	30	10	12	9	12	9	2nd
Gera	Jute mesh	7440	30	10	12	9	9	9	2nd
Gera	Jute mesh	75227	30	10	12	9	9	9	2nd
Gera	Cement floor	74110	30	10	12	9	12	9	2nd
Gera	Cement floor	7440	30	10	12	9	9	9	3rd
Gera	Cement floor	75227	30	10	12	9	9	9	3rd
Gera	Bare soil	74110	12	6	6	9	9	6	7th
Gera	Bare soil	7440	12	6	6	9	9	6	7th
Gera	Bare soil	75227	12	6	6	9	9	6	7th
JARC	Mesh wire	74110	30	10	10	9	12	12	2nd
JARC	Mesh wire	7440	30	10	10	9	12	9	2nd
JARC	Mesh wire	75227	30	10	12	9	9	9	3rd
JARC	Bamboo	74110	30	10	12	12	12	12	2nd
JARC	Bamboo	7440	30	10	12	9	12	9	2nd
JARC	Bamboo	75227	30	10	12	9	12	9	2nd
JARC	Palm leaves mat	74110	30	10	12	9	9	12	2nd
JARC	Palm leaves mat	7440	30	10	12	9	9	9	3rd
JARC	Palm leaves mat	75227	30	10	12	9	9	9	3rd
JARC	Jute mesh	74110	30	10	12	9	9	9	3rd
JARC	Jute mesh	7440	30	10	12	9	9	9	3rd
JARC	Jute mesh	75227	30	10	12	9	9	9	3rd
JARC	Cement floor	74110	30	8	12	9	9	9	3rd
JARC	Cement floor	7440	30	8	12	9	9	9	3rd
JARC	Cement floor	75227	30	8	12	9	9	9	3rd
JARC	Bare soil	74110	12	6	6	9	9	6	7th
JARC	Bare soil	7440	12	6	6	6	9	6	7th
JARC	Bare soil	75227	12	6	6	9	9	6	7th

Appendix Table 6. Standard parameters and their respective values used for washed coffee raw quality evaluation (ECX, 2010)

Raw value (40%)																	
Defects (20%)				Shape and make (10%)		Color (5%)		Odor (5%)		Cup cleanness(15 %)		Acidity (15%)		Body (15%)		Flavor (15%)	
1^0(count)(10%)	pts	2^0 (weight) (10%)	pts	Quality	pts	Quality	pts	Quality	pts	Quality	pts	Intensity	pts	Quality	Pt s	Quality	pts
0	10	<5%	10	V.good	10	Bluish	5	Clean	5	Clean	15	Pointed	15	Full	15	Good	15
1-4	8	<8%	8	Good	8	Gravish	4	F.clean	4	F .clean	12	M.pointed	12	M.Full	12	F .good	12
5-6	6	<10%	6	F.good	6	Greenish	3	Trace	3	1cd	9	Medium	9	Medium	9	Average	9
7-10	4	<12%	4	Average	4	Coated	2	Light	2	2cd	6	Light	6	Light	6	Fair	6
11-15	2	<14%	2	Fair	2	Faded	1	Moderate	1	3cd	3	Lacking	3	Thin	3	commonish	3
>15	1	>14%	1	Small	1	White	0	Strong	0	>3cd	0	N.D	0	N.D	0	N.D	0

Appendix Table 7. Standard parameters and their respective values used for unwashed coffee raw quality evaluation and grading as per ECX (2010)

Raw value (40%)						Cup value (60%)							
Defects (30%)				Odor 10(%)		Cup cleanness(15%)		Acidity (15 %)		Body (15%)		Flavor (15%)	
Primary (count)(15%)	Pts	Secondary (wt)(15%)	Pts	Quality	Pts	Quality	Pts	Intensity	Pts	Quality	Pts	Quality	Pts
<5	15	<5%	15	Clean	10	Clean	15	Pointed	15	Full	15	Good	15
6-10	12	<10%	12	F.clean	8	F. clean	12	M.pointed	12	M .full	12	F.good	12
11-15	9	<15%	9	Trace	6	1 CD	9	Medium	9	Medium	9	Average	9
16-20	6	<20%	6	Light	4	2 CD	6	Light	6	Light	6	Fair	6
21-25	3	<25%	3	Moderate	2	3 CD	3	Lacking	3	Thin	3	Commonish	3
>25	1.5	>25%	1.5	Strong	0	>3 CD	0	ND	0	ND	0	ND	0

Appendix Table 8. Partial budget analysis for dry processing

Location	Material	Installation Cost 1	Material life time 2	Installation cost for for the first year 3	Days to draying 4	Labor price/day/3kg Cherry 5	Cost of coffee cherry(3kg) 6	Total cost (3+5+6) 7	Revenue	Net benefit
Gera	Mesh wire	15.93	5	3.19	19.5	5.38	19.5	28.02	39.75	11.73
Gera	Bamboo	10.6	1	10.6	18	4.5	19.5	34.60	39.05	4.45
Gera	Palm leaves mat	10.6	1	10.6	19.5	5.38	19.5	35.47	38.90	3.43
Gera	Jute mesh	8.6	1	8.6	20.5	6.88	19.5	34.97	39.05	3.93
Gera	Cement floor	12	5	2.4	18.5	4.88	19.5	26.77	38.90	12.13
Gera	Soil	0.6	1	0.6	18	4.5	19.5	24.60	17.64	(-6.96)
Jimma	Mesh wire	14.93	5	3.00	17.5	5.13	21	29.53	39.90	10.37
Jimma	Bamboo	9.93	1	9.93	13	3.25	21	34.18	39.05	4.87
Jimma	Palm leaves mat	9.93	1	9.93	14.5	3.63	21	34.55	38.97	4.42
Jimma	Jute mesh	8.26	1	8.26	14.5	3.63	21	32.88	38.82	5.94
Jimma	Cement floor	10	5	2	13	3.25	21	28.25	38.82	10.57
Jimma	Soil	0.6	1	0.6	14.5	3.63	21	25.22	17.64	(-7.58)

Appendix Table 9. Partial budget analysis for wet processing

Location	Drying material	Installation Cost 1	Material life time 2	Installation cost for for the first year 3	Days to draying 4	Labor price/day/3kg Cherry 5	Cost of coffee cherry(6kg) 6	Total cost (3+5+6) 7	Revenue	Net benefit
Gera	Mesh wire	15.93	5	3.19	7	1.75	39	43.94	73.43	29.49
Gera	Bamboo	10.6	1	10.6	7.5	2.05	39	51.65	72.84	21.19
Gera	Palm leaves mat	10.6	1	10.6	9.5	3.43	39	53.03	72.43	19.40
Gera	Jute mesh	8.6	1	8.6	8	2.42	39	50.02	72.43	22.41
Gera	Cement floor	12	5	2.4	11	4.17	39	45.57	65	19.43
Gera	Soil	0.6	1	0.6	11	4.17	39	43.77	32.24	-11.53
Jimma	Mesh wire	14.93	5	3.00	5	1.5	42	52.47	72.64	20.18
Jimma	Bamboo	9.93	1	9.93	5	1.5	42	53.43	72.45	19.02
Jimma	Palm leaves mat	9.93	1	9.93	5.5	2	42	53.93	72.84	18.91
Jimma	Jute mesh	8.26	1	8.26	5	1.5	42	51.76	71.85	20.09
Jimma	Cement floor	10	5	2	8	2.75	42	46.57	62.35	15.78
Jimma	Soil	0.6	1	0.6	9	4.25	42	46.85	38.23	(-8.62)

Appendix Table 10. A Weather data of Gera during the study period (2009-2010)

Date	Rainfall, mm	Temperature, ^{0}c																			
		Maximum	Minimum	Dry bulb					Wet bulb					Dew point Temperature, ^{0}C				
				06	09	12	15	18	06	09	12	15	18	06	09	12	15	18
25/dec/09	0.0		8.5	13.0	14.5	23.0	18.5	15.5	12.5	13.5	19.5	14.5	15.0	12.0	12.9	17.9	13.9	14.7
26>>	0.0		10.0	13.5	14.6	21.5	22.0	17.5	12.0	13.0	18.5	15.0	16.0	11.0	13.3	16.1	13.9	15.2
27>>	4.1		11.5	12.5	13.0	22.5	15.5	15.5	12.0	13.0	19.5	14.5	15.0	11.7	13.0	18.2	13.3	14.7
28>>	5.0		12.5	13.5	14.5	19.5	16.5	13.5	13.0	14.5	16.5	15.5	15.0	12.7	14.5	15.0	14.9	14.7
29>>	20		13.0	14.5	16.0	21.5	18.5	17.0	14.0	13.0	18.5	17.5	16.5	13.7	14.4	17.1	17.0	14.2
30	0.0		12.5	4.0	15.8	19.0	20.5	18.0	13.5	14.8	17.0	17.5	16.5	13.2	14.	16.0	16.0	15.2
31>>	0.0		10.5	14.0	15.5	22.0	23.5	18.0	13.0	14.5	17.0	19.5	17.0	12.4	13.9	14.3	17.7	16.5
1/Jan/10	0.0		12.5	14.0	15.5	23.5	24.5	22.0	13.5	14.5	19.5	21.0	17.0	12.7	13.9	17.7	19.5	14.3
2	0.0		9.0	11.5	13.5	22.8	23.5	11.0	10.0	12.0	17.8	20.0	17.0	8.9	11.0	15.3	18.4	16.0
3	0.0		7.5	11.5	11.5	22.5	24.5	10.5	9.0	10.5	18.5	21.0	14.5	8.6	9.8	16.6	19.5	13.1
4	0.0		6.5	10.0	12.0	22.0	25.5	21.0	9.5	11.5	15.5	18..0	17.5	9.1	11.2	11.6	14.1	15.7
5	0.0		6.0	12.5	14.0	22.5	24.0	19.0	11.0	13.0	17.0	20.0	14.5	10.0	12.4	14.0	18.2	11.7
6	0.0		5.0	8.5	10.5	23.5	25.5	20.5	7.5	10.0	19.0	20.5	14.0	5.6	9.6	16.0	18.3	9.7
7	0.0		5.5	10.5	11.5	23.5	25.5	24	9.0	10.5	18.5	20.0	14.5	7.8	9.3	16.1	17.5	10.4
8	0.0		5.5	10.5	11.5	23.0	25.0	24	9.0	10.5	18.5	19.0	17.0	7.8	9.8	12.9	16.1	14.9
9	0.0		6.5	10.0	12.5	22.5	25.5	22.0	9.5	11.5	18.5	18.0	17.0	9.1	10.8	13.2	14.1	14.3
10	0.0		12.0	13.0	15.5	23.5	24.5	19.5	12.5	15.0	16.0	18.5	17.0	12.2	14.7	11.5	15.6	15.7
11	0.0		6.5	11.0	12.5	23.0	20.5	19.5	9.5	11.5	18.0	17.0	16.5	8.4	16.9	15.5	15.1	15.0
12	0.0		9.5	11.8	13.5	22.5	24.0	20.5	10.8	13.0	19.5	19.5	17.0	10.1	12.7	18.2	17.5	15.7
13	0.0		9.0	12.5	14.0	23.0	25.8	19.0	11.0	13.0	20.0	16.8	16.0	10.0	12.4	18.7	10.6	14.4
14	0.0		8.5	13.0	15.5	22.5	26.2	22.5	12.0	14.0	19.5	22.2	15.0	11.3	13.1	18.2	26.6	10.2
15	0.0		9.0	11.0	12.5	24.5	26.5	23.5	10.0	12.5	18.0	22.5	15.5	9.2	12.5	14.7	21.0	10.5
16	18.6		7.0	10.8	11.5	23.5	25.5	15.0	9.8	11.0	19.5	22.0	14.0	9.0	10.6	17.7	20.6	13.4
17	14.6		8.5	14.0	16.5	23.0	26.5	21.5	13.0	15.5	18.5	23.5	17.5	12.4	14.9	16.6	22.5	15.5
18	6.4		100	12.0	13.5	20.5	24.5	20.5	11.0	12.5	18.0	21.5	16.5	10.3	11.1	16.8	20.3	14.4
19	0.0		10.5	11.0	13.5	20.0	22.5	18.5	10.5	12.0	16.5	17.5	16.0	10.1	11.0	14.6	14.9	14.7
20	11.4		11.5	14.5	16.0	20.5	24.0	19.0	13.0	15.0	17.0	20.0	17.0	12.1	14.4	15.1	18.2	16.1
21	14.4		12.0	14.0	16.5	25.5	24.5	21.5	13.5	15.5	19.5	26.5	17.5	13.2	14.9	17.7	18.8	14.6

Appendix Table 10. Continued

Date	Relative Humidity, %					Wind speed, m/sec(at 2m)					Dry bulb	**Wet bulb**	**Relative humidity**	**Dew point**	**Class A (total)**	**Soil t^0, 5cm**	**Soil t^0, 20cm**	**Soil t^0, 50cm**	**Wind speed at 2m in m/sec**
	06	09	12	15	18	06	09	12	15	18									
25/Dec /09	95	85	73	91	95	0.35	1.34	0.75	0.50	0.57	16.3	15.0	89	14.3	XX	18.5	18.4	20.3	0.90
26 >>	85	85	63	74	87	1.06	0.68	1.60	0.61	0.58	17.0	14.9	79	13.8	1.42	18.1	17.5	20.1	0.99
27 >>	95	100	76	74	78	0.00	0.60	1.04	0.70	0.42	15.8	14.8	88	14.3	2.86	17.9	18.0	20.0	0.57
28 >>	95	100	74	91	78	0.00	0.05	0.85	0.23	0.26	15.9	14.9	88	14.4	4.22	18.1	18.5	19.7	0.40
29 >>	95	91	76	91	86	0.50	0.56	0.94	0.46	0.45	17.5	16.1	88	12.0	2.00	19.5	18.5	19.8	0.59
30	95	91	82	75	78	0.23	0.50	0.14	0.19	0.48	17.5	15.9	84	14.9	1.86	19.7	18.5	19.8	0.35
31 >>	90	91	64	75	92	0.29	0.50	1.50	0.64	0.55	18.6	16.2	81	15.0	1.98	20.3	18.5	19.8	0.76
1/jan/10	95	91	70	73	61	0.19	0.88	1.59	1.11	0.57	19.0	17.0	78	18.6	3.34	22.0	189	19.9	0.87
2	84	86	62	73	82	0.63	1.27	1.12	0.41	0.57	20.0	13.3	77	13.7	4.46	20.4	18.8	20.5	0.80
3	94	90	69	73	82	0.45	1.18	1.10	1.01	6.69	16.9	14.7	82	13.6	3.76	19.7	19.1	20.4	0.89
4	95	95	52	48	72	0.34	1.25	1.26	0.77	0.62	18.1	14.1	72	12.3	4.42	20.5	19.3	20.5	0.85
5	84	91	58	70	62	0.64	1.15	1.12	1.62	1.75	18.4	15.1	70	13.3	2.76	21.1	19.6	20.7	0.89
6	77	95	66	64	49	0.19	1.07	1.12	0.19	0.38	17.7	13.7	70	11.5	5.41	20.6	18.8	20.6	0.90
7	83	90	63	70	50	1.07	0.66	1.12	1.21	1.52	18.4	14.8	70	12.3	5.00	21.2	19.1	20.5	0.67
8	83	90	53	64	68	0.80	0.87	1.03	1.09	0.48	18.1	14.5	70	12.3	3.95	21.4	19.4	20.7	0.96
9	95	90	56	62	61	0.14	0.94	1.12	1.09	0.67	18.7	14.5	70	12.3	4.26	22.1	20.4	20.5	0.83
10	95	95	46	58	78	0.00	0.21	1.51	1.12	5.77	19.2	15.8	4	13.9	4.50	22.1	20.1	20.9	0.88
11	84	95	62	58	74	0.08	0.72	0.94	0.19	.60	15.3	14.5	77	13.0	XX	19.6	19.5	21.2	0.46
12	90	95	76	66	71	0.28	1.22	1.11	0.53	0.35	18.5	15.8	85	14.7	XX	21.6	19.6	20.8	0.75
13	84	91	76	4071	74	0.08	1.30	1.59	0.60	0.81	18.9	15.4	73	13.2	4.80	22.4	19.8	20.7	0.78
14	90	86	76	70	45	1.43	1.86	2.03	0.86	0.35	19.9	16.5	73	14.7	4.32	22.7	19.9	21.1	1.40
15	90	10	74	71	43	0.19	1.05	1.41	0.31	0.57	19.6	15.7	72	13.6	3.88	22.9	20.4	21.5	0.66
16	90	95	70	73	91	0.32	0.59	2.22	0.76	0.69	17.1	15.3	84	13.6	3.10	22.1	20.3	21.1	0.89
17	91	91	69	78	64	0.31	1.12	0.88	1.10	0.61	20.3	17.6	80	14.3	12.50	22.1	19.9	21.2	0.82
18	90	85	79	77	68	0.26	.46	0.86	0.56	0.61	18.2	15.9	81	14.7	6.40	20.1	19.0	21.3	0.55
19	95	91	71	62	78	0.24	1.02	0.56	0.51	0.43	17.1	14.5	78	13.1	1.58	20.4	18.3	21.1	0.55
20	86	92	71	70	82	0.11	0082	1.73	0.77	0.58	18.8	16.4	80	15.2	7.82	21.5	18.5	20.9	0.82
21	95	86	70	70	64	0.16	1.02	1.190	0.98	0.65	20.1	17.2	78	15.8	14.40	20.3	19.3	20.4	0.80

Appendix Table 11. A Weather data of Jimma during the study period (2009-2010)

Date	Rainfall, mm	Temperature ^{0}c													Dew point Temperature, ^{0}C					Relative Humidity, %				
		Maximum	Minimum	Dry bulb					Wet bulb															
				06	09	12	15	18	06	09	12	15	18	06	09	12	15	18	06	09	12	15	18
28/nov/09	35.6	30.5	13.2	14.0	19.5	25.5	29.0	24.5	14.0	15.5	16.0	18.5	17.5	14.0	12.1	10.2	12.9	11.9	100	67	37	37	51
29	50.8	30.0	13.0	13.5	19.0	25.5	26.5	24.0	13.0	16.0	16.5	16.5	18.0	12.7	14.4	11.1	10.5	14.4	95	74	40	36	57
30	TR	25.5	14.0	14.5	15.0	21.5	25.0	22.5	14.5	15.0	17.0	18.0	18.0	14.5	15.0	14.6	14.4	15.0	100	100	64	51	65
1dec/09	0.2	27.5	12.0	12.0	19.5	24.5	27.0	20.0	12.0	17.0	17.5	18.0	15.5	13.5	11.7	12.5	14.7	13.1	100	81	45	49	50
2	0.3	28.0	13.0	13.0	18.5	25.0	29.0	23.0	13.0	16.0	18.0	19.0	17.0	10.5	11.6	7.8	9.0	9.8	100	86	32	31	44
3	0.2	28.5	11.0	11.0	16.0	24.0	25.0	23.5	11.0	15.0	16.0	17.0	17.0	8.0	11.6	8.3	13.1	16.0	100	86	34	50	69
4	1.0	28.5	13.0	13.0	18.0	24.5	27.0	25.0	12.5	16.0	16.0	17.0	18.0	13.0	14.4	12.5	15.0	14.4	100	91	45	52	47
5	6.0	28.0	12.5	13.0	17.5	25.0	25.5	23.0	12.5	16.0	17.5	17.0	17.0	13.7	14.2	11.2	13.8	13.5	95	86	44	46	53
6	0.0	27.5	12.0	12.0	18.0	25.0	26.0	24.0	12.0	16.0	17.0	17.5	17.0	9.6	11.6	13.3	5.2	9.8	95	86	48	25	42
10	0.0	24.0	15.0	15.0	17.0	21.0	24.0	22.5	15.0	16.0	18.0	18.0	17.0	8.6	9.6	7.6	5.1	8.7	94	79	33	22	36
11	TR	25.0	14.5	14.5	18.5	22.0	24.5	21.5	14.5	15.5	17.5	17.0	17.5	5.6	9.1	10.4	6.1	9.1	88	79	39	23	38
12	8.3	26.5	11.0	15.0	18.5	24.5	25.0	25.0	15.0	15.5	18.5	18.5	17.5	6.5	11.6	11.5	10.5	11.9	100	81	42	38	49
13	0.4	24.5	15.0	15.5	18.0	21.5	25.0	21.5	15.0	16.0	17.5	17.0	17.0	11.5	12.9	12.5	10.5	14.3	100	70	41	32	61
14	14.8	22.0	15.0	15.0	16.5	25.0	26.5	19.0	15.0	15.5	18.0	18.0	17.0	12.2	13.1	11.1	10.5	13.5	95	70	40	32	53
15	0.1	28.5	10.0	10.0	15.0	23.0	27.0	24.0	10.0	14.0	18.0	18.5	18.0	13.0	13.1	12.1	10.5	13.2	100	78	38	32	56
16	0.1	27.5	12.0	12.0	17.5	25.0	27.0	23.0	12.0	15.0	18.0	17.5	17.0	10.3	13.9	14.3	15.6	12.8	90	82	61	39	57
17	0.0	28.0	14.0	14.0	15.0	24.0	27.5	24.5	14.0	14.0	18.5	18.5	16.0	13.0	13.4	13.5	12.5	14.7	100	91	48	41	54
18	0.0	29.0	12.0	12.0	17.0	25.0	28.0	24.0	12.0	15.0	17.0	18.5	16.5	14.0	13.9	11.9	10.1	12.9	100	86	45	31	53
19	0.0	28.5	13.0	13.0	17.0	26.0	28.0	24.0	13.0	14.5	18.0	18.0	16.5	12.0	15.2	10.4	9.4	13.2	100	78	39	31	56
20	0.2	27.5	14.0	14.5	18.0	25.0	26.5	24.5	14.0	16.0	17.5	18.5	17.0	13.5	13.7	10.4	7.0	9.5	100	86	39	29	41
21	1.2	22.5	15.0	15.0	16.5	22.0	22.5	21.0	14.0	15.0	17.0	17.5	17.0	8.6	12.8	9.8	7.0	9.5	100	81	35	29	41
22	1.3	29.0	14.0	14.0	15.0	17.5	19.0	18.0	13.5	14.5	15.5	15.5	16.0	11.0	12.8	9.8	7.0	11.5	95	81	35	29	46
23	2.3	25.5	13.0	13.5	16.0	21.5	24.5	22.0	13.0	15.0	17.0	15.0	16.0	11.0	12.8	10.2	7.0	12.8	100	81	37	31	47
24	4.1	25.5	12.5	12.5	16.0	23.5	25.0	15.0	12.5	15.5	17.0	16.0	15.0	10.0	13.1	11.5	8.1	12.2	100	86	42	31	47
25	0.2	28.5	13.0	13.0	14.0	16.5	18.0	18.0	13.0	14.0	15.0	15.5	16.0	13.0	13.1	8.7	10.1	13.2	100	70	36	31	48
26	1.4	29.0	13.0	13.5	16.5	23.0	24.0	22.0	13.0	15.0	17.0	14.5	17.0	9.8	12.1	8.3	9.4	12.8	95	70	34	31	43
27	5.3	22.0	14.0	14.5	16.0	18.5	19.5	18.0	14.0	15.5	16.0	16.0	16.0	10.0	12.5	12.5	12.5	13.5	100	77	50	41	49
28	0.2	22.5	15.0	15.0	16.0	20.5	21.5	18.0	15.0	15.5	17.0	17.0	15.5	14.0	12.1	10.2	12.9	11.9	100	67	37	37	51
29	1.5	24.5	14.0	14.0	16.0	23.0	23.0	19.0	14.0	15.5	17.5	16.0	17.0	12.7	14.4	11.1	10.5	14.4	95	74	40	36	57

Appendix Table 11. Continued

Date	Wind speed, m/sec(at 2m)					Temperature	Dry bulb	Wet bulb	Relative humidity	Dew point	Soil t^0, 5cm	Soil t^0, 10cm	Soil t^0, 20cm	Soil t^0, 50cm	Soil t^0, 100cm	Wind speed at 2m in m/sec	
	06	09	12	15	18												
28/nov/09	0.18	1.12	1.36	1.08	0.74	22.0	22.5	16.3	58	12.2	27.0	28.8	24.6	23.3	23.4	0.90	22.0
29	0.00	0.76	1.25	0.90	0.63	22.0	21.7	16	60	12.6	23.8	24.4	23.2	22.4	23.2	0.71	22.0
30	0.02	0.44	1.20	0.71	0.33	20.3	19.7	16.5	76	14.7	22.5	22.8	22.6	22.8	23.3	0.54	20.3
1/dec/09	0.22	0.86	1.22	0.77	0.45	21.3	20.6	16.0	67	13.4	24.4	24.7	23.1	23.1	23.8	1.06	21.3
2	0.01	0.98	1.34	1.07	0.48	21.5	21.7	16.6	65	14.0	24.7	25.4	23.4	23.4	24.2	0.94	21.5
3	0.19	0.90	1.36	0.50	0.48	20.5	19.9	15.2	68	12.5	24.7	25.7	24.0	24.0	24.6	0.79	20.5
4	0.07	1.27	1.63	0.86	0.49	21.8	21.5	15.9	60	12.7	25.3	26.5	23.3	23.3	24.6	0.84	21.8
5	0.19	1.98	0.50	0.86	0.46	21.0	19.8	15.3	67	12.6	23.2	23.6	22.1	21.9	22.6	0.53	21.0
6	0.10	0.96	2.15	1.22	0.58	18.0	17.3	15.5	82	14.2	21.0	20.5	21.2	22.0	22.8	0.51	18.0
10	1.98	0.99	1.33	0.93	0.68	18.8	18.2	16.0	81	14.7	20.9	21.4	21.0	22.0	22.8	0.56	18.8
11	0.05	0.84	1.49	0.57	0.41	19.3	19.0	16.0	75	14.1	20.9	21.4	21.0	22.0	22.8	0.51	19.3
12	0.04	1.00	0.48	1.41	0.42	19.3	19.2	15.7	74	13.8	21.6	22.6	21.1	21.4	22.7	0.68	19.3
13	0.08	0.97	1.38	1.03	0.47	19.3	19.5	15.8	71	13.6	21.6	22.0	20.9	21.8	22.7	0.59	19.3
14	0.19	0.86	1.48	1.03	0.52	19.8	20.7	16.5	69	14.3	24.4	24.7	23.1	22.9	23.3	0.73	19.8
15	0.22	1.07	1.12	0.32	0.45	20.6	20.3	16.3	71	14.0	24.7	25.4	23.2	23.1	23.2	0.77	20.6
16	0.16	0.90	1.19	0.99	0.47	18.8	18.5	15.9	65	12.4	24.7	26.5	24.0	23.1	23.4	0.66	18.8
17	0.19	0.94	0.39	1.79	0.49	19.8	20.4	16.2	65	12.1	25.3	26.5	23.3	23.0	23.3	0.61	19.8
18	0.12	0.91	1.54	1.15	0.51	19.5	20.2	14.2	60	10.0	25.3	25.8	23.4	23.0	23.3	0.82	19.5
19	0.20	1.17	1.64	1.00	0.57	18.3	20.3	12.7	52	7.3	24.6	25.8	23.4	23.0	23.1	0.73	18.3
20	0.11	1.01	1.69	0.79	0.55	18.3	19.9	14.1	61	10.7	23.5	24.8	22.8	22.8	23.1	0.66	18.3
21	0.09	1.15	1.81	0.77	0.59	18.8	19.9	13.9	60	10.2	23.7	24.7	23.0	22.7	23.3	0.74	18.8
22	0.11	1.17	1.31	1.21	0.54	17.5	18.5	14.8	72	12.7	23.2	23.6	23.1	22.7	23.2	0.80	17.5
23	0.12	1.18	1.48	1.02	0.56	19.3	19.2	15.0	69	12.6	22.1	22.4	22.4	22.5	23.1	0.66	19.3
24	0.16	1.19	1.52	1.25	0.59	17.8	17.7	13.8	69	11.3	22.0	23.8	22.2	22.3	23.0	0.81	17.8
25	0.10	1.41	0.77	2.09	0.61	19.0	19.9	14.3	62	10.8	22.5	21.8	22.4	22.2	22.9	0.78	19.0
26	0.09	1.02	1.41	0.70	0.50	19.0	19.2	14.3	61	10.6	21.8	22.4	22.2	22.5	23.0	0.79	19.0
27	0.59	0.78	1.15	0.99	0.54	18.8	18.5	15.9	65	12.4	24.7	26.5	24.0	23.1	23.4	0.66	18.8
28	0.18	1.12	1.36	1.08	0.74	18.3	20.4	16.2	65	12.1	25.3	26.5	23.3	23.0	23.3	0.61	19.8
29	0.00	0.76	1.25	0.90	0.63	19.5	20.2	14.2	60	10.0	25.3	25.8	23.4	23.0	23.3	0.82	19.5

Appendix Table 12. A climate data of Jimma (1968-2009)

Month	Rainfall (mm)		Rainy days (No)		Air Temprature (^{o}C.) at 2M.				Soil Temprature (^{o}C.)		Relative Humidity (%)		Sun shine (Hr./Months)		Radiation (cal./cm.^{2})		
					Minimum		Maximum		Surface								
	2009	Mean 1968-08	2009	Mean 1968-08	2009	Mean 1969-08	2009	Mean 1969-08	2007	Mean 1969-08	2009	Mean 1974-08	2009	Mean 1969-08	1993	Mean 1969-73	Mean 1981-92
1	2	3	4	5	6	7	8	9	10	11	13	14	15	16	17	18	19
Jan	79.3	(35.5)	12	(6)	9.7	(9.8)	27.6	(27.0)	13.6	(8.5)	59	(58)	7.4	(7.0)	395.3	(629)	(418.6)
Feb.	57.9	(42.5)	7	(8)	11.5	(11.0)	28.7	(27.7)	12.7	(10.0)	59	(57)	8.7	(6.8)	374.2	(642)	(386.8)
Mar.	116.6	(97.5)	12	(13)	13.6	(12.7)	29.2	(27.6)	16.2	(11.4)	60	(59)	8.4	(6.4)	373.9	(633)	(412.7)
Apr	121.5	(126.1)	18	(15)	13.8	(13.5)	28.1	(26.9)	15.7	(12.3)	65	(63)	7.7	(6.1)	411.4	(647)	(397.3)
May	212.7	(183.2)	13	(18)	13.9	(13.6)	26.1	(25.7)	14.3	(9.1)	65	(68)	8.0	(5.9)	440.8	(641)	(386.7)
Jun	197.9	(213.7)	21	(22)	14.8	(13.3)	20.5	(24.1)	15.3	(12.7)	70	(74)	8.0	(4.7)	411.9	(593)	(389.0)
Jul	178.3	(223.7)	21	(23)	15.4	(13.4)	24.0	(22.6)	15.4	(12.6)	75	(79)	4.4	(3.2)	403.4	(480)	(338.9)
Aug	260.8	(220.4)	28	(24)	15.0	(13.4)	24.2	(22.9)	15.1	(12.6)	77	(79)	5.0	(3.9)	411.5	(531)	(349.8)
Sep	243.8	(190.2)	25	(20)	15.2	(13.1)	25.7	(24.1)	16.2	(12.2)	75	(75)	1.4	(5.1)	445.6	(613)	(409.4)
Oct	100.0	(113.6)	13	(12)	14.4	(11.5)	26.2	(25.2)	16.4	(10.4)	71	(69)	6.4	(7.1)	474.7	(676)	(434.3)
Nov	88.1	(53.3)	4	(6)	11.2	(9.6)	28.2	(25.8)	17.1	(8.2)	61	(67)	8.9	(7.8)	490.6	(674)	(420.4)
Dec	67.7	(33.7)	21	(5)	14.0	(8.6)	26.5	(26.4)	15.0	(7.4)	70	(61)	5.7	(8.0)	427.6	(610)	(403.8)
Total	1724.6	(1495.6)															
Mean			16	(14)	13.5	(11.9)	26.3	(25.5)	15.2	(10.6)	68	(67)	6.7	(6.0)	421.7	(614)	(395.6)

Appendix Table 12. Continued

Month	Evaporation class (mm./months)		Wind speed (km./hrs.)					
			At 1 Mt.				At 2 Mt.	
	2001	Mean 1969-00	2009	Mean 1969-77	Mean 1983-01	Mean 2004-08	2009	Mean 1977-08
12	20	21	22	23	24	25	26	27
Jan	4.78	(5.23)	-	(2.77)	(1.93)	(2.64)	2.39	(2.54)
Feb.	6.16	(5.08)	-	(3.27)	(2.27)	(3.23)	5.45	(2.82)
Mar.	5.30	(3.38)	-	(3.21)	(2.63)	(2.84)	3.32	(3.18)
Apr	5.93	(5.14)	3.13	(3.35)	(2.62)	(2.88)	2.88	(3.25)
May	4.89	(4.80)	3.88	(3.33)	(2.46)	(2.55)	3.96	(2.95)
Jun	4.08	(4.19)	3.11	(2.98)	(2.33)	(2.57)	2.93	(2.73)
Jul	3.39	(3.13)	2.32	(2.91)	(1.77)	(2.03)	2.08	(2.27)
Aug	3.73	(3.40)	2.20	(2.82)	(1.87)	(1.71)	1.77	(2.14)
Sep	4.97	(4.28)	1.97	(2.94)	(1.80)	(1.79)	1.68	(2.21)
Oct	4.68	(4.67)	1.87	(2.88)	(1.69)	(1.81)	1.53	(2.13)
Nov	4.61	(4.69)	2.10	(2.21)	-	(1.71)	1.82	(2.20)
Dec	4.72	(4.54)	1.81	(3.38)	(1.88)	(1.86)	1.52	(2.30)
Total								
Mean	4.77	(4.54)	2.49	(2.92)	(2.09)	(2.30)	2.61	(2.54)

Appendix Table 13. A climate data of Gera (GARSC) (1975-2009)

Month	Rainfall (mm)		Rainy days (No)		Air Temprature (^{o}C.) at 2M.					Relative Humidity (%)		Sun shine (Hr./Months)	
					Minimum			Maximum					
	2009	Mean 1968-08	2009	Mean 1975-08	2009	Mean 1981-99	Mean 2005-08	2004	Mean 1969-08	2009	Mean 1981-08	2009	Mean 1981-08
1	2	3	4	5	6	7	8	9	10	13	14	15	16
Jan	26.3	(44.1)	5	(6)	8.1	(8.5)	(9.0)	26.6	(25.5)	81	(65)	6.4	(6.7)
Feb.	95.6	(55.8)	9	(8)	9.3	(9.5)	(9.8)	26.6	(26.5)	69	(61)	7.5	(6.6)
Mar.	210.4	(122.5)	17	(14)	9.4	(10.8)	(11.0)	27.3	(26.4)	71	(64)	6.5	(6.1)
Apr	132.8	(142.6)	7	(14)	11.9	(11.7)	(12.4)	26.1	(25.8)	76	(67)	6.7	(5.7)
May	102.7	(205.4)	10	(18)	11.2	(12.1)	(12.6)	25.9	(25.0)	82	(74)	6.9	(5.5)
Jun	183.1	(279.7)	17	(23)	11.6	(11.1)	(12.6)	23.0	(23.5)	87	(79)	5.9	(4.4)
Jul	177.4	(253.8)	17	(23)	11.7	(11.8)	(12.5)	22.3	(22.2)	94	(82)	3.0	(3.2)
Aug	219.3	(236.7)	12	(22)	12.3	(11.8)	(12.6)	22.6	(22.2)	86	(81)	3.2	(3.5)
Sep	194.2	(242.9)	15	(21)	12.0	(11.6)	(12.5)	23.1	(23.0)	86	(79)	4.3	(4.4)
Oct	197.9	(155.1)	12	(14)	10.4	(9.8)	(10.9)	24.0	(24.1)	83	(73)	5.1	(6.2)
Nov	56.0	(65.3)	4	(7)	7.6	(8.3)	(8.9)	24.7	(24.5)	75	(69)	7.5	(7.2)
Dec	73.0	(44.0)	11	(6)	10.5	(7.8)	(7.8)	25.1	(24.9)	82	(66)	4.8	(7.2)
Total	1668.7	(1837.2)											
Mean			11	(15)	10.5	(10.4)	(11.1)	24.8	(24.5)	81	(72)	5.6	(5.6)

Appendix Table 13. Continued

Month	Evaporation class (mm./months)			Wind speed (km./hrs.)			
				At 1 Mt.		At 2 Mt.	
	2009	Mean 1981-83	Mean 1986-07	2009	Mean 1981-08	2009	Mean 1981-08
12	20	21		22	23	0.92	27
Jan	3.58	(4.24)	(3.87)	2.53	(2.01)	1.62	(2.06)
Feb.	3.58	(5.74)	(3.97)	2.51	(2.19)	2.12	(2.29)
Mar.	4.89	(6.07)	(4.36)	2.53	(2.39)	2.38	(2.44)
Apr	-	(5.28)	(4.00)	2.40	(2.23)	2.59	(2.29)
May	5.74	(6.35)	(3.98)	2.52	(2.14)	2.46	(2.21)
Jun	5.82	(6.45)	(3.51)	2.53	(1.99)	1.51	(2.06)
Jul	3.30	(5.44)	(2.91)	2.03	(1.84)	1.45	(2.71)
Aug	5.32	(3.37)	(2.90)	2.03	(1.90)	2.03	(1.91)
Sep	5.59	(5.25)	(3.20)	-	(1.97)	1.64	(1.88)
Oct	6.23	(5.13)	(3.56)	2.09	(2.11)	4.24	(2.00)
Nov	4.40	(4.65)	(3.61)	2.20	(2.07)	2.01	(2.05)
Dec	3.86	(4.19)	(3.39)	1.82	-		(2.08)
Total							
Mean	4.76	(5.18)	(3.61)	2.29	(2.08)	2.08	(2.17)