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# Association of Arabica Coffee Quality Attributes with Selected Soil Chemical Properties

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**Abstract:** Coffee (*Coffea arabica* L.) bean quality attributes differ based on the origin of the produce. Several agro-ecological conditions influence coffee bean quality attributes. Soil chemical properties may be some of the factors affecting the quality attributes. However, no study has so far been conducted to elucidate the association of coffee bean qualities with soil chemical properties in both major and minor coffee growing regions of Ethiopia. Thus, this research was conducted with the objective of establishing association of chemical soil properties with coffee cup quality attributes. Coffee beans as well as soil samples from which the beans originated were subjected to chemical analysis. The coffee beans and the corresponding soil samples originated from large scale coffee plantations (Bebeka, Gemadro and Goma), districts from southwestern major coffee growing region (Gore, Jimma, Lemkefa), West (Gimbi), East (Badano, Chiro, Darolebu, Habro and Melkabelo), South (Yirgacheffe) and northwestern minor coffee growing districts (Ankasha, Bure, Mecha and Jabi). The soil samples were collected from the depth of 0 - 50 cm near the coffee trunks and samples of ripe coffee cherries were picked up from the trees during the 2010/11 harvest season. Selected chemical properties of the soil, namely, available potassium, cation exchange capacity, exchangeable acidity, exchangeable bases, available micronutrients, available phosphorus, total nitrogen, soil pH, electrical conductivity, and percent organic carbon were determined from 53 soil samples in Jimma University soil laboratory and Wolkitie Soil Testing and Soil Fertility Improvement Centre using the established procedures. The sampled red coffee cherries were carefully subjected to the dry processing methods and the separated beans tested for quality attributes in accordance with Ethiopian Commodity Exchange (ECX) and Specialty Coffee Association of America (SCAA) coffee quality test procedures and standards. Correlation and stepwise regression analyses were done to establish the association of the selected soil chemical properties with the coffee bean quality attributes. The correlation analysis revealed that coffee quality attributes were positively and significantly associated with CEC (r = 0.36**), available soil Mg content (r = 0.28*), exchangeable acidity ($H^+$) (r = 0.35*), and soil pH (r = 0.30*). However, the coffee quality attributes were negatively and significantly associated with soil available Cu (r = - 0.35*), available Zn (r = - 0.40**), and total N (r = - 0.40**). The regression analysis showed that coffee quality attributes were more profoundly dependent on available Fe content ($R^2$ =0.22) and CEC ($R^2$ = 0.13) in the soil. The soil CEC and available soil iron (Fe) accounted for 13 and 21.9%, respectively of the observed variation in the overall coffee quality attributes that determines the final coffee grade and consumer preferences. Therefore, it could be concluded that coffee quality attributes improved with increase in the levels of soil CEC, Mg, H1+, and pH, while decreasing with increase in the levels of available soil Cu, Zn and total N. However, enhanced soil CEC and available iron content led to improved grade and overall specialty coffee quality attributes whilst enhanced soil available zinc and copper as well as total soil nitrogen led to reduced grade and overall specialty coffee quality attributes.

**Keywords**: Available soil iron; *Coffea arabica* L.; CEC; Coffee grade; Specialty coffee quality attributes; coffee cup quality

## 1. Introduction

Arabica coffee (*Coffea rabica* L) grows in Ethiopia, which is the place of its origin. Thus, one understands well the ecological requirements of Arabica coffee when visiting the live progenies in their homeland in the Ethiopian high rainfall natural forests (Wintgens, 2004; Wrigley, 1988). Coffee grows in a wide range of ecologies in its original forest habitat. It occurs in the multi-strata of forest ecosystems in the clay-silicaceous soils of granite as it does on soils of volcanic origin or even on alluvial soils (Wrigley, 1988; Paulos, 1994; Malavolta, 2003; Wintgens, 2004). The plantation crops such as tea, coffee, and rubber have different agro-climatic requirements and are cultivated in diverse soil types (Jessy, 2011).

An effective depth of greater than 150 cm enables the coffee plant to exploit a greater volume of soil for nutrients and water. Highly suitable areas are those with high soil organic matter (SOM) (> 3%) content and slightly acidic soils (between pH 5.3 and 6.5) (Paulos, 1994). The bulk of coffee soils in Ethiopia are classified as *Nitosols*, which are highly weathered, originated from volcanic rocks, deep, well drained and have medium to high contents of most of the essential elements, except nitrogen and phosphors (Paulos, 1994).

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The physical environment including the soil is one of the most important factors that influence coffee quality (Wintgens, 2004; Läderach, 2007)). Avelino *et al.* (2005) showed that the quality of Jamaica Blue Mountain coffee and the Kenya AA type coffee share common properties that could be due to favourable influence of altitude and soil. Other studies revealed that volcanic soils often produce pointed acidity, good body, and a balanced cup (Njorge, 1998; Pinkert, 2004; Bertrand *et al.*, 2006).

In Ethiopia, coffee is not only produced in natural forests where it originated but also it is expanding to other regions that experience full sun to partial shade environment. In both major and minor coffee growing regions, the influence of soil properties on coffee quality is not well studied. Taye (2011) conducted research to determine the status of soil nutrient elements, and characterize the soils on which coffee is grown. The metal composition of coffee bean variations due to their differences in geographical origin was also reported (Abera, 2006). Abera (2006) analysed the metal contents (Ca, Cd, Cr, Co, Cu, Fe, K, Mg, Mn, Ni, Pb and Zn) of raw and roasted coffee beans obtained from five different parts of Ethiopia (Wollega, Sidamo, Harar, Bench-Maji and Kaffa zones), and found that the observed the metal concentrations in roasted coffee beans were relatively higher than their corresponding raw coffee samples. Abebe *et al.* (2008) reported inverse relationships between coffee cup quality and soil nitrogen to phosphorus ratio and soil Zn content at Shako. The authors also found direct associations coffee cup quality with soil K, Ca, CEC, pH, and micronutrients at Yayo forest coffees in Ethiopia.

Nevertheless, the associations of soil chemical properties and coffee beans quality of different origins in Ethiopia require further research considering the changing conditions of climate and farming practices. Thus, the objective of this research was to elucidate associations of coffee quality attributes from major and minor coffee growing regions in Ethiopia with soil chemical properties.

## 2. Materials and Methods

### 2.1. Site Selection and Sample Preparation

The study sites were purposely selected considering the natural barriers and/or spatial location and agro climatic situation (Figure1). The study sites included Bebeka, Gemadro, Goma, Gore, Jimma, Lemkefa, (Southwest); Gimbi (West); Yirgacheffe (South); Ankasha, Bure, Mecha, Jabi (Northwest); and Badano, Chiro, Darolabu, Habro, Malkabalo (East) woredas (districts) of coffee growing regions during the 2010/11 harvest season. Soil samples per replication (sub-farm) were collected from three sub-samples from the depth of 0 – 50 cm from the immediate rhizosphere near the coffee trunk, from which ripe coffee cherries were picked up at the same time for studying quality attributes of the coffee beans.

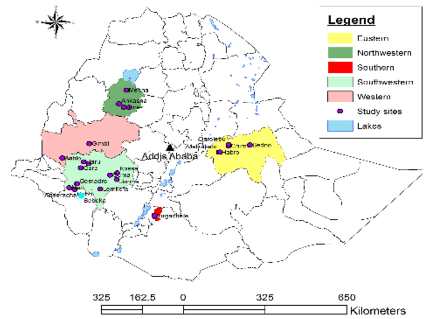


Figure 1. Map of coffee origins from which the green coffee bean and soil samples were collected.

### 2.2. Laboratory Analysis

**Soil sample analysis**: A composite of three soil subsamples was taken per replication. Three replications were considered per site. A total of 53 soil samples (Table 1) were collected for laboratory analysis. The soil samples were air-dried in the laboratory and crushed and sieved through a 2 mm sieve for determining the selected soil chemical properties. Soil pH was determined with 1:2.5 soil: water suspension, and measured with a digital pH metre. Organic Carbon was determined by the potassium dichromate oxidation method (Walkley and Black, 1934). Total nitrogen (TN) was measured using the Kjeldahl method (Jackson, 1958), Available phosphorus was determined by Bray II Method followed by quantification in a UV-vis spectrophotometer (Bray and Kurtz, 1945); andEC was determined on the supernatant obtained from a 1:2.5 (soil: water) suspension using a conductivity bridge at the laboratory of Jimma University College of Agriculture and Veterinary Medicine (JUCAVM). The exchangeable bases (Ca and Mg) were measured by extraction with $NH_4OAC$ followed by quantification using a flame photometer. Exchangeable K was extracted by the sodium acetate method. Exchangeable acidity was extracted with 1M KCl, followed by the quantification of Al and H by titration. Available micronutrients iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) were determined by digesting with nitric-perchloric acid followed by quantification by atomic absorption spectrophotometer. Cation exchange capacity (CEC) was determined by the titration method at Wolkitie Soil Testing and Soil Fertility Improvement Centre.

**Coffee quality analysis:** Fifty-one coffee samples (Table 2) were carefully prepared by the dry processing method, and handed over to ECX (100 g), Jimma Centre and Efico (50 g) in Belgium. A panel of 3-4 trained, experienced and internationally certified (Q graders) cuppers took 6 to 8 cc of the brew from 5 cups using soupspoons and forcefully slurped it to spread evenly over the entire surface of the tongue and palate and then expectorated on to the spittoon. Cup cleanness, acidity, body, and flavour were evaluated as per the standard method. Finally, the preliminary grade assessment was made based on the scores of the raw and cup quality analyses (ECX, 2009).With regard to specialty assessment by Efico, aroma, acidity, flavour, body, aftertaste, and balance attributes were evaluated. Then, the overall attribute was determined as an average of these six attributes (SCAA, 2009).

**2.3. Statistical Analysis**

One way ANOVA was conducted for both soil and coffee samples. Moreover, Pearson correlation analysis was conducted to determine the associations between soil chemical properties and coffee quality attributes. Regression analysis was also conducted for soil chemical properties and coffee quality attributes using SPSS 16 v2 software (SPSS Inc.2007). In the regression analysis, the soil chemical properties were considered as independent and coffee quality attributes as dependent (response) factors to assess how much of the variation in the coffee quality attributes could be accounted for by the predictors.

## 3. Results

**3.1. Chemical Properties of Soils and Coffee Quality Attributes**

**3.1.1. Chemical Properties of Soils**

Soil chemical properties showed highly significant variations among the study sites (Table 1).Variation in soil properties at natural state is obvious not only at distant sites even in a neighbourhood because of time, soil forming factors, and human manipulation for agriculture (Jenny, 1994). It is reported that soils vary from place to place because the intensity of the factors is different at different locations *(*Anonymous, *n.d.*).

**3.1.2. Coffee Quality Attributes of Different Regions**

Coffee quality attributes including hundred bean weight (HBW), secondary defects, odour, and total points showed significant difference (Table 2A). These attributes dominate the preliminary grade assessment (ECX, 2009). For specialty attributes, bean moisture content and acidity were significantly different and non-significant otherwise (Table 2B). Although the p-value is 0.069 mean separation with Tukey HD showed that coffee samples from Ankasha exceeded as compared to those from Bebeka.

**3.2. Association of Soil Chemical Properties with Coffee Quality Attributes**

Pearson correlation analysis showed positive and significant correlations between soil CEC and coffee acidity, flavour, total point, and perfumed attributes. Positive and significant ($P < 0.05$) correlations were observed between $H^{1+}$ concentration and hundred bean weight (HBW); between soil available Mg content, balance, aftertaste, and overall coffee quality; and between pH and secondary defects. However, negative and significant ($P < 0.05$) correlations were recorded between Cu and HBW; between Zn and odour; and between total N and body. Other chemical soil properties viz. K, Ca, Fe, Mn, P, EC, and soil organic carbon content did not show significant correlations with all coffee quality attributes. Similarly, moisture content, aroma, and fruity quality attributes did not show significant correlations with any of the soil chemical properties (Table 3).

Table 1. Mean values of soil chemical properties of the study sites.

| Farm | No. | **K** (mg/kg) | **CEC** (meq/100g) | **H** (meq/100g) | **Mg** (meq/100g) | **Ca** (meq/100g) | **Fe** (meq/100g) | **Mn** (meq/100g) | **Cu** (meq/100g) | **Zn** (meq/100g) | **P** (ppm) | **N** (%) | **pH** (Water) | **EC** (mS/cm) | **C** (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anderacha | 3 | $17.80^{c}$ | $30.00^{def}$ | $0.97^{bcd}$ | $3.37^{bcde}$ | $27.83^{a}$ | $9.57^{a}$ | $6.37^{k}$ | $2.73^{d}$ | $6.30^{abcd}$ | $1.37^{b}$ | $4.80^{a}$ | $6.37^{abc}$ | $0.02^{c}$ | $3.93^{ab}$ |
| Ankesha | 3 | $12.87^{efg}$ | $31.87^{cde}$ | $0.63^{fgh}$ | $4.23^{ab}$ | $11.00^{fg}$ | $5.73^{abcde}$ | $7.53^{j}$ | $3.17^{c}$ | $4.57^{defg}$ | $0.47^{fg}$ | $2.23^{cdef}$ | $6.00^{bc}$ | $0.02^{c}$ | $2.43^{cd}$ |
| Bebeka | 3 | $11.37^{g}$ | $21.53^{ghi}$ | $0.63^{fgh}$ | $2.13^{efgh}$ | $11.47^{efg}$ | $4.13^{cde}$ | $9.80^{g}$ | $0.53^{i}$ | $5.67^{bcdef}$ | $0.50^{efg}$ | $2.10^{cdefg}$ | $6.00^{bc}$ | $0.03^{c}$ | $2.97^{bcd}$ |
| Badano | 3 | $16.03^{d}$ | $38.57^{abc}$ | $0.23^{j}$ | $3.93^{bc}$ | $29.27^{a}$ | $3.90^{cde}$ | $2.33^{o}$ | $2.27^{e}$ | $4.50^{defgh}$ | $0.70^{de}$ | $1.87^{defg}$ | $6.93^{abc}$ | $0.03^{c}$ | $2.97^{bcd}$ |
| Bure | 3 | $22.87^{a}$ | $23.00^{fgh}$ | $0.50^{hi}$ | $4.43^{ab}$ | $16.47^{cd}$ | $6.03^{abcde}$ | $13.90^{c}$ | $3.50^{b}$ | $7.83^{a}$ | $0.63^{def}$ | $2.37^{cdef}$ | $6.40^{abc}$ | $0.03^{c}$ | $3.10^{bc}$ |
| Chiro | 3 | $11.70^{g}$ | $39.93^{ab}$ | $0.57^{fgh}$ | $4.53^{ab}$ | $13.93^{def}$ | $2.97^{e}$ | $2.90^{n}$ | $1.93^{f}$ | $3.90^{fghi}$ | $2.80^{a}$ | $1.60^{defg}$ | $6.37^{abc}$ | $0.03^{c}$ | $3.13^{abc}$ |
| Darolebu | 3 | $14.20^{e}$ | $35.87^{bcd}$ | $0.33^{ij}$ | $3.63^{bcd}$ | $13.10^{efg}$ | $3.47^{de}$ | $2.53^{no}$ | $1.57^{g}$ | $4.43^{efgh}$ | $0.57^{defg}$ | $3.03^{bc}$ | $6.60^{abc}$ | $0.04^{c}$ | $1.83^{d}$ |
| Gemadro | 3 | $9.63^{hi}$ | $14.13^{ij}$ | $0.90^{cde}$ | $0.87^{h}$ | $3.63^{h}$ | $5.50^{abcde}$ | $1.77^{p}$ | $0.90^{h}$ | $2.50^{i}$ | $0.53^{efg}$ | $3.77^{b}$ | $6.53^{abc}$ | $0.04^{c}$ | $3.27^{abc}$ |
| Gimbi | 3 | $13.40^{ef}$ | $25.13^{efg}$ | $1.17^{b}$ | $1.93^{fgh}$ | $4.23^{h}$ | $3.70^{cde}$ | $3.50^{lm}$ | $0.50^{i}$ | $2.87^{ghi}$ | $0.47^{fg}$ | $1.50^{efg}$ | $6.27^{abc}$ | $0.04^{c}$ | $3.10^{bc}$ |
| Goma | 3 | $21.67^{a}$ | $27.47^{efg}$ | $1.07^{bc}$ | $2.70^{cdef}$ | $17.77^{bc}$ | $7.33^{abcd}$ | $14.67^{b}$ | $0.43^{i}$ | $6.73^{ab}$ | $0.93^{c}$ | $2.23^{cdef}$ | $5.87^{c}$ | $0.05^{c}$ | $4.30^{a}$ |
| Gore | 3 | $8.17^{i}$ | $27.57^{efg}$ | $2.33^{a}$ | $1.23^{gh}$ | $6.33^{h}$ | $3.80^{cde}$ | $9.07^{i}$ | $0.43^{i}$ | $2.70^{hi}$ | $0.53^{efg}$ | $2.23^{cdef}$ | $6.30^{abc}$ | $0.05^{c}$ | $3.97^{ab}$ |
| Habro | 3 | $19.73^{b}$ | $30.70^{de}$ | $0.73^{efg}$ | $2.43^{defg}$ | $10.30^{g}$ | $4.70^{bcde}$ | $3.80^{l}$ | $0.97^{h}$ | $5.70^{bcdef}$ | $0.57^{defg}$ | $2.43^{cde}$ | $7.00^{ab}$ | $0.05^{c}$ | $2.33^{cd}$ |
| Jabi | 3 | $12.10^{fg}$ | $31.37^{cde}$ | $0.67^{fgh}$ | $5.47^{a}$ | $19.87^{b}$ | $4.70^{bcde}$ | $9.07^{h}$ | $2.70^{d}$ | $4.77^{def}$ | $0.50^{efg}$ | $2.57^{cd}$ | $6.53^{abc}$ | $0.05^{c}$ | $2.43^{cd}$ |
| Jimma | 3 | $22.50^{a}$ | $15.70^{hij}$ | $0.57^{fgh}$ | $2.47^{defg}$ | $12.63^{efg}$ | $5.10^{bcde}$ | $11.63^{e}$ | $0.40^{i}$ | $5.43^{bcdef}$ | $0.40^{g}$ | $1.40^{fg}$ | $6.40^{abc}$ | $0.06^{bc}$ | $3.50^{abc}$ |
| Lem | 3 | $9.67^{hi}$ | $28.63^{defg}$ | $0.77^{def}$ | $2.70^{cdef}$ | $13.33^{efg}$ | $7.70^{abc}$ | $16.90^{a}$ | $0.40^{i}$ | $6.67^{abc}$ | $0.40^{g}$ | $2.57^{cd}$ | $6.17^{abc}$ | $0.06^{bc}$ | $3.93^{ab}$ |
| Mecha | 3 | $16.47^{cd}$ | $45.85^{a}$ | $0.53^{ghi}$ | $4.63^{ab}$ | $14.17^{de}$ | $6.00^{abcde}$ | $12.77^{d}$ | $3.80^{a}$ | $6.13^{abcde}$ | $0.77^{cd}$ | $2.07^{cdefg}$ | $5.97^{bc}$ | $0.06^{bc}$ | $2.97^{bcd}$ |
| Melkabelo | 2 | $19.80^{b}$ | $38.33^{bc}$ | $0.90^{cde}$ | $4.60^{ab}$ | $20.10^{b}$ | $2.65^{e}$ | $2.90^{n}$ | $2.20^{e}$ | $4.90^{cdef}$ | $0.45^{fg}$ | $2.45^{cde}$ | $7.15^{a}$ | $0.11^{ab}$ | $3.85^{ab}$ |
| Yirgachafe | 3 | $9.83^{h}$ | 11.00 | $0.63^{fgh}$ | $3.37^{bcde}$ | $11.33^{efg}$ | $8.63^{ab}$ | $10.43^{f}$ | $0.40^{i}$ | $5.60^{bcdef}$ | $0.40^{g}$ | $1.13^{g}$ | $6.20^{abc}$ | $0.13^{a}$ | $3.70^{ab}$ |
| P-value | | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.006 | <0.001 | <0.001 |
| Mean | | 14.90 | 28.38 | 0.78 | 3.23 | 14.16 | 5.36 | 7.98 | 1.59 | 5.07 | 0.73 | 2.35 | 6.38 | 0.05 | 3.19 |
| SD | | 4.71 | 9.13 | 0.45 | 1.31 | 6.86 | 2.20 | 4.75 | 1.19 | 1.52 | 0.57 | 0.90 | | 0.03 | 0.73 |
| *CV%* | | 31.63 | 32.18 | 57.92 | 40.42 | 48.47 | 41.08 | 59.56 | 74.81 | 30.06 | 77.98 | 38.13 | 7.08 | 63.50 | 22.83 |

*Note: Means followed by the same letter in the column are not significantly different at P ≤ 0.05*

Table 2. Coffee quality attributes.
A. Preliminary grade attributes.

| Farm | No. | HBW | Preliminary defects | Secondary defects | Odour | Acidity | Body | Flavour | Total points |
|---|---|---|---|---|---|---|---|---|---|
| Bebeka | 3 | 16.04 abc | 15 a | 14 a | 9.33 ab | 11 a | 11 a | 9 a | 84.3 a |
| Anderacha | 3 | 15.39 abc | 15 a | 14 a | 10 a | 10 a | 9 a | 9 a | 82.0 a |
| Gemadro | 3 | 15.02 abc | 15 a | 9 ab | 10 a | 12 a | 10 a | 9 a | 80.0 ab |
| Lem | 3 | 15.64 abc | 9.5 a | 5 b | 10 a | 10 a | 9 a | 9 a | 67.5 b |
| Jimma | 3 | 15.03 abc | 15 a | 9 ab | 10 a | 12 a | 12 a | 11 a | 84.0 a |
| Goma | 3 | 15.44 abc | 15 a | 9 ab | 10 a | 12 a | 10 a | 12 a | 83.0 a |
| Gore | 3 | 18.60 a | 15 a | 14 a | 10 a | 12 a | 11 a | 11 a | 88.0 a |
| Gimbi | 3 | 16.16 abc | 14 a | 10 ab | 10 a | 10 a | 9 a | 10 a | 78.0 ab |
| Yirgachafe | 3 | 14.94 abc | 15 a | 15 a | 10 a | 12 a | 10 a | 10 a | 87.0 a |
| Jabi | 3 | 13.94 bc | 15 a | 15 a | 10 a | 10 a | 9 a | 10 a | 84.0 a |
| Bure | 3 | 14.71 abc | 15 a | 11 ab | 8.67 b | 12 a | 10 a | 10 a | 81.7 a |
| Ankesha | 3 | 13.57 c | 15 a | 6.5 ab | 10 a | 11 a | 10 a | 12 a | 79.5 ab |
| Mecha | 3 | 13.99 bc | 14 a | 12 ab | 10 a | 11 a | 10 a | 10 a | 82.0 a |
| Chiro | 2 | 17.60 abc | 15 a | 13.5 ab | 10 a | 12 a | 12 a | 12 a | 89.5 a |
| Habro | 3 | 16.59 abc | 15 a | 12 ab | 10 a | 11 a | 10 a | 11 a | 84.0 a |
| Darolebu | 2 | 18.08 ab | 15 a | 15 a | 10 a | 10 a | 10 a | 8 a | 83.0 a |
| Melkabelo | 2 | 16.72 abc | 15 a | 10.5 ab | 10 a | 12 a | 10.5 a | 10.5 a | 83.5 a |
| Badano | 3 | 15.21 abc | 15 a | 14 a | 10 a | 11 a | 10 a | 10 a | 85.0 a |
| P-value | | .003 | .136 | .001 | .022 | .314 | .411 | .133 | .001 |
| mean | | 15.60 | 14.57 | 11.57 | 9.88 | 11.13 | 10.10 | 10.15 | 82.40 |
| sd | | 1.70 | 1.98 | 3.74 | 0.47 | 1.37 | 1.46 | 1.70 | 5.83 |
| CV | | 10.9 | 13.6 | 32.3 | 4.8 | 12.3 | 14.4 | 16.7 | 7.1 |

*Note: Means followed by the same letter in the column are not significantly different at P ≤ 0.05; HBW = Hundred bean weight*

B. Specialty grade attributes.

| Farm | No. | Water content | Aroma | Body | Acidity | Balance | Fruity | Perfumed | Flavour | Aftertaste | Overall | Specialty Grade |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bebeka | 3 | 9.13 c | 4.67 a | 5.00 a | 5.67 ab | 4.17 b | 5.00 a | 3.00 a | 4.00 a | 4.67 a | 4.52 a | 1.67 a |
| Anderacha | 3 | 9.43 bc | 5.00 a | 5.00 a | 5.33 b | 5.00 ab | 3.67 a | 4.17 a | 4.00 a | 5.00 a | 4.65 a | 1.67 a |
| Gemadro | 3 | 9.63 abc | 5.67 a | 5.33 a | 6.33 ab | 5.67 ab | 5.67 a | 5.67 a | 5.67 a | 6.00 a | 5.75 a | 1.00 a |
| Lem | 3 | 9.13 c | 6.00 a | 5.33 a | 7.50 ab | 6.17 ab | 5.33 a | 4.83 a | 5.17 a | 5.83 a | 5.77 a | 1.00 a |
| Jimma | 3 | 9.03 c | 6.33 a | 5.83 a | 8.00 a | 6.17 ab | 6.67 a | 6.00 a | 6.17 a | 6.00 a | 6.40 a | 1.00 a |
| Goma | 3 | 8.53 c | 5.00 a | 5.33 a | 5.67 ab | 5.17 ab | 6.00 a | 4.33 a | 5.17 a | 5.67 a | 5.29 a | 1.33 a |
| Gore | 3 | 8.87 c | 5.67 a | 5.33 a | 6.67 ab | 5.83 ab | 4.67 a | 3.67 a | 3.33 a | 4.67 a | 4.98 a | 2.00 a |
| Gimbi | 3 | 9.57 bc | 6.00 a | 6.00 a | 5.67 ab | 6.00 ab | 6.67 a | 4.67 a | 5.83 a | 6.00 a | 5.85 a | 1.00 a |
| Yirgachafe | 3 | 8.77 c | 5.67 a | 5.67 a | 5.50 b | 5.33 ab | 6.33 a | 5.67 a | 5.67 a | 6.17 a | 5.75 a | 1.67 a |
| Jabi | 3 | 6 a | 6.00 a | 6.33 a | 6.67 ab | 6.17 ab | 3.33 a | 5.00 a | 5.50 a | 6.00 a | 5.63 a | 1.33 a |
| Bure | 3 | 8.83 c | 6.17 a | 6.33 a | 6.50 ab | 5.83 ab | 6.50 a | 6.00 a | 6.00 a | 6.00 a | 6.17 a | 1.00 a |
| Ankesha | 3 | 10.77 ab | 7.33 a | 6.67 a | 7.50 ab | 6.83 a | 4.33 a | 6.67 a | 7.17 a | 7.17 a | 6.71 a | 1.00 a |
| Mecha | 3 | 9.23 c | 5.67 a | 5.83 a | 6.33 ab | 6.00 ab | 6.17 a | 4.33 a | 5.50 a | 6.00 a | 5.73 a | 1.00 a |
| Chiro | 2 | 8.20 c | 6.00 a | 6.50 a | 6.50 ab | 6.00 ab | 7.00 a | 5.50 a | 5.00 a | 6.00 a | 6.06 a | 1.00 a |
| Habro | 3 | 9.30 bc | 5.00 a | 5.00 a | 5.33 b | 5.00 ab | 6.33 a | 4.33 a | 4.00 a | 4.33 a | 4.92 a | 1.33 a |
| Darolabu | 2 | 8.97 c | 6.00 a | 6.50 a | 7.17 ab | 6.00 ab | 5.00 a | 4.17 a | 4.67 a | 5.83 a | 5.67 a | 1.00 a |
| Melkabelo | 2 | 9.00 c | 6.00 a | 6.00 a | 6.50 ab | 6.00 ab | 6.50 a | 6.00 a | 7.00 a | 7.00 a | 6.38 a | 1.00 a |
| Badano | 3 | 9.20 c | 6.50 a | 6.67 a | 7.50 ab | 6.50 ab | 5.67 a | 6.17 a | 6.00 a | 5.83 a | 6.35 a | 1.00 a |
| P-value | | .000 | .305 | .160 | .001 | .069 | .715 | .545 | .275 | .650 | .358 | .477 |
| mean | | 9.29 | 5.81 | 5.80 | 6.46 | 5.76 | 5.56 | 4.98 | 5.30 | 5.76 | 5.68 | 1.24 |
| sd | | 0.79 | 1.02 | 0.89 | 1.04 | 0.91 | 1.99 | 1.75 | 1.62 | 1.31 | 1.02 | 0.55 |
| CV% | | 8.5 | 17.6 | 15.4 | 16.1 | 15.8 | 35.7 | 35.1 | 30.6 | 22.8 | 17.9 | 44.6 |

Note: Means followed by the same letter in the column are not significantly different at $P \leq 0.05$

Table 3. Pearson correlation coefficients (r) between chemical properties of soils and coffee quality attributes.

| | HBW | Secondary defects | Odour | Acidity | Body | Flavour | Total point | MC | Aroma | Balance | Fruity | Perfumed | After taste | Overall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K | -0.06 | -0.03 | -0.06 | -0.01 | 0.22 | 0.06 | 0.09 | -0.10 | -0.05 | -0.02 | 0.13 | 0.07 | 0.08 | 0.06 |
| CEC | -0.05 | 0.08 | 0.13 | 0.32* | 0.22 | 0.34* | 0.36** | 0.04 | 0.13 | 0.03 | 0.12 | 0.29* | 0.18 | 0.18 |
| H | 0.35 | 0.05 | 0.01 | 0.03 | 0.09 | 0.09 | 0.12 | -0.06 | -0.06 | -0.07 | -0.09 | -0.10 | -0.07 | -0.14 |
| Mg | -0.17 | 0.09 | -0.05 | 0.06 | 0.10 | 0.20 | 0.15 | 0.14 | 0.27 | 0.32* | -0.03 | 0.26 | 0.28* | 0.28* |
| Ca | -0.20 | 0.05 | 0.02 | -0.06 | -0.01 | 0.02 | 0.02 | 0.03 | -0.01 | 0.04 | -0.12 | -0.01 | -0.05 | -0.02 |
| Fe | -0.26 | -0.15 | 0.00 | -0.02 | -0.26 | -0.08 | -0.27 | -0.04 | -0.09 | -0.12 | -0.02 | 0.07 | 0.03 | -0.06 |
| Mn | -0.18 | -0.21 | -0.27 | 0.13 | -0.11 | 0.03 | -0.25 | -0.13 | -0.03 | -0.03 | 0.10 | -0.06 | -0.02 | -0.01 |
| Cu | -0.35* | 0.05 | -0.08 | -0.01 | -0.22 | -0.14 | -0.02 | 0.22 | 0.17 | 0.23 | -0.12 | 0.10 | 0.11 | 0.15 |
| Zn | -0.21 | -0.05 | -0.40** | 0.15 | -0.13 | 0.02 | -0.06 | -0.11 | 0.04 | 0.00 | 0.16 | 0.16 | 0.18 | 0.15 |
| P | 0.21 | 0.17 | 0.03 | 0.04 | -0.01 | 0.07 | 0.16 | -0.14 | -0.12 | -0.07 | 0.02 | -0.02 | 0.02 | -0.07 |
| N | 0.04 | -0.02 | 0.08 | -0.14 | -0.40** | -0.22 | -0.19 | 0.11 | -0.14 | -0.14 | -0.22 | -0.11 | -0.06 | -0.19 |
| pH | 0.15 | 0.3* | 0.05 | -0.08 | 0.05 | -0.10 | 0.24 | 0.00 | 0.11 | 0.06 | 0.01 | 0.17 | 0.10 | 0.11 |
| EC | 0.17 | 0.12 | -0.03 | 0.00 | 0.20 | -0.25 | 0.06 | -0.18 | -0.04 | 0.01 | 0.05 | 0.01 | 0.05 | 0.03 |
| %OC | 0.03 | -0.24 | 0.03 | 0.23 | 0.12 | 0.19 | -0.02 | -0.19 | -0.07 | -0.12 | 0.04 | -0.04 | -0.08 | -0.08 |

Note: * and **, significant at $P < 0.05$ and 0.01, respectively; HBW = hundred bean weight (g); MC = green coffee bean moisture content (%), K =available potassium, CEC= cation exchange capacity, Mg = magnesium, Ca =calcium, Fe =iron, Mn = manganese, Cu =copper, Zn =zinc, P =available phosphorus, N = total nitrogen, pH =soil acidity, EC =electrical conductivity, %OC =percent organic carbon.

**Preliminary coffee quality attributes**: The preliminary grade assessment was made based on the scores of the raw and cup quality analyses of the arrivals in this case of the supplied samples (ECX, 2009). The results of the regression analysis revealed that the variation in hundred beans weight was accounted for/expressed 12, 18.5 and 26.7% by Cu, P and Fe, respectively, while 30.2 and 33.8% was by EC, and H, respectively. Soil pH accounted for 8.5% of the variation in secondary defect. Zinc (Zn) and Fe accounted for 16.1 and 20.3% of the variation in odour, respectively. Regarding the acidity and perfumed attributes, CEC accounted for 8.6 and 8.0% of the variations, respectively. Total N and EC accounted for 16.2 and 25.2%, while K, CEC and Cu accounted for 30.5, 35.1 and 38.6% of the variation in body, respectively. The coffee flavour variation was accounted for by CEC, EC, Mg, and Cu by about 10.7, 15.5, 21.1 and 25%, respectively. Soil magnesium (Mg) accounted for 7.5, 9.6 and 7.7% of the variation in coffee aroma, balance, and overall attributes, respectively. For the total point attribute, which is the basis for the final grading, 13 and 21.9% of the variation was accounted for by soil CEC and available soil iron (Fe), respectively (Table 4).

**Specialty coffee quality attributes:** Specialty analysis was conducted using the same samples that scored a preliminary grade of 1, 2, and 3. Specialty assessment was made by Efico, based on aroma, acidity, flavour, body, aftertaste, and balance attributes. Then, the overall score was calculated as an average of these six attributes (SCAA, 2009). Copper (Cu) and EC accounted for 4.94 and 4.19% of the variation in moisture content of the green coffee beans, respectively. The variations in coffee aroma, balance, overall, and aftertaste were contributed by Mg to the extent of 7.48, 9.63, 7.67, and 7.44%, respectively. Moreover, 5.36% of the variation in coffee aftertaste was contributed by soil Ca. The variations in fruity and perfumed attributes of 4.7 and 7.98% were accounted for by total N and CEC, respectively (Table 2).

Table 4. Regression coefficients ($R^2$) between soil chemical properties and coffee quality attributes.

| Quality attributes | Variable | Partial R2 | Model R2 | C(p) | F-Value | Pr > F |
|---|---|---|---|---|---|---|
| Hundred bean weight (g) | Cu | 0.1197 | 0.1197 | 3.0481 | 6.66 | 0.0129 |
| | P | 0.0650 | 0.1847 | 1.3504 | 1.3504 | 0.0562 |
| | Fe | 0.0818 | 0.2665 | -1.2987 | -1.2987 | 0.0266 |
| | EC | 0.0356 | 0.3021 | -1.3199 | -1.3199 | 0.1327 |
| | H | 0.0356 | 0.3376 | -1.3426 | -1.3426 | 0.1270 |
| Secondary defect | pH | 0.0850 | 0.0850 | -2.4751 | 4.55 | 0.0379 |
| Odour | Zn | 0.1606 | 0.1606 | -6.1563 | 9.38 | 0.0036 |
| | Fe | 0.0420 | 0.2027 | -6.2014 | 2.53 | 0.1183 |
| Acidity | CEC | 0.0863 | 0.0863 | -1.3228 | 4.63 | 0.0364 |
| Body | N | 0.1617 | 0.1617 | 8.6517 | 9.45 | 0.0034 |
| | EC | 0.0901 | 0.2518 | 4.6694 | 5.78 | 0.0201 |
| | K | 0.0533 | 0.3051 | 3.1318 | 3.60 | 0.0638 |
| | CEC | 0.0460 | 0.3511 | 2.0776 | 3.26 | 0.0775 |
| | Cu | 0.0345 | 0.3856 | 1.7879 | 2.53 | 0.1190 |
| Flavor | CEC | 0.1071 | 0.1071 | 3.6314 | 5.88 | 0.0190 |
| | EC | 0.0481 | 0.1552 | 2.9066 | 2.73 | 0.1050 |
| | Mg | 0.0556 | 0.2108 | 1.7545 | 3.31 | 0.0752 |
| | Cu | 0.0394 | 0.2502 | 1.5212 | 2.42 | 0.1269 |
| Total points | CEC | 0.1303 | 0.1303 | 1.9497 | 7.34 | 0.0093 |
| | Fe | 0.0888 | 0.2191 | -1.0457 | 5.46 | 0.0237 |
| Moisture content (%) | Cu | 0.0494 | 0.0494 | -0.5066 | 2.54 | 0.1171 |
| | EC | 0.0419 | 0.0913 | -0.5578 | 2.22 | 0.1432 |
| Aroma | Mg | 0.0748 | 0.0748 | -4.2584 | 3.96 | 0.0522 |
| Balance | Mg | 0.0963 | 0.0963 | -5.7675 | 5.22 | 0.0267 |
| Fruity | N | 0.0468 | 0.0468 | -2.1582 | 2.40 | 0.1274 |
| Perfumed | CEC | 0.0798 | 0.0798 | 0.8768 | 4.25 | 0.0446 |
| Aftertaste | Mg | 0.0744 | 0.0744 | -2.4590 | 3.94 | 0.0528 |
| | Ca | 0.0536 | 0.1280 | -3.0370 | 2.95 | 0.0924 |
| Overall | Mg | 0.0767 | 0.0767 | -2.5639 | 4.07 | 0.0491 |

## 4. Discussion

The coffee quality attributes increased with increase in the levels of soil CEC, Mg, H1+, and pH, while decreasing with the increase in the levels of soil Cu, Zn and total N. Consistent with the results of this study, the best soils of good quality coffee are lava, volcanic ash soils, basic rocks and alluvial deposits that exhibit a high cation-exchange capacity and a favourable soil organic matter status (Anonymous, n.d). Soils with a high percentage of organic material are more fertile, less liable to erosion and have a better water and nutrient retention capacity (Mitchell, 1988). The acidity level of the soil is also reported to produce a good quality coffee (Avelino et al., 2005).

The finding of this research particularly related to the associations of soil N and Mg with coffee quality is in agreement with the report of Yara (2010), who reported that increased level of soil Mg improved coffee quality while increased levels of soil N decreased it. The study further revealed that flowering and berry set were favoured by soil N, P, S, B and Zn. Bean size was favoured by soil N, P, B and Z while yield was improved by N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn. Soil N was helpful for disease tolerance. Caffeine content increased with increase in soil Mg and S levels (Yara, 2010).

The results of this study are in agreement with the findings of Abebe et al. (2008) who reported that CEC and pH had positive correlation with coffee quality at Yayo and Shako (both Southwest Ethiopia). However, contrasting the results of this study, Abebe et al. (2008) found positive associations between soil N and Zn and coffee quality. On the other hand, the results of this study showed no associations between soil available P, K, and Ca contents and coffee quality attributes, which is in contrast to the findings of the above-mentioned author, who reported positive associations between these nutrients in the soil and coffee quality attributes. Available soil magnesium, calcium, nitrogen, phosphorus, and soil pH were negatively associated with coffee quality attributes (Mekonen 2009), which is inconsistent with the results of this study. The contrasts between certain results of this study and that of the other authors may be ascribed to environmental and climatic factors as well as the coffee processing methods employed during the study. However, it was reported that soil properties are problematic to map for a number of reasons (Läderach, 2007). Thus, soil characteristics maps do not exist at a large scale for the study areas.

The observed wide variations in the soil chemical properties of the five different coffee growing regions could be ascribed to the variability in the parent material and the climatic factors that affect soil formation. Accordingly, warmer and wetter south and south-western and northern regions have generally acidic soils whilst the cooler and drier eastern region has neutral to alkaline soils. Similarly, that nutrient and soil organic matter contents varied across the regions as well as districts within the regions could be attributed to differences in the soil forming processes as well as the variations in anthropogenic activities (Jonasson, 1933; Sylvain, 1955). As reported by Oberthür et al. (n.d.), accurate information on the location and associated environmental conditions is needed for improved quality, traceability and transparency with respect to both origin and production processes. Readily available descriptions of coffee growing areas have until now been generalized over a wide range of sites and with only a limited number of descriptors. Soil is usually quoted as a basic factor impacting on coffee quality (Cofenac, 2003; Illy, 2001). It is generally accepted that volcanic soils produce the best quality coffee especially with regard to the attributes of acidity and body (Griffin, 2001). Illy (2001) quotes that micronutrients frequently show a non-linear correlation between their concentration in the soil and cup quality. Another study (Foote, 1963 cited by Läderach (2007)) has shown that nutrient deficiencies may decrease cup flavour. On the other hand, there is a very clear and positive link between gustative qualities and low soil fertility (Pochet, 1990). Griffin (2001) states that potassium also augments the body of a coffee and increases the weight of the bean. Avelino et al. (2002) showed that low contents of calcium affect coffee quality, Cofenac (2003) states that magnesium content favours the characteristics of aroma and flavour. Cofenac (2003) also showed that high contents of nitrogen and iron in coffee soils contribute directly to improved acidity of the brew. Avelino et al. (2002) found that excess aluminium affects coffee quality negatively, while Cofenac (2003) states that high contents of copper negatively affects aroma, flavour and body characteristics.

## 5. Conclusion

This study has demonstrated that soil chemical properties have both negative and positive associations with coffee quality attributes. The correlation analysis signified that factors that lead to increased soil CEC, available magnesium, exchangeable acidity, and soil pH may lead to enhanced coffee quality attributes whereas factors that lead to enhanced contents of available copper, zinc, and total nitrogen in the soil may reduce coffee quality attributes. The regression analysis further indicated that increased soil CEC and available iron (Fe) content had a direct positive influence on the overall coffee quality attributes, which is the basis for the final grading of coffee beans. It could, thus, be concluded that increasing the cation exchange capacity of and available iron content of soils leads to significantly enhanced overall coffee quality attributes and consumer preferences. Therefore, it may be tentatively recommended that coffee farmers in Ethiopia should particularly improve the soil towards enhanced cation exchange capacity and available iron content to improve quality attributes of coffee beans. However, the results of this study need to be verified by repeating the experiment by involving additional soil chemical properties and weather variables as well as farm management practices.

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# Genotype x Environment Interactions for Seed Yield in Sesame in Western Ethiopia

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**Abstract:** As sesame is a short day plant and sensitive to light, heat, and moisture stress the yield is not stable. The selection of stable genotypes that interact less with the varying environment in which they are to be grown is required. The extent of genotype by environment interaction indicates the likelihood of adaptation of a given genotype to a particular agro-ecology and helps to design a breeding strategy for developing varieties suitable for cultivation in a target area. The objective of the study was to assess the significance and magnitude of GEI effect on sesame seed yield and to evaluate the efficiency of the combined use of AMMI and GGE techniques to study GEI. The treatment consisted of ten sesame genotypes grown in four locations (Angar, Uke, Wama and Bako) in western Ethiopia during the 2011 and 2012 main cropping seasons (June to October). The experiment was laid out as a randomized complete block design with three replications. The seed yield data were analysed using additive main effects and multiplicative interaction (AMMI) and the genotype and genotype x environment interaction effect (GGE) biplot. The AMMI analysis showed that environment, genotype, and genotype by environment interaction significantly ($P \leq 0.01$) influenced seed yield. Both AMMI stability value and the GGE–biplot indicated that EW002 (G1) and BG006 (G2) were the most stable genotypes with high seed yields. The result showed that Uke could be used as the best test location for sesame yield trial in the future. The GGE-biplot model showed that eight environments used for the study belong to three different environments. Four genotypes viz. EW002 (G1), BG006 (G2), Obsa (G8) and Dicho (G9) were identified as desirable. In conclusion, the results of the study revealed that EW002 and BG006 are the best genotypes for high seed yield and stability, and could be recommended for production in western Ethiopia. Both AMMI and GGE-biplot produced similar results, suggesting that either of the two can be used at a time.

**Keywords:** AMMI; GGE-biplot; Seed yield; *Sesamum indicum* L. Stability; Test environment

## 1. Introduction

Genotype by environmental interaction (GEI) is generally considered a hindrance to crop improvement in most cases (Kang, 1998). It may also, however, offer an opportunity for selecting and using genotypes that show positive interactions with locations and the prevailing environmental conditions (exploiting specific adaptability or yield stability) (Ceccarel1, 1996; Annicchiarico, 2002). Evaluation of genotypic performances at a number of environments provides useful information on genotypic adaptation and stability (Crossa, 1990; Ceccarell, 1996). Such a strategy provides the means for exploitation of GEI as an advantage rather than considering it as a hindrance to crop variety development.

Analysing the magnitude of GEI by proper techniques rather than neglecting them is useful for exploiting the opportunities and or limiting the disadvantages that these effects may cause. Several statistical models have been proposed for studying the GEI effect and exploiting its advantage. The two frequently used statistical analyses are the additive main effects and multiplicative interaction (AMMI) model, the genotype main effect, and the genotype x environment interaction effect (GGE) model (Gauch, 2006).

AMMI model combines the analysis of variance, geno type and environment main effects with principal component analysis of GEI into a unified approach (Gauch and Zobel, 1996). However, the GGE biplot method, which is always close to the best AMMI model in most cases (Ma *et al.* 2004), was developed to use some of the functions of these methods jointly. Purchase *et al.* (2000) developed a quantitative stability value known as the AMMI stability value (ASV) to rank genotypes through the AMMI model. The developed ASV was considered to be the most appropriate single method to describe the stability of genotypes. Gruneberg *et al.* (2005) showed that AMMI, as a multivariate tool was highly effective for the analysis of multi-environment trials (MET).

The GGE- methodology, which is composed of two concepts- the biplot concept (Gabriel, 1971) and the GGE concept (Yan *et al.*, 2000) was used to visually analyse the multi-environment yield trial (MEYTs) data. The GGE concept is based on the understanding of genotype by environment interaction (GE) and genotype (G) and they are the two sources of variation that are relevant to genotype evaluation and that they must be considered simultaneously (Yan, 2002).

The GGE-biplot model provides breeders with a more complete and visual evaluation of all aspects of the data

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by creating a biplot that simultaneously represents mean performance and stability as well as identifying mega environments (Yan and Kang, 2003; Ding *et al.,* 2007). The difference of AMMI from GGE is that GGE-biplot analysis is based on environment centered PCA whereas AMMI analysis is based on double centered PCA. For the research purpose of gaining accuracy AMMI and GGE are still equally useful (Gauch *et al.,* 2008).

Sesame (*Sesamum indicum* L.) is an indigenous crop widely produced in the lowlands receiving high rainfall in western Ethiopia. Breeding sesame to develop high-yielding varieties for the western part of the country was started in 2005. As a result, two varieties were officially released in 2010 for the area and some advanced breeding lines were identified (Dagnachew *et al*., 2011). As sesame is a short day plant and sensitive to light, heat, and moisture stress the yield is not stable (Mohammed, 2015). The information on GEI is required to recommend released varieties and select elite breeding lines. However, this type of genetic information is lacking for sesame varieties recommended or being cultivated in western Ethiopia.

Seed yield of sesame can vary considerably between genotypes and seasons due to GEI (Suvarna *et al*., 2011). Hagos and Fetien (2011) reported that 13 sesame genotypes grown at different sites in the northwestern Ethiopia showed significant genotype by location interactions for seed yield. A study conducted to assess the oil contents of 20 sesame varieties for stability and adaptation at six locations in southern Ethiopia indicated highly significant GEI (Zenebe and Hussein, 2011). Several studies were carried out on GEI on sesame by Bo-Shim *et al.* (2003), Kumaresan and Nadarajan (2010), Ahmed and Ahmed (2012), and Mirza *et al.* (2013), who reported highly significant genotypes, environment, and GEI for seed yields of sesame genotypes.

A crop variety is best if it has a high mean yield and a consistent performance when grown across diverse locations and years (Gauch *et al*., 2008). Plant breeders usually evaluate a series of genotypes across environments before a new improved genotype is released for production (Naghavi *et al*., 2010). Therefore, identification of genotypes that perform consistently better across environments should be emphasized (Annicchiarico, 2009). Studying the underlying factors of the GEI effect and quantifying unexplained variations are of prime importance for selection and recommendation of environmentally stable crop varieties (Signor *et al*., 2001). Therefore, this research was conducted to assess significance and magnitude of genotype x environment interaction effects on seed yield of sesame and to evaluate the efficiency of the combined use of AMMI and GGE techniques to study GEI.

## 2. Materials and Methods

### 2.1. Experimental Locations

Ten sesame genotypes were grown in four locations in 2011 and 2012 crop seasons (Table 1). The four locations, namely, Anger, Uke. Wama, and Bako, represent major sesame growing agro-ecologies for sesame production in western Ethiopia. Two of the locations, namely Angar and Uke are found 50 km apart in Angar and Didessa valleys. Wama is found in the valley of Wama while Bako is found in the basin of Gibe. The four locations are also used as testing sites for sesame breeding by Agricultural Research Center. The environments were given codes for ease of data handling and analysis. Years were considered as environments.

### 2.2. Planting Material

The planting material consisted of ten sesame genotypes. The genotypes comprised two released sesame varieties for western Ethiopia, seven advanced breeding lines, and a local check (Table 2). They were selected based on their high yield, good agronomic characters and disease resistance in western Ethiopia. All genotypes have determinate growth habit with a white seed color. The genotypes were also given codes for data analysis (Table 3).

### 2.3. Treatments and Experimental Design

The treatments consisted of ten sesame genotype (EW002s, BG006, EW023-2, EW003-1, EW0011-4, EW008-1, EW011-2, Obsa, Dicho, and Wama) (Table 1). The genotypes were planted from June 13 to 16 each year at each location. The experiment was laid out as a randomized complete block design with three replications. The seed was drilled in each row at seeding rate of 5 kg ha$^{-1}$ in plot consisting of 6 rows of 5 meter length each with the spacing of 40 cm.

### 2.4. Experimental Procedure

First plowing was done by tractor in May 12 to 17 each year at all locations. At planting the land was prepared manually. Sowing was done at all locations on June 13 to 16 both years. Nitrogen fertilizer in the form of urea was applied at the rate of 46 kg N ha$^{-1}$ at planting. Twenty days after planting, thinning was done to 10 cm spacing between plants. Hand weeding was done four times at a fortnightly interval starting 15 days after planting. The genotypes were harvested on October 14 to 18 each year. Seed yield per plot of the middle four rows were taken and reported in kg ha$^{-1}$.

### 2.5. Data Analysis

The AMMI model, which combines the standard analysis of variance with principal component analysis (Zobel *et al*., 1988), was used to estimate the magnitude of G x E interaction. Bartlett's test (Steel and Torrie, 1980) indicated heterogeneity error variance for the trait seed yield in each of the four locations for two years and then the data log transformed to proceed further for pooled analysis. The AMMI analysis and the IPCA were performed using Agro base 20. The AMMI's stability value (ASV) was calculated to rank genotypes in terms of yield stability using the formula suggested by Purchase *et al.* (2000) as shown below.

AMMI Stability Value:

$$(ASV) = \sqrt{\left[\frac{SSIPCA1}{SSIPC2} IPCA1score\right]^2 + (IPCA2\ score)^2}$$

*Where: SS= sum of squares, IPCA1= Interaction principal component analysis axis one, IPCA2= Interaction principal component analysis axis two.*

In general, an absolute stability value (ASV) was determined using a procedure that combines IPCA1 and IPCA 2. The GGE-biplot shows the first two principal components (PC1 and PC2, also referred to as primary and secondary effects, respectively) derived from subjecting environmental centered yield data (yield variation due to GGE) to singular value decomposition (Yan *et al.*, 2000).

For raw data of seed yield biplots of the first two principal components were constructed using Genstat 15th edition and used to illustrate the relation among genotypes, environments and between the genotypes and environments.

In the present study, genotype-focused scaling was used to compare genotypes, while environment focused, scaling was used to compare environments. Furthermore, symmetric scaling was preferred in visualizing the which–won-where pattern of the multi-environment trial yield data (Yan, 2002).

Table 1. Description of four locations used for evaluation of sesame genotypes.

| Location | Soil type | Temperature(mean) | Rainfall (mm) | Latitude | Longitude | Altitude m.a.s.l. |
|---|---|---|---|---|---|---|
| Angar | Humic nitosol | 22$^0$C | 1699 | 09$^0$ 32'N | 0360 37'E | 1355 |
| Uke | Humic nitosol | 22 $^0$C | 1730 | 09$^0$ 22'N | 0360 31'E | 1383 |
| Wama | Vertisol | 21 $^0$C | 1680 | 08$^0$ 58'N | 0360 48'E | 1436 |
| Bako | Humic nitosol | 20 $^0$C | 1465 | 09$^0$ 04'N | 0370 02'E | 1597 |

*Note: Agro climatology and Geospatial Research Division, EIAR, 2016' m.a.s,l = Metres above sea level.*

Table 2. Description of 10 sesame genotypes evaluated in four locations during the 2011 and 2012 cropping season.

| Entry | Genotype | Category | DM | PH | BP | YP |
|---|---|---|---|---|---|---|
| 1 | EW002 | Elite breeding line | 124 | 140 | 9 | 17 |
| 2 | BG006 | Elite breeding line | 123 | 138 | 7 | 16 |
| 3 | EW023 -2 | Elite breeding line | 125 | 142 | 5 | 12 |
| 4 | EW003-1 | Elite breeding line | 122 | 145 | 7 | 17 |
| 5 | EW0011-4 | Elite breeding line | 124 | 140 | 8 | 14 |
| 6 | EW008-1 | Elite breeding line | 121 | 137 | 7 | 16 |
| 7 | EW011-2 | Elite breeding line | 124 | 139 | 7 | 16 |
| 8 | Obsa | Released in 2010 | 119 | 135 | 7 | 14 |
| 9 | Dicho | Released in 2010 | 120 | 140 | 8 | 16 |
| 10 | Wama | Local (farmers' cultivar) | 121 | 137 | 6 | 15 |

*Note: DM = days to maturity, PH = plant height (cm), branches per plant and YP = yield per plant.*

Table 3. Genotypes and environments and their codes

| No | Genotype | Genotype code | No | Environments | Env. code |
|---|---|---|---|---|---|
| 1 | EW002 | G1 | 1 | Angar 2011 | E1 |
| 2 | BG006 | G2 | 2 | Uke 2011 | E2 |
| 3 | EW023- 2 | G3 | 3 | Wama 2011 | E3 |
| 4 | EW003-1 | G4 | 4 | Bako 2011 | E4 |
| 5 | EW0011-4 | G5 | 5 | Angar 2012 | E5 |
| 6 | EW008-1 | G6 | 6 | Uke 2012 | E6 |
| 7 | EW011-2 | G7 | 7 | Wama 2012 | E7 |
| 8 | Obsa | G8 | 8 | Bako 2012 | E8 |
| 9 | Dicho | G9 | | | |
| 10 | Wama | G10 | | | |

## 3. Results and Discussion

### 3.1. AMMI Analysis

The AMMI analyses of variance showed that seed yield was significantly ($P \leq 0.01$) influenced by environment, genotype, and genotype-environment interaction (GEI) (Table 4). The significant effect of GEI on seed yield implied differential responses of the genotypes across the environments. This suggestion is consistent with that of Primomo *et al.* (2002) who found similar results in soybean. Significant GEI complicates selection since the variety with the highest mean yield may not be the best genetically (Signor *et al.*, 2001).

In the present study, GEI, environment and genotype explained 45.11%, 38.64%, and 16.25% of the total variation, respectively (Table 4). The magnitude of GEI sum of squares was close to two-third of the variation due to genotype as a main effect, indicating that there were differences in genotypic responses across the environments. This is in agreement with the results of Yan and Kang (2003), who indicated that large GEI, relative to genotype effect suggests the possible existence of different mega-environments with different top-yielding genotypes. It was reported that multi-environment trial data may constitute a mixture of crossover and non-crossover types of GEI. Crossover type of GEI indicates change in the yield ranking of genotypes across environments and the non-crossover types of GEI shows a constant yield ranking of genotypes across environments (Yan and Hunt, 2001; Matus-Cadiz *et al*., 2003). According to Gauch and Zobel (1996, 1997), in normal multi-environment yield trials, environment accounts for about 80% of the total variation, while G and GEI each accounts for about 10%, which is in contrast to the results of the present study (Table 4).

The AMMI analysis partitioned the sum of squares of GEI into seven interaction principal component axes (IPCA), of which the first five IPCA were significant (Table 4). The results from the AMMI model showed that, the first IPCA captured 42.26% of the interaction sum of squares. Similarly, the second and the third (IPCA2 and IPCA3) explained 30.36% and 16.19% of the GEI sum of squares, respectively. The sum of squares for the first five IPCAs cumulatively contributed to 98.50 % of the total GEI. In this line, Zobel *et al.* (1988) proposed that two interaction principal component axes for AMMI model were sufficient for a predictive model. Other interaction principal component axes captured were mostly non-predictive random variation and did not fit to predict validation observations. Therefore, in general, the model chosen by predictive criterion consists of two IPCA (Kaya *et al*., 2002).

Table 4. Analysis of variance (ANOVA) for seed yield (2011 and 2012).

| Sources | DF | SS | MS | Total variation explained (%) | (%) G x E Explained | Cumulative (%) |
|---|---|---|---|---|---|---|
| Total | 239 | 6.835 | | | | |
| Environments | 7 | 2.355 | 0.336*** | 38.64 | | |
| Reps within Env. | 16 | 0.268 | 0.017 | | | |
| Genotypes | 9 | 0.990 | 0.110*** | 16.25 | | |
| Genotype x Env. | 63 | 2.749 | 0.044*** | 45.11 | | |
| IPCA1 | 15 | 1.161 | 0.077*** | | 42.26 | 42.26 |
| IPCA2 | 13 | 0.834 | 0.064*** | | 30.36 | 72.62 |
| IPCA3 | 11 | 0.445 | 0.040*** | | 16.19 | 88.81 |
| IPCA4 | 9 | 0.164 | 0.018*** | | 5.97 | 94.78 |
| IPCA5 | 7 | 0.102 | 0.015*** | | 3.72 | 98.50 |
| IPCA6 | 5 | 0.028 | 0.006 | | 1.02 | 99.52 |
| IPCA7 | 3 | 0.013 | 0.004 | | 0.48 | 100.0 |
| Residual | 144 | 0.473 | 0.003 | | | |

*Note: Grand mean = 2.811; R-squared = 0.9308; C.V. = 2.04%; **P<0.01; *** P<0. 001; IPCA=Interaction principal component axis.*

Purchase (1997) reported that the IPCA scores of genotypes in the AMMI analysis are an indication of the stability of a genotype over environments. The greater the absolute value IPCA scores, the more specifically adapted a genotype is to a particular environment. The more IPCA2 scores approximate to zero, the more stable or adapted the genotype is over all environments sampled (Gauch and Zobel, 1996; Ferney *et al*., 2006).

The genotype G2 (BG006) and G1 (EW002) showed the lowest absolute scores for the IPCA1 and they were the most stable followed by G9 (Dicho) (Table 5). The more the IPCA score approximates to zero in absolute terms, the more stable or adapted the genotype is over all the environments sampled (Alberts, 2004). When IPCA2 was considered, G5 (EW0011-4) was the most stable followed by G8 (Obsa). Stability rank of genotypes varied for IPC1 to IPC2. This means that the two IPCA have different values and meanings. Therefore, the other option is to calculate ASV to get estimated value between IPCA1 and IPCA2 scores as ASV was reported to produce a balance measurement between the two IPCA scores (Purchase, 1997).

In the present study, Genotype G2 (BG006), G5 (EW0011-4) and G1 (EW002) were found to be stable (Table 5). Although EW0011-14 was the second stable genotype for ASV, it was ranked 9$^{th}$ for mean seed yield. As per the value of ASV the most unstable genotypes were G7 (EW011-2), G10 (Wama) and G3 (EW023-2). It is to note that a genotype with low ASV values is considered more stable than a genotype with high ASV (Purchase, 1997).

Table 5. Mean yield (kg ha-1) rank, IPCA1 and 2 scores and ASV sesame genotypes tested across four locations of western Ethiopia in 2011 and 2012.

| No | Genotype | Yield | Rank | IPCA1 | IPCA2 | ASV | Rank |
|---|---|---|---|---|---|---|---|
| 1 | EW002 | 881 | 1 | 0.0281 | -0.2684 | 0.27 | 3 |
| 2 | BG006 | 750 | 3 | -0.002 | -0.0852 | 0.09 | 1 |
| 3 | EW023- 2 | 556 | 10 | -0.3322 | 0.0818 | 0.47 | 8 |
| 4 | EW003 -1 | 735 | 4 | -0.1997 | 0.3797 | 0.47 | 7 |
| 5 | EW0011-4 | 608 | 9 | -0.1219 | 0.0076 | 0.17 | 2 |
| 6 | EW008-1 | 625 | 8 | 0.2112 | 0.3499 | 0.46 | 6 |
| 7 | EW011-2 | 710 | 5 | 0.4572 | 0.1466 | 0.65 | 10 |
| 8 | Obsa | 847 | 2 | -0.2845 | -0.0729 | 0.40 | 5 |
| 9 | Dicho | 704 | 6 | -0.0925 | -0.3056 | 0.33 | 4 |
| 10 | Wama | 646 | 7 | 0.3364 | -0.2335 | 0.52 | 9 |

*Where: IPCA1= Interaction principal component analysis axis one; IPCA2= Interaction principal component analysis axis two; ASV = AMMI stability value.*

Site mean can easily define whether the environment is favorable or not for a crop to perform well. In the present study, the site mean observed ranged from the lowest of 400 (kg ha$^{-1}$) at E4 (Bako) to the highest 888 kg ha$^{-1}$ at E2 (Uke), with a grand mean of 706 kg ha$^{-1}$ (Table 6). Thus, environments E2 (Uke in 2011), E3 (Wama in 2011), E5 (Anger in 2012), E6 (Uke 2012), and E8 (Bako in 2012) were rich; E1 (Anger in 2011) and E7 (Wama in 2012) were moderate; and E4 (Bako in 2011) was poor. G1 (EW002) and G8 (Wama) gave the highest yields across the environments and G2 (BG006), G4 (EW003-1) and G7 (EW011-2) produced above average seed yield. G1 (EW002) ranked first at four environments: at E2 (Uke in 2011), E5 (Anger in 2012), E7 (Wama in 2012 and E8 (Bako in 2012). The other high yielding genotype G8 (Obsa) performed best at the two environments: E4 and E6. This differential yield ranking of the genotypes across the environments revealed that the G x E interaction effect was a crossover type (Yan and Hunt 2001; Matus-Cadiz *et al.,* 2003). Based on the combination of mean seed yield, ASV and IPCA1 values, BG006 (G2) and EW002 (G1) were the two best genotypes.

Table 6. Mean seed yield (kgha$^{-1}$) of 10 sesame genotypes tested in eight environments.

| Genotype | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 | Mean |
|---|---|---|---|---|---|---|---|---|---|
| G1 | 662 | 1185 | 781 | 340 | 963 | 954 | 1038 | 1123 | 881 |
| G2 | 774 | 748 | 695 | 409 | 867 | 721 | 808 | 978 | 750 |
| G3 | 383 | 880 | 533 | 489 | 403 | 651 | 500 | 608 | 556 |
| G4 | 867 | 909 | 690 | 621 | 748 | 727 | 341 | 975 | 735 |
| G5 | 454 | 833 | 643 | 372 | 782 | 591 | 511 | 678 | 608 |
| G6 | 774 | 821 | 714 | 372 | 623 | 817 | 578 | 302 | 625 |
| G7 | 1266 | 808 | 896 | 245 | 784 | 541 | 622 | 514 | 710 |
| G8 | 515 | 892 | 881 | 664 | 899 | 977 | 960 | 983 | 846 |
| G9 | 512 | 964 | 838 | 307 | 552 | 638 | 818 | 1005 | 704 |
| G10 | 691 | 843 | 838 | 184 | 671 | 512 | 802 | 622 | 645 |
| Site mean | *690* | *888* | *751* | *400* | *729* | *713* | *698* | *779* | *706* |

*Where: E1 = Angar 2011; E2 = Uke 2011; E3 = Wama 2011; E4 = Bako 2011; E5 = Angar 2012; E6 = Uke 2012; E7 = Wama 2012 and E8 = Bako 2012.*

### 3.2. GGE-Biplot Analysis

#### 3.2.1. Ranking of Genotypes Based on Yield and Stability

Based on the scores of PC1 and PC2, the sesame genotype in this study area can be divided into three groups (Figure1). The first group included four stable genotypes (G1=EW002; G2=BG006; G8= Obsa; and G9=Dicho) that were high yielding as near zero PC2 scores showed genotypic stability. Group two included two unstable and low yielding genotypes (G3 = EW023-2; and G7 = EW0011-2) and group three consisted of four genotypes (G4 = EW003-1; G5 = EW0011-4, G6 = EW008-1; and G10 = Wama) that were low yielding but stable. A position in either direction away from the biplot origin indicated greater GEI and reducing stability (Yan, 2002). Unlike PC1, PC2 which was related to genotypic stability, divided the genotypes of interest into different groups.

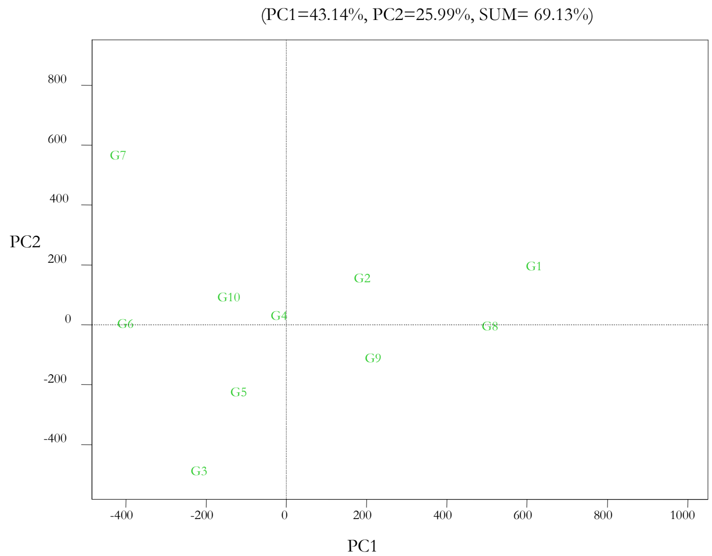


Figure 1. GGE-biplot based on genotype-focused scaling for comparison the genotypes.

GGE-biplot based on genotype focused scaling is shown to detect the locations of genotypes. It has been reported that when PC1 in GGE- biplot approximates the genotype (mean performance), PC2 must approximate the G x E associated with each genotype which is the measure of stability or instability (Yan *et al.*, 2000; Yan, 2002). Kaya *et al.* (2006) reported that the genotypes having PC1 > 0 were recognized as high yielding while those genotypes having PC1 score < 0 were identified as low yielding.

### 3.2.2. Relationships among Test Environments

A GGE-biplot, which was based on environment scaling, is shown to estimate the pattern of environments (Figure 2). Environment PC1 scores were obtained in both positive and negative scores. This case exhibited that PC1 scores present proportional genotypic yield differences across environments which were caused by both crossover and non-crossover GEI. Similar to PC1, PC2 had both positive and negative scores. It gives rise to the crossover GEI, leading to disproportionate genotypic yield differences across environments (Yan *et al.*, 2000). A genotype may, on one hand, have large positive interaction with some environments; it may, on the other hand, have large negative interaction with some other environments.

Favorable test environments should have large PCA1 scores (more discriminating of genotypes) and near zero PC2 scores (more representative of an average environment) (Yan *et al.,* 2001). Test environment with larger vectors like E8 (Bako in 2012), E7 (Wama in 2012) and E5 (Anger 2012) were more discriminating for the genotypes. These environments may be better test environments under limited resources and whenever there is a need to conduct multi-environment yield trials in a limited number of locations.

The correlation coefficients among the eight test environments (locations by year combination) are presented in Table 7. The vector view of the GGE biplot (Figure 2) illustrates a summary of the interrelationship among the environments and base the line that connects the biplot origin and the marker of the test environment are called environment vectors (Yan and Tinker, 2006) . The 28 correlation coefficients were calculated and six of which were found to be significant. Five pairs of the environments were significantly positively correlated because the angles between them were less than $90^0$ (acute angle). On the other hand, E3 and E4 were highly negatively correlated. The presence of strong negative correlation (wide obtuse angle) among locations is an indication of a strong crossover which means genotype by environment interaction (Yan and Tinker, 2006). The angle between the vectors of two environments is related to their correlation coefficient (Kaya, *et al.*, 2006). The cosine of an angle between the vectors of two environments approximate the genetic correlation between them (Kroonenberg, 1995; Yan 2002, 2001) and allows visualization of similarity between environments in ranking genotypes (Yan, 2001). According to the theory, an acute angle indicates a positive correlation, an obtuse angle indicates a negative correlation and a right angle shows existence of no correlation (Yan and Kang, 2003; Yan and Tinker, 2006; Kandus *et al.,* 2010).

Environments E2 and E5, E2 and E4, E2 and E6, E4 and E6, E5 and E6 were similar in their discrimination of the genotypes being significantly positively correlated (Table 7). Such significant correlations among test environments suggest that an indirect selection for seed yield can be practical across the test environments. For instance, the genotype adaptable to or high yielding in the environment E6 may also show a similar response to environments E4 and E5. An indirect selection can be applied in the case where the same character is measured on the same genotypes in different environments. Where there are no correlation error effects among environments, the phenotypic correlation between environments may be used to investigate indirect responses to selection (Cooper and Delacy, 1994).

The presence of close association among test locations suggests that the same information about the genotypes could be obtained from fewer test locations and hence the potential to reduce the testing costs. If two locations are closely correlated consistently across years one of them can be dropped without loss of much information about the genotypes.

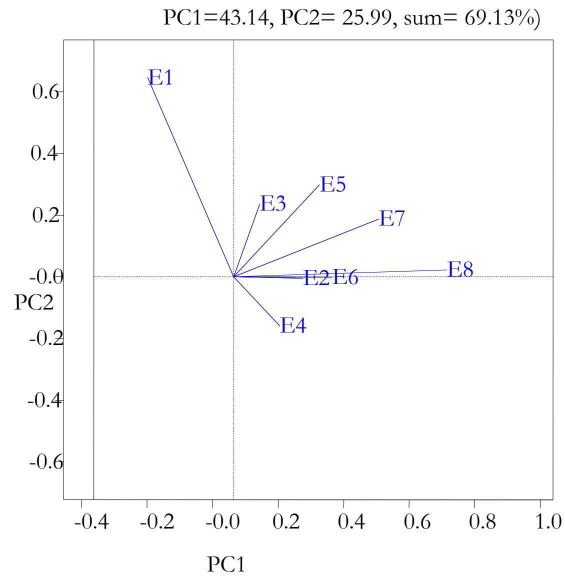


Figure 2. GGE-biplot based on environment-focused scaling for environments. PC and E stand for principal component and the environments, respectively.

Table 7. Correlation coefficient among the eight test environments.

| | E1 | E2 | E3 | E4 | E5 | E6 | E7 |
|---|---|---|---|---|---|---|---|
| E2 | -0.1428 | | | | | | |
| E3 | -0.6659 | -0.4903 | | | | | |
| E4 | 0.4211 | 0.6977* | -0.8784** | | | | |
| E5 | -0.2808 | 0.7003* | -0.1195 | 0.3931 | | | |
| E6 | -0.1428 | 1.0000*** | -0.4903 | 0.6977* | 0.7003* | | |
| E7 | -0.2111 | 0.3936 | 0.2337 | 0.2082 | 0.1593 | 0.3936 | |
| E8 | -0.2905 | 0.1158 | 0.2612 | 0.0594 | 0.2251 | 0.1157 | 0.0865 |

*Where: E1 = Angar 2011; E2 = Uke 2011; E3 = Wama 2011; E4 = Bako 2011; E5 = Angar 2012; E6 = Uke 2012; E7 = Wama 2012 and E8 = Bako 2012; *, ** and *** indicate significance at P < 0.05, P < 0.01 and P < 0.001 respectively*

### 3.2.3. Which–Won–Where Pattern of Genotypes

The genotypes that are located far away from the biplot origin are connected with straight lines, so that a polygon or vertex hull is formed with all other genotypes contained within the vertex hull (Figure 3). The vertex genotypes are G1, G8, G3, G6 and G7. These genotypes are the most responsive; they are either the best or the poorest genotypes in some or all of the environments. The rays are perpendicular lines between adjacent genotypes on the polygon which facilitates a visual comparison among them. For instance, Ray1 is perpendicular to the side that connects genotype G7 and G1; Ray 2 is perpendicular to the side that connects genotype G8 and G3; Ray 3 is perpendicular to the side that connects genotype G3 and G6; Ray 4 is perpendicular to the side that connects genotype G6 and G7.

The “which–won- where” view of the GGE-biplot is an effective visual tool in mega environment analysis (Yan *et al.,* 2007). The visualization of the which–won-where pattern of multi-environment yield trial data is important for studying a possible existence of different mega–environments in a region (Gauch and Zobel 1997; Yan *et al*., 2000, 2001). The four rays divided the biplot into four sectors and the environments fell into three of them (Figure 3). The falling of all environments into a single sector indicates that a single genotype has the highest yield in all environments. The falling of all environments into different sectors means that different genotypes win in different sectors (Yan *et al.,* 2007). The vertex genotypes for each quadrant (sector) are the one that gave the highest yield for the environment that fall within that quadrant (Yan, 2002). G1 and G8 are the vertex genotypes for sector 1 in that they produced the highest yields. The vertex genotype G7 produced the highest yields at E1 and E3 whereas the remaining other two vertex genotypes G6 and G3 produced poor yields in almost all of the environments. Actually, they were the poorest genotypes in some or most of the environments.

Figure 3 biplot analysis suggests 3 mega-environments. The first mega contained five environments viz., E2, E5, E6, E7 and E8 with genotype G1 and G8. The second mega-environment contained only one environment E4 whereas the third mega was with two environments namely E1 and E3. According to the section ‘visual comparison of two genotypes in different environments’ the line perpendicular to the polygon side that connects G7 and G1 facilitates the comparison between G7 and G1, G1 yielded higher than G7 in most of the environments because six environments were on the side of G1. Similarly, the line perpendicular to the polygon side that connects genotypes G8 and G3 facilitates the comparison between G8 and G3; G8 yielded higher than G3 in six environments that fall into the G8 sector because they are on the side of G8. Figure 3 indicates that there were three test environments (mega- environments) for evaluation of sesame genotypes in western Ethiopia. These mega environments were represented by genotype G1, G8 and G7. The results of this study may be confirmed by findings of multi-year experiments.

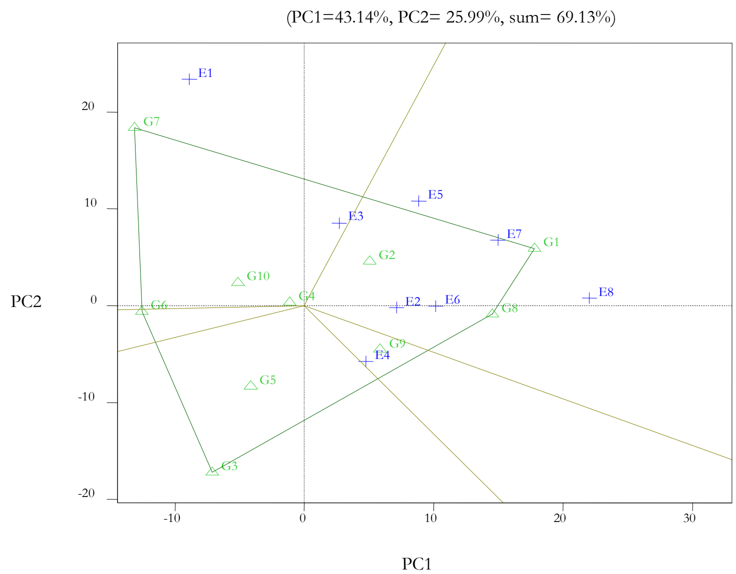


Figure 3. The polygon view of the GGE- biplot based on symmetrical scaling for which -won -where pattern for genotypes and environments. PC, G and E stands for principal component, genotype and environments, respectively.

**3.2.4. Comparison of Genotypes**

In the present study, genotype G1 was a desirable genotype for seed yield and stability followed by G2, G8 and G9 which are located in the next concentric circle. The low yielding genotype G7 and G10, G5, G6 and G3 are undesirable because they are far away from the ideal genotype (Figure 4). An ideal genotype is a one that has both high mean seed yield and high stability; it is defined as a one that is the highest yielder in all test environments (Yan and Kang, 2003; Farshadfar *et al*., 2012). Although an ideal genotype may not exist in reality, it can be used as a reference for evaluating genotypes (Mitrovic *et al*., 2012). A genotype is desirable if it is closer to the ideal genotype (Yan and Hunt, 2002; Kaya *et al*., 2006).

The centre of concentric circle in Figure 4 represents the position of an ideal genotype which is defined by a projection on the mean environment axis that equals the longest vector of the genotype that had above average yield and by a zero projection on the perpendicular line (zero variability across environments). Because the unit of both PC1 and PC2 for the genotype is the original unit of yield in a genotype-focused scaling (Figure 4), the unit of AEC abscissa (mean yield) and ordinate (stability) should also be the original unit of yield. The unit of distance between genotypes and an ideal genotype, in turn, is the original unit of yield. Therefore, the ranking based on the genotype-focused scaling assumes that stability and mean yield are equally important (Yan, 2002).

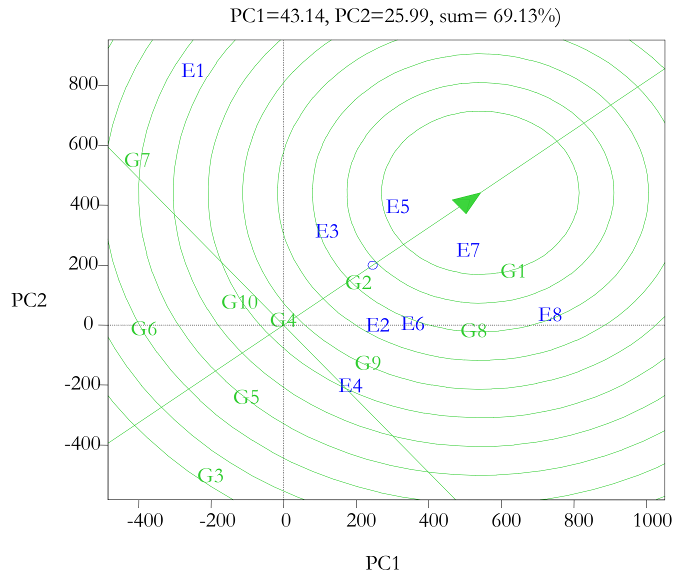


Figure.4. GGE–biplot based on genotype focused scaling for comparison of the genotypes. PC, G and E stand for principal component, genotypes, and environments, respectively. Details of the genotypes and environments are given in Tables 1 and 2.

## 4. Conclusions

The study has demonstrated that EW002 (G1), BG006 (G2), Obsa (G8), and Dicho (G9) are desirable genotypes for seed yield and stability. These genotypes can be used as parents in sesame breeding programs in the future. Furthermore EW002 and BG006 are the best stable genotypes with high seed yield and could be recommended for commercial production for western Ethiopia. Environments viz., Uke 2011 (E2), Angar 2012 (E5), Uke 2012 (E6), Wama 2012 (E7) and Bako 2012 (E8) were identified as favorable test environments for sesame production. Among the test sites, Uke is the best and it is recommended as a test location for sesame breeding in the future. Both AMMI and GGE-biplot tools produced similar results and could be used alternatively rather than simultaneously.

## 5. Acknowledgements

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# Estimation of Global Solar Radiation using Solar PV and Its Comparison with Sunshine Duration Using Quadratic and Gaussian Fits

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**Abstract:** Solar energy is the prime energy source of hydrologic parameter such as evapotranspiration and aerodynamic parameter like wind. Knowledge of daily global solar radiation is important to estimate all solar energy related parameters. In this study, mean daily global solar radiation at Haramaya University (HU) and Dire Dawa (DD) meteorological stations were estimated using sunshine duration data, which were recorded using Campbell-Stock Heliograph as the input of Angstrom-Prescott model. These values were further used to calculate the half hourly power intensity of solar radiation by applying Collares-Pereira and Rabl's model. A 14 cm by 14 cm 12 V solar module was used to take indirect measurements of the solar radiation at the interval of 30 minutes from sunrise to sunset throughout the course of the study period. Readings were made in terms of voltage using a multi-meter, from which power intensities were calculated. Finally, comparisons were made between the estimated values of the half hourly power intensity of the solar radiation and the corresponding measured values to examine the degree of variability between the measured and estimated values of solar radiations using quadratic and Gaussian fits. The estimated values of the half hourly power intensity of the solar radiation agreed closely with the corresponding measured values within the error range of 15% when Gaussian fit was used but only within the error range of 10% when the quadratic fit was used. Gaussian fit reflected the actual solar radiation better than the quadratic fit despite the larger difference between the estimated and measured values. It could be concluded that satisfactory estimates of mean daily global solar radiation were obtained at both locations by using solar modules in the absence of pyranometers, and the errors could be minimized by selecting the appropriate mathematical function.

**Keywords**: Campbell-Stock Heliograph, Solar Module*;* Angstrom-Prescott model; Half hourly power intensity; Collares-Pereira; Rabl's model.

## 1. Introduction

Solar radiation at the outer edge of the atmosphere can be predicted with high precision as it depends essentially on astronomical geometric parameters. At the earth's surface, prediction is more difficult because of the interaction of the solar beam with the atmosphere aerosols, varying cloud cover, and variability of the reflecting surfaces. There are four basic types of measuring instruments for radiation components, namely, sunshine recorder, pyrheliometers, pyranometers and pyrgeometers. The first one delivers information on sunshine duration. The second delivers information on shortwave radiation normal to the surface. The third measures the hemispherical shortwave beam, diffuse and global radiation. The last measures long wave terrestrial radiation. Differences within the data recorded by these instruments, apart from insufficient maintenance and calibration, are due to the differences in what they measure.

Photovoltaic (PV) cells not only use the direct component of light, but also produce electricity even when the sky is overcast. To determine the PV electricity generation potential for a particular site, it is important to assess the average total solar radiation received over a year. Irradiance has the greatest impact on PV power. Beyond irradiance, module temperature, angle of incidence (AOI) and atmospheric mass (AM) also affect a module's or an array's power and production (del-Cueto, 2007; Myers, 2009; King et al., 1997). Module temperature is, in turn, influenced by ambient temperature, cloud patterns, and wind speed.

In most developing countries, there are no properly recorded radiation data. What are usually available are sunshine duration data obtained by a sunshine recorder. Ethiopia is one such country, which lacks properly recorded solar radiation data and, like many other countries, what is available is sunshine duration data. However, given the number of sunshine hours and local atmospheric conditions, sunshine duration data with the help of empirical model can be used to estimate daily average solar radiation (Duffie and Beckman, 1991).

The physical quantity of sunshine duration (n) is routinely observed at most weather stations. For climatological purposes, derived terms such as daily sunshine hours are used with percentage quantities, such as relative daily sunshine duration, n/N, where N may be related to the extraterrestrial or to the maximum sunshine duration. According to World Meteorological Organization (WMO, 2003), sunshine duration during a given period is defined as the sum of those sub-periods for which the direct solar irradiance exceeds 120 Wm-2. In order to homogenize the data of the worldwide network for sunshine duration, a special design of the Campbell-Stokes Sunshine Recorder, the so-called Interim Reference Sunshine Recorder (IRSR) was recommended (Adam, 2012). The requirements of sunshine recorders vary depending on site, season and according to the dominant cloud formation. The dominant

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cloud formation can be mainly described by three ranges of relative daily sunshine duration ($n/N$) such as "cloudy sky" ($0 \leq n/N < 0.30$), "scattered clouds" ($0.30 \leq n/N < 0.70$) and "fair weather" ($0.70 \leq n/N \leq 1.00$) (WMO, 2006; Adam, 2012).

There are four main types of errors in sunshine duration registration with this type of instrument. The over-burning of the registration paper during intermittent sunshine results in overestimation of sunshine duration. The threshold sensitivity of the Campbell-Stokes Recorder of 120 W $m^{-2}$ results in underestimation of sunshine duration. The analysis of the registration paper made by hand may cause additional errors in either direction. Finally, deteriorations of the performance of the glass sphere caused by weather phenomena like rain or hoarfrost or due to insufficient maintenance results in underestimation of sunshine duration.

In principle, the amount of solar radiation reaching the earth's surface could be calculated from the extraterrestrial radiation provided that losses in the atmosphere, which are caused by several processes such as absorption and scattering, are known (Iqbal, 1983; Pisimanis *et al*., 1987). Nevertheless, the best way of knowing the amount of global solar radiation at a site is to install measuring devices such as Pyranometers at many locations in a given region but this is a very costly exercise. For stations where no measured data are available, the common practice is to estimate global solar radiation from other measured meteorological parameters like surface pressure, relative humidity, sunshine duration, minimum and maximum temperatures and precipitation using empirical and physical models. The models' results may then be used for locations of similar meteorological and geographical characteristics for which solar radiation data are not available (EEPCO, 2007).

In this study, estimation of global solar radiation based on sunshine duration is made and compared with the value obtained from direct measurement of voltage output of solar PV at Haramaya University and Dire Dawa meteorological stations. The objective of this study was to estimate global solar radiation by direct measurement using solar PV and compare the result to solar radiation estimated from sunshine duration at the two locations, using two fitting methods.

## 2. Materials and Methods

### 2.1. Descriptions of the Study Areas

The study was carried out at Haramaya University (HU) and Dire Dawa (DD). Haramaya University is at an average altitude of 2043 m.a.s.l. and is located at a latitude of 90 0'N and longitude of 420 0'E. The place has a mean maximum temperature of 28.50C and mean minimum temperature of 12.60C. It is situated in the semi-arid tropical belt of eastern Ethiopia and is characterized by a sub-humid type of climate with an average annual rainfall of about 790 mm. Field experiment was also conducted at Dire Dawa, which has an average altitude of 1197 m.a.s.l. and is located at 90 6' N latitude and 480 8' E longitude. It lies in the semi-arid belt of Eastern Rift Valley and has annual average rainfall of 612 mm. The mean maximum and minimum temperatures at Dire Dawa are 31.35 and 18.05oC, respectively.

### 2.2. Data Collection

Sunshine duration data were obtained from the two meteorological stations (HU and DD) identified as HUMS and DDMS, respectively. Actual radiation measurements were conducted for a week at Haramaya University (13/06/12 -19/06/2012) and for another week at Dire Dawa (01/07/2012 -07/07/2012). At Haramaya University, data was collected at a specific location with the altitude of 2024 m above sea level.

A solar module of 14 cm by 14 cm of 12 V was used in this study to record the voltage of solar radiation at every half hour interval. The solar module was calibrated using 14 Ω and the same value was used to estimate the power. Voltage measurements were taken using a multi-meter every half hour from sunrise to sunset. Corresponding sunshine duration data were obtained from the two stations (i.e., HU and DD meteorological stations) to estimate the daily global solar radiation and the two values were compared.

### 2.3. Data Analysis and Mathematical Methodologies Used

Several empirical models exist to evaluate the daily global solar radiation, utilizing available meteorological and geographical parameters such as sunshine duration and latitude. In this study, the daily global solar radiation was estimated from sunshine duration using Angstrom-Prescott model (Prescott, 1940). The formula can be written as described by Medugu and Yakubu (2011):

$$H = H_o\left(a + b\frac{n}{N}\right) \quad (1)$$

$H$ is daily global solar radiation and $H_o$ is daily extraterrestrial radiation, both measured in kWh $m^{-2}$. $H_o$ is calculated from several parameters as described by Medugu and Yakubu (2011):

$$H_o = \frac{24 \times 3600 \times Gsc}{\pi}\left(1 + 0.033 \times cos\left(\frac{2\pi n_d}{365}\right)\right) \times \left(cos(\phi)\, cos(\delta)\, sin(\omega_s) + \frac{\pi\omega_s}{180} sin(\phi)\sin(\delta)\right). \quad (2)$$

$G_{sc}$ is the solar constant approximately equal to 1367 W $m^{-2}$ (Antonio and Hedgus, 2005); $n_d$ is day number of the year starting from January 1st as 1, $\phi$ is the latitude of the area and $n$ is daily number of hours of bright sunshine.

The solar declination angle ($\delta$) is calculated as:

$$\delta = 23.45\, sin\,(360\frac{284 + n_d}{365}). \quad (3)$$

The solar hour angle($\omega_s$) is given as:

$$os^{-1}(-tan\,(\phi)\, tan\,(\delta)). \quad (4)$$

The maximum possible daily hours of bright sunshine, $N$, is calculated using Eq. 5 (Zhou *et al*., 2005).

$$N = \frac{2}{15}\omega_s. \quad (5)$$

*a* and *b* is regression coefficients (Medugu and Yakubu, 2011), respectively given as:

$$a = -0.110 + 0.235\cos(\phi) + 0.323\frac{n}{N}. \quad (6)$$

$$b = 1.449 - 0.553\cos(\phi) - 0.694\frac{n}{N}. \quad (7)$$

In order to find the solar radiation intensity obtained on half hourly basis, first, the mean daily global solar radiation (*H*) was evaluated. Once the solar radiations of all hours of the day were computed, the daily total was obtained by summing the values of individual hours. Thereafter, the estimated half hourly power intensity $(I_{p,est})$ of solar radiation was calculated as (Collares-Pereira and Rabl, 1979):

$$I_{p,est} = r_t \times H. \quad (8)$$

Where $r_t$ is the ratio of hourly total to daily total global radiation dependent on several parameters as shown in Eqn. 9.

$$r_t = \frac{\pi}{24}(x + y * \cos\omega)\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \frac{\pi}{180} * \omega_s * \cos\omega_s}. \quad (9)$$

The solar hour angle, $\omega$, is calculated from (Scharmer and Greif, 2000)

$$\omega = (t_L - 12)15^0. \quad (10)$$

$t_L$ is local solar time in hours. The *x* and *y* in equation (9) are dependent on $\omega_s$ and are expressed as shown in Eqns. 11 and 12, respectively.

$$x = 0.409 + 0.5016\sin\left(\omega_s - \frac{\pi}{3}\right). \quad (11)$$

$$y = 0.6609 - 0.4767\sin\left(\omega_s - \frac{\pi}{3}\right). \quad (12)$$

The sum of all $r_t$ for all half hours adds up approximately to one. Hence, multiplying $r_t$ for a specific time with estimated mean daily global solar radiation (*H*) gives estimated half hourly intensity of solar radiation. Solar power intensities were estimated from the electrical power obtained from measured voltages using

$$I_{p,meas} = \frac{P}{A}. \quad (13)$$

$$P = \frac{V^2}{R}. \quad (14)$$

$I_{p,meas}$ values were then compared with the corresponding values of the estimated half hourly power intensity of solar radiation. The graphs and area estimations were made using MATLAB, and finally, percent error estimations of both quadratic and Gaussian fits were made as:

$$Percent\ Error = \frac{Estimated\ value - Measured\ value}{Measured\ value} \times 100. \quad (15)$$

Finally, the percent errors were computed for each day using both fits to see how the powers estimated from sunshine duration varied from the power calculated using PV measured values.

## 3. Results and Discussion

### 3.1. Daily Sunshine Hours Obtained from the Two Experimental Sites

Daily sunshine hours obtained from each site were between 4 and 10.5 hours as shown in Table 1. The values of the two sites averaged over the week were 7.76±1.23 and 6.80±2.43 for Haramaya University Meteorological station (HUMS) and Dire Dawa University Meteorological station (DDMS), respectively. The low average sunshine duration recorded at DDMS could be due to more cloud cover during the week the measurements were taken. The cloud coverage of the atmosphere was more intense in July than in June. Note that measurements were taken during the month of June at HUMS and July at DDMS.

Table 1. Sunshine Duration of Each Day at Each Study Site.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| HUMS | Date | 13/06/12 | 14/06/12 | 15/06/12 | 16/06/12 | 17/06/12 | 18/06/12 | 19/06/12 |
| | Hours | 9.7 | 7.4 | 6.0 | 8.6 | 6.7 | 8.2 | 7.7 |
| DDMS | Date | 1/7/2012 | 2/7/2012 | 3/7/2012 | 4/7/2012 | 5/7/2012 | 6/7/2012 | 7/7/2012 |
| | Hours | 5.6 | 4.0 | 9.0 | 8.0 | 4.4 | 10.5 | 6.1 |

As indicated in Table 1, on four of the seven days DD experienced more cloud cover and thus had sunshine durations of about six hours or less. On the other hand, HU had sunshine durations in excess of six hours for most days of the week.

### 3.2. Estimation of Mean Daily Global Solar Radiation using Sunshine Durations

Summaries of the values of mean daily global solar radiation using sunshine duration for HUMS are given in Table 2. Intensity obtained using PV measurement were also shown for comparison on the last column. Table 3 shows corresponding values calculated for DDMS. The high values obtained at HU are understandable since the data were for June when the intensity of solar radiation is relatively higher since the sun is nearly overhead during this time of the year. Based on $n/N$ values (WMO, 2006; Adam, 2012) of Tables 2 and 3, HUMS had only one fair weather ($n/N > 0.7$) day while DDMS had two. During the remaining days HUMS had fairly scattered clouds ($0.30 < n/N < 0.7$) with more days having $n/N$ values closer to fair weather day value. DDMS also experienced scattered clouds with clouds more intense than that of HUMS since the $n/N$ values for some of the days were closer to the lower value (0.30) than to the higher one (0.7). The values obtained at HUMS site were higher than that of DDMS values as indicated by the values of the average of the week. The low value at DDMS is due to the low values of sunshine durations. Besides, DDMS experienced higher variability (as indicated by the standard deviation (> 0.8)) compared to that of HUMS, which is close to 0.4. The measure of standard deviation is also a good indicator of cloudy and sunny days at DDMS compared to HUMS, which had days with closer weather conditions.

The ratio of measured power to calculated power ($I_{p,meas}/H$) based on the values of Tables 2 and 3 show 0.89 and 0.80, respectively. The fact that DDMS showed lower value indicates that the PV was more influenced by temperature at DDMS than at HUMS. Temperature adversely affects the performance of PV (del-Cueto, 2007; Myers, 2009; King *et al.*, 1997). Thus, the higher temperature at DDMS than at HUMS may have contributed to the lower performance of PV at the former.

Table 2. Estimation of Mean Daily Global Solar Radiation at HUMS.

| Date | n | $n_d$ | Δ | $\omega_s$ | N | n/N | a | B | $H_o$ | H ($kWm^{-2}$) | $I_{p.msd}$($kWm^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 13/06/12 | 9.7 | 165 | 23.27 | 93.91 | 12.52 | 0.77 | 0.37 | 0.37 | 10.18 | 6.67 | 6.03 |
| 14/06/12 | 7.4 | 166 | 23.31 | 93.91 | 12.52 | 0.59 | 0.31 | 0.49 | 10.18 | 6.15 | 5.72 |
| 15/06/12 | 6.0 | 167 | 23.35 | 93.92 | 12.52 | 0.48 | 0.28 | 0.57 | 10.18 | 5.60 | 5.24 |
| 16/06/12 | 8.6 | 168 | 23.39 | 93.93 | 12.52 | 0.69 | 0.34 | 0.43 | 10.18 | 6.48 | 5.72 |
| 17/06/12 | 6.7 | 169 | 23.41 | 93.93 | 12.52 | 0.53 | 0.29 | 0.53 | 10.17 | 5.89 | 4.89 |
| 18/06/12 | 8.2 | 170 | 23.43 | 93.94 | 12.52 | 0.65 | 0.33 | 0.45 | 10.17 | 6.38 | 5.58 |
| 19/06/12 | 7.7 | 171 | 23.44 | 93.94 | 12.53 | 0.61 | 0.32 | 0.48 | 10.17 | 6.24 | 5.52 |
| Average of the week | | | | | | | | | | 6.20±0.36 | 5.53±0.37 |

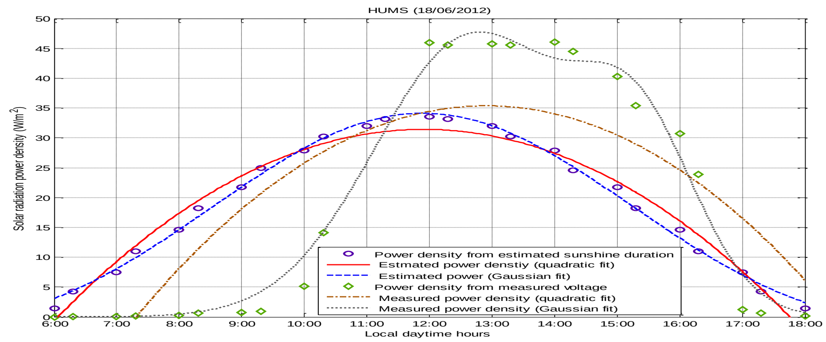
Table 3. Estimation of Mean Daily Global Solar Radiation at DDMS.

| Date | n | $n_d$ | Δ | $\omega_s$ | N | n/N | a | B | $H_o$ | H($kWm^{-2}$) | $I_{pmsd}$ ($kWm^{-2}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/7/2012 | 5.6 | 183 | 23.05 | 93.91 | 12.52 | 0.45 | 0.27 | 0.59 | 10.18 | 5.41 | 4.20 |
| 2/7/2012 | 4.0 | 184 | 22.97 | 93.89 | 12.52 | 0.32 | 0.23 | 0.68 | 10.19 | 4.51 | 3.52 |
| 3/7/2012 | 9.0 | 185 | 22.89 | 93.88 | 12.52 | 0.72 | 0.35 | 0.40 | 10.19 | 6.57 | 5.20 |
| 4/7/2012 | 8.0 | 186 | 22.80 | 93.86 | 12.51 | 0.64 | 0.33 | 0.46 | 10.19 | 6.34 | 5.50 |
| 5/7/2012 | 4.4 | 187 | 22.70 | 93.84 | 12.51 | 0.35 | 0.24 | 0.66 | 10.19 | 4.76 | 3.67 |
| 6/7/2012 | 10.5 | 188 | 22.59 | 93.82 | 12.51 | 0.84 | 0.39 | 0.32 | 10.20 | 6.75 | 5.61 |
| 7/7/2012 | 6.1 | 189 | 22.48 | 93.80 | 12.51 | 0.49 | 0.28 | 0.56 | 10.20 | 5.66 | 4.57 |
| Average of the week | | | | | | | | | | 5.71 ± 0.88 | 4.61±0.85 |

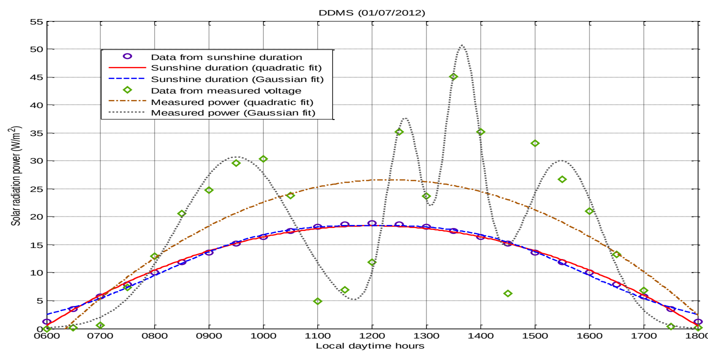
### 3.3. Degree of Variability between Estimated and Measured Values of Solar Radiation

The half hourly power intensity of solar radiation was calculated from PV measured solar radiation using Eqn. 13. From the observed result, the half hourly estimated and the intensity obtained from the measured voltages were shown with their corresponding cumulative sums (as samples, one each, for the two sites) in Fig. 1. Curve fits through the data points were made using Quadratic and Gaussian models.

As observed in the sample figures, Gaussian fits reflected the reality (presence of clouds) better than quadratic fits particularly when fitting data points obtained from voltage measurement. Unlike quadratic fit whose cumulative area has sufficient contribution during midday, Gaussian fits have subdued contribution especially when there were cloud covers during midday and early or late afternoon hours. This in turn may have undermined the total daily contribution and as a result power intensity obtained by voltage measurement was smaller than intensity estimated from sunshine duration. The results are reflected in Tables 4 and 5 for the two sites in which the cumulative power intensities of the Gaussian fits were always less than the corresponding quadratic fits.




(A)




(B)

Figure 1. Representative sample figures: (A) at HUMS on 18/06/2012 and (B) at DDMS on 01/07/2012) shown to illustrate how daily solar intensity varied with model type used to fit the curve.

Table 4. Summary of cumulative power density of daily solar radiation (kWhm$^{-2}$d$^{-1}$) at HUMS estimated using two models (Quadratic and Gaussian fits.

| HUMS Calculated quantities | Date/Month/Year | | | | | | |
|---|---|---|---|---|---|---|---|
| | 13/6/2012 | 14/6/2012 | 15/6/2012 | 16/6/2012 | 17/6/2012 | 18/6/2012 | 19/6/2012 |
| CEPQF (kWhm$^{-2}$d$^{-1}$) | 5.67 | 5.28 | 4.87 | 5.53 | 4.40 | 4.77 | 4.67 |
| $R^2$ | 0.977 | 0.977 | 0.977 | 0.977 | 0.977 | 0.978 | 0.996 |
| CEPGF (kWhm$^{-2}$d$^{-1}$) | 5.63 | 5.23 | 4.82 | 5.48 | 4.37 | 4.74 | 4.64 |
| $R^2$ | 0.997 | 0.992 | 0.992 | 0.992 | 0.992 | 0.992 | 0.996 |
| CEPQF-CEPGF | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.03 | 0.03 |
| CMPQF (kWhm$^{-2}$d$^{-1}$) | 6.38 | 5.19 | 4.80 | 5.31 | 4.51 | 5.60 | 5.54 |
| $R^2$ | 0.890 | 0.660 | 0.650 | 0.710 | 0.580 | 0.740 | 0.740 |
| CMPGF (kWhm$^{-2}$d$^{-1}$) | 6.30 | 5.12 | 4.70 | 5.24 | 4.49 | 5.53 | 5.43 |
| $R^2$ | 0.900 | 0.960 | 0.770 | 0.920 | 0.880 | 0.920 | 0.920 |
| CMPQF-CMPGF | 0.07 | 0.08 | 0.10 | 0.07 | 0.03 | 0.07 | 0.11 |
| CEPGF –CMPGF | -0.67 | 0.12 | 0.12 | 0.25 | -0.12 | -0.78 | -0.79 |
| ((CEPGF-CMPGF)/CMPGF)*100% | 10.6 | 2.3 | 2.6 | 4.7 | 2.7 | 14.2 | 14.6 |
| CEPQF –CMPQF | -0.70 | 0.08 | 0.06 | 0.22 | -0.11 | -0.83 | -0.87 |
| ((CEPQF–CMPQF)/CMPQF)*100% | 11.0 | 1.6 | 1.3 | 4.1 | 2.4 | 14.8 | 15.6 |

*Note: CEPQF = Cumulative estimated power data quadratic fitted, CEPGF = Cumulative estimated power data Gaussian fitted, CMPQF = Cumulative measured power data quadratic fitted, CMPGF = Cumulative measured power data Gaussian fitted, $R^2$ = measure of fit .*

As observed in Table 4, most of the differences between the quadratic and Gaussian fits were positive while differences between estimated and measured Gaussian fits could be either positive or negative. This implies that the sunshine duration underestimates the solar radiation intensity or the PV panel overestimates the value. PVs have the inherent problem of not accurately estimating solar radiation since they are temperature-dependent and have also low efficiency of only 10% (Rao and Parulekar, 2009).

Quadratic fits slightly overestimated the power density compared to the Gaussian fits for both estimated and measured values (CEPQF-CEPGF >0 and CMPQF – CMPGF >0). Percent differences computed both in terms of quadratic and Gaussian fitted values showed differences of up to 15%. Variability was higher when the sky was overcast since Gaussian fit reflected the reality during such times than quadratic fit and estimation by Gaussian fit was lower on overcast days.

While taking the voltage measurements of the solar module in this work, the values were generally very small on the multi-meter recording when the wind blew with a high speed and when the sky was covered with clouds as well as when a humid air blew at the moment of data recording. This showed the influences of the three atmospheric parameters on the performance of the solar module. However, since the differences between the measured and estimated values in most cases were less than 10% (average difference of approximately 7.25%) one can conclude that sunshine duration can give a good estimation of solar intensity and actual solar radiation intensity measurement can be made with PV as long as high accuracy (> 90%) is not expected.

Since the estimated power intensity of solar radiation in a given day depends on the sunshine duration, the underestimation of solar radiation might be due to errors in sunshine duration registration with the Campbell-Stokes recorder. The key component for Campbell-Stokes recorder is a glass bowl, which is working as a burning glass. It burns a track in a registration paper when the sun is shining with sufficient intensity. The threshold intensity normal to the solar beam for registration of sunshine by this measuring technique is about 120W $m^{-2}$ (Duffie and Beckman, 1991), and it results in underestimation of sunshine duration. The analysis of the registration paper made by hand may cause additional errors. Deteriorations of the performance of the glass sphere caused by weather phenomena and lack of maintenance can also be a reason for the underestimation of sunshine duration. However, in this study, none of these factors seemed to have influenced the performances of the devices since the estimated power intensities were always higher than the measured values.

As shown in Table 4, the errors on the 16th and 17th of June were very small compared to the other dates. The weather conditions of those dates could be identified by calculating the mean daily clearness index of the solar radiation. Clearness index, ($K_T = H/H_0$) is the percentage deflection of the incoming global radiation by the sky and therefore indicates both the level of availability of solar radiation and changes in the atmospheric conditions in a given locality. According to Duffie and Beckman (1991) it depends on the location and time of the year considered. Below 0.3 indicates very overcast climates and above 0.6, very sunny climates. In the present work, $K_T = 0.64$ for June 16/2012, which implies a very sunny day whereas $K_T = 0.58$ for June 17/2012, is close to the theoretical value and represents a sunny day. Thus, the cumulative power intensity of solar radiation showed a fairly good agreement between estimated and measured values with an average error of 7.25%.

The data obtained at Dire Dawa meteorology station are presented in Table 5. In the Table, the estimated solar radiation intensity from the sunshine duration showed errors ranging from 0.4 to 15% for Gaussian fit and between 0.5 to 7% for the quadratic fit. The fact is that the Gaussian fit is a more realistic fit reflecting sunny and cloudy times accurately while the quadratic fit showed less deviation from the curve fitted based on the data of the sunshine duration. Note that a sunshine duration fit is closer to the quadratic than the Gaussian, which may explain the fact that the percent error between estimated and measured quadratic fits was smaller than the ones between the Gaussian fits.

Table 5. Summary of cumulative power density of daily solar radiation ($kWhm^{-2}d^{-1}$) at DDMS estimated using two models (Quadratic and Gaussian fits).

| DDMS | Date/Month/Year | | | | | | |
|---|---|---|---|---|---|---|---|
| Calculated quantities | 1/7/2012 | 2/7/2012 | 3/7/2012 | 4/7/2012 | 5/7/2012 | 6/7/2012 | 7/7/2012 |
| CEPQF (kWhm-2d-1) | 4.10 | 3.38 | 4.92 | 4.75 | 3.58 | 5.05 | 4.24 |
| R2 | 0.977 | 0.977 | 0.977 | 0.977 | 0.977 | 0.977 | 0.977 |
| CEPGF (kWhm-2d-1) | 4.03 | 3.35 | 4.88 | 4.71 | 3.54 | 5.02 | 4.21 |
| R2 | 0.997 | 0.997 | 0.997 | 0.997 | 0.997 | 0.997 | 0.997 |
| CEPQF-CEPGF | 0.08 | 0.02 | 0.04 | 0.03 | 0.04 | 0.04 | 0.03 |
| CMPQF (kWhm-2d-1) | 3.83 | 3.24 | 4.82 | 5.04 | 3.35 | 5.08 | 4.18 |
| R2 | 0.450 | 0.639 | 0.868 | 0.830 | 0.525 | 0.642 | 0.682 |
| CMPGF (kWhm-2d-1) | 3.69 | 3.13 | 4.74 | 4.90 | 3.06 | 5.04 | 4.65 |
| R2 | 0.960 | 0.836 | 0.908 | 0.951 | 0.711 | 0.722 | 0.815 |
| CMPQF-CMPGF | 0.14 | 0.11 | 0.08 | 0.14 | 0.29 | 0.04 | -0.47 |
| CEPGF –CMPGF | 0.34 | 0.23 | 0.14 | -0.19 | 0.48 | -0.02 | -0.44 |
| ((CEPGF–CMPGF)/CMPGF)*100% | 9.2 | 7.2 | 2.9 | 3.8 | 15.8 | 0.4 | 9.5 |
| CEPQF –CMPQF | 0.27 | 0.14 | 0.09 | -0.30 | 0.23 | -0.02 | 0.06 |
| ((CEPQF–CMPQF)/CMPQF)*100% | 7.0 | 4.3 | 1.9 | 5.9 | 6.7 | 0.5 | 1.5 |

*Note: CEPQF = Cumulative estimated power data quadratic fitted, CEPGF = Cumulative estimated power data Gaussian fitted, CMPQF = Cumulative measured power data quadratic fitted, CMPGF = Cumulative measured power data Gaussian fitted,* $R^2$*= measure of fit; DDMS = Dire Dawa Meteorological station.*

## 4. Conclusions

Comparisons have been made for half hourly power intensity of estimated and measured values of solar radiation at Haramaya University's Meteorological Station (HUMS) and Dire Dawa Meteorological Station (DDMS). Most of the measured values were consistent with the estimated ones throughout the day to within an error range of 15% in the worst cases. At HUMS, the intensity of solar radiation showed an error of about 15% and at DDMS the error was generally less than 10%. Although this study is specific to HU and DD, the solar module used for the study can be used to measure solar radiation at any time rather than predicting the solar radiation using sunshine duration alone. The results of this study indicated a fairly good agreement between estimation of cumulative power intensity of solar radiation and its corresponding measured values. Better results could have been obtained if temperature corrections were made for PV data. The Gaussian fits better reflected the daily solar radiation intensity but it also showed higher percent error at both sites. The quadratic fit showed better agreement with the estimated power when data points were closer to the normal distribution. Despite a very great simplification, the solar module appears to be well suited for measuring the solar radiation at any time since it is less expensive and more readily available than other devices. However, because of its low efficiency, it may not be suitable for calibration of sunshine recorder devices like Campbell-Stokes recorder.

The results of the study have demonstrated that even when materials that have lower accuracy such as solar modules are used for estimating global solar radiation, a better estimation could be obtained by selecting a better mathematical function to reduce the error. Since this study was conducted for a short duration, it is advisable to use data accumulated over long durations to make a conclusive recommendation.

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# Effect of Integrated Climate Change Resilient Cultural Practices on Productivity of Faba Bean (*Vicia faba* L.) under Rain-fed Conditions in Hararghe Highlands, Ethiopia

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**Abstract**: Alternative sustainable agriculture under the pressing impacts of climate variability on crop production is a primary concern in the Ethiopian development agenda towards sustained food security. Use of integrated crop management through climate resilient cultural practices that target diversity of produce, yield stability, losses due to pests, and reduction in economic and environmental risks is an appropriate strategy for sustainability of agricultural production. Field studies were conducted in Hararghe highlands, specifically at Haramaya during the 2012 and 2013 and at Arbarakate in the 2013 main cropping seasons to assess effects of integrated climate change resilient cultural practices on faba bean productivity. Three on-farm-based climate change resilient cultural practices: intercropping, compost application and furrow planting alone and in integration with the other practices were evaluated using Dagaga and Bulga-70 faba bean varieties and Melkassa-IV maize variety. The results showed that furrow planting with compost application in row intercropping increased soil moisture by up to 3.23% and cooled the soil temperature by up to 1.06$^{o}$C compared to sole cropping at Haramaya in 2013. Furrow planting with application of compost led to production of the highest (3.47 t ha$^{-1}$ in 2012 and 4.25 t ha$^{-1}$ in 2013) faba bean grain yields at Haramaya. The same treatment at Arbarakate produced the maximum (5.29 t ha$^{-1}$) faba bean grain yield in 2013. This was closely followed by the yield obtained in response to the application of compost at both locations in 2013 and by the yield obtained in response to furrow and sole cropping at Haramaya in 2012. Compost fertilization with or without furrow planting led to the production of consistently heavier grains. The total Land Equivalent Ratio (1.01 to 1.76) indicated a higher grain yield advantages of faba bean-maize intercropping over sole faba bean cropping at both locations over the two years. The overall results demonstrated that integrated climate resilient cultural practices significantly increased productivity of the crop as a result of enhancing contents of soil nutrients, soil moisture, soil organic carbon, and regulating soil and canopy temperatures as well as through buffering the root environment.

**Keywords**: Compost; Furrow planting; Grain yield; Land Equivalent Ratio; Row intercropping; Soil moisture and temperature; Sole cropping

## 1. Introduction

Faba bean (*Vicia faba* L.) is a cool-season crop and is grown worldwide as a grain and green-manure legume. The crop is used for both human consumption and animal feed as a source of protein and carbohydrate (Salmeron *et al.*, 2010). It is a common breakfast food in many regions and countries, including Ethiopia (Singh and Bhatt, 2012). Faba bean is also used as an excellent component of crop rotations - capable of fixing atmospheric nitrogen; and is used as green manure to reduce the use of nitrogen fertilizers due to environmental concerns (Salmeron *et al.*, 2010; Singh and Bhatt, 2012). Moreover, it is useful in the sustainability of cropping systems via crop diversification, leading to decreased disease, pest and weed build-up (Jensen *et al.*, 2010).

Globally, China is the largest producer of faba bean, followed by Egypt, Ethiopia and France (Salmeron *et al.*, 2010). In Africa, Egypt, Ethiopia, Sudan and Morocco are the leading producers of the crop (Akibode and Maredia, 2011). In Ethiopia, faba bean production is estimated to account for 3.94% of the total grain production (CSA, 2014). However, the average yield of faba bean under smallholder farmers ranges from 1.0 to 1.2 t ha$^{-1}$, which is five times lower than the faba bean production in Central Europe and some sub-Saharan African countries (Agegnehu *et al.*, 2006). Faba bean production fluctuates and the world's cultivated area of faba bean decreased in the last 50 years (Rosegrant, 2010) though it has high production potential. Climate variability, diseases, weeds, and other pests are the major factors constraining faba bean production. Faba bean is regarded as a drought-sensitive crop (Grashoff, 1990) and the major factor restricting faba bean cultivation is the high year-to-year yield variability usually due to drought or moisture stress (Karamanos and Gimenez, 1991).

Climate is one of the main determinants of agricultural crop production (Knox *et al.*, 2011; Turner, 2011). Agriculture is often regarded as one of the sectors most

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vulnerable to climate change in the developing world. Similarly, agriculture in Ethiopia is heavily dependent on rain-fed production where its geographical location and topography, plus a low adaptive capacity, make the country highly vulnerable to the adverse impacts of climate change. Agriculture constitutes 40% of the country's GDP, on which 80% of the people rely for their livelihoods (FDRE-EPA, 2011). Currently, 30 developing nations face water shortages and by 2050, this could increase to 50 nations mostly in the developing countries (Dixon, 2009). Water scarcity and the degradation of arable crop land are the most serious obstacles inhibiting future increases in food production (Dixon, 2009).

Climate change has the potential to exacerbate the stresses on crop plants, potentially leading to catastrophic yield reductions to both irrigated and non-irrigated crops. This phenomenon could be manifested through increased moisture stress and drought in which crop production declines and entire harvests can be lost, greatly impacting seed viability, and plant growth, development, stature, phenology, fruiting, seed mass, seed quality, fiber quality, and the qualities of beverage crops, fruits, and aromatic and medicinal plants (Masters *et al.*, 2010). Simultaneously, climate change will alter phasing of plant life-cycle stages and their rates of development for pests and pathogens and associated antagonistic organisms (Chakraborty, 2011). Thus, on one hand, the level of crop losses will increase while the efficacy of control measures could fall when faced with greater populations of pests and pathogens (Coakley *et al.*, 1999).

Increase in the projected world population [in the case of Ethiopia, estimated to be 130 million by 2030, (FDRE-EPA, 2011)] and consequent human needs for food, cause additional pressure on the limited natural resources and the sustainability of agriculture. However, land is a primary resource that cannot be created. There is, therefore, a finite amount beyond which the cropped area cannot be increased. About 40% of the world's arable land is now degraded to some extent and most of that land is in the least developed nations in densely populated, rain-fed farming areas, where overgrazing, deforestation and inappropriate land use compound the problems (Dixon, 2012). In Ethiopia, food production on a continually shrinking farm size is also a prime developmental challenge for a rapidly ever growing population.

Considering all the uncertainties, it will be very important to develop effective mitigating or adaptive crop management strategies that minimize the risk of severe crop losses under the future climatic conditions, primarily focusing on improved management and use of the limited natural resource bases. The strategies may include shifts in crops and varieties adapted to future climate, shifts in crop diversification resistant or tolerant to insect pests and diseases (Fadda, 2011) and biodiversity restoration (Li, 2011). Diversification of agricultural systems can also significantly reduce the vulnerability of production systems to greater climate variability and extreme events, thus protecting vulnerable rural farmers and agricultural production (Li, 2011). Moreover, integrated nutrient management (Katungi *et al.*, 2009), and conservation agriculture and efficient moisture conservation (Heluf, 2003) practices are also included under risk aversion from the impacts of climate variability and extreme weather events on subsistence agriculture and farmers.

Integrating on-farm-based climate change resilient cultural practices for production and management of crop diseases has a dual role for understanding effects of climate change and the role of these practices for mitigation or adaptation. However, research on field plot-based empirical climate change effects is practically a challenge but could be approached through climate change resilient cultural practices. These practices enhance the capacity of an ecological system to absorb stresses while retaining its organizational structure and productivity, the capacity for self-organization, and the ability to adapt to stress and change following a perturbation (Cabell and Oelofse, 2012). Thus, a "resilient" agroecosystem would be capable of providing food production, even when challenged by severe drought or by erratic rain-fall (Heal, 2000).

To this effect, productivity of faba bean needs to be assessed and characterized under integrated climate change resilient cultural practices. Nonetheless, field-based data on effects of climate variability and crop productivity in Ethiopia is limited. The consequences of new cropping systems designed to mitigate or adapt to climate change should be studied. Since food legumes used by farmers will be key components of many cropping systems and management options, such cropping systems and management options should be revisited based on the current changing environments (Ahmed *et al.*, 2011). Thus, the potential of integrated climate resilient cultural practices to sustainably maintain crop production in the face of current and future climate change scenarios has to be elucidated. Therefore, the objective of this study was to assess the effect of integrated climate resilient cultural practices on faba bean productivity under rain-fed conditions in Hararghe highlands of Ethiopia.

## 2. Materials and Methods

### 2.1. Experimental Sites

Field experiments were conducted at two locations under rain-fed conditions in the 2012 and 2013 main cropping seasons. The 2012 main cropping season field experiment was conducted on a sandy clay loam soil (Gelgelo, 2012) on the main campus of Haramaya University at the experimental field station. The station is located at 9°26'N and 42°3'E with an altitude of 2006 m.a.s.l. The mean annual rain-fall for the location is 790 mm with mean minimum and maximum temperatures of 14 and 23.4 °C, respectively. The 2013 field experiment was conducted at Haramaya University on the same soil and on a clay vertisol at Arbarakate Farmers' Training Center (FTC) during the main cropping season. Arbarakate FTC is located at 9°2.86'N and 40°54.79'E with an altitude of 2274 m.a.s.l. in West Hararghe Zone at a distance of about 180 km to the west of Haramaya. Arbarakate is characterized by extended higher precipitation (estimated to exceed 1300 mm per annum) and many rainy days during the cropping periods with mean daily temperatures ranging between 13.14 and 17.52 °C. The soil of the experimental site at Haramaya had organic matter content of 1.0%, total nitrogen content of 0.17%, available phosphorus content of 8.72 mg kg$^{-1}$ and pH of 8.13 (Gelgelo, 2012). Some of selected soil properties at Arbarakate included organic matter (3.49%), organic carbon (2.03%), total nitrogen (0.17%), available phosphorus (38.24 mg kg$^{-1}$) and pH (5.66) (own analysis).

**2.2. Weather Data at Experimental Sites during the Cropping Seasons**

Monthly total rainfall in mm, daily maximum and minimum temperatures in °C were obtained for Haramaya University experimental site of the cropping periods of the seasons from its own meteorological station. The weather data obtained from the nearby stations for Arbarakate were found unrepresentative and consequently not included here. However, the weather trend at Arbarakate was characterized by many rainy days, extended period of rainfall and the daily minimum and maximum temperatures were derived using the Adiabatic Lapse Rate Model (Brunt, 2007) from the nearby meteorological station. Also the monthly total rain-fall and the monthly average temperature in the cropping seasons are presented in Table 1.

Table 1. Monthly mean temperature (°C) and monthly total rainfall (mm) during faba bean growing periods at Haramaya and Arbarakate, Ethiopia, in 2012 and 2013 main cropping seasons.

| Cropping month | Mean of temperature (°C) | | | Monthly rain-fall (mm) | |
|---|---|---|---|---|---|
| | Haramaya | | Arbarakate | Haramaya | |
| | 2012 | 2013 | 2013 | 2012 | 2013 |
| June | 19.97 | 19.30 | 17.52 | 0.00 | 15.80 |
| July | 18.56 | 17.63 | 15.81 | 214.00 | 215.40 |
| August | 18.90 | 18.25 | 16.48 | 149.50 | 185.10 |
| September | 18.73 | 18.43 | 16.62 | 105.00 | 142.10 |
| October | 15.50 | 16.82 | 15.47 | 4.60 | 71.60 |
| November | 14.68 | 15.04 | 13.14 | 0.50 | 81.70 |
| Mean | 17.72 | 17.58 | 15.84 | 78.93 | 118.62 |

**2.3. Experimental Materials**

**2.3.1. Planting material**

The two faba bean varieties used in this study were Degaga (moderately resistant to major faba bean diseases) and Bulga-70 (moderately susceptible) and their characteristic features are presented in Table 2. Both faba bean varieties were obtained from Holleta Agricultural Research Center, Ethiopia. The maize variety used as a component crop was Melkassa-IV (*ECA-EE-36*), which was obtained from Melkassa Agricultural Research Center, Ethiopia. Melkassa-IV was released in 2006 with an agronomic attribute: area of adaptation (altitude of 1000-1600 meters above sea level, rainfall of 500-700 mm annual rainfall), early maturing (105 days) and a production potential of 2-4 t ha$^{-1}$.

Table 2. Characteristic features of faba bean varieties used for the field experiment at Haramaya and Arbarakate, Ethiopia, during the 2012 and 2013 main cropping seasons.

| Faba bean variety | Year of release | Area of adaptation | | Maturity (days) | Seed size (g) | Yield (t/ha) | |
|---|---|---|---|---|---|---|---|
| | | Altitude (m) | Annual rainfall (mm) | | | On station | On farm |
| Degaga | 2002 | 1800-3000 | 800-1100 | 116-135 | 400-450 | 2.5-5.0 | 2.0-4.5 |
| Bulga-70 | 1994 | 2300-3000 | 800-1100 | 143-150 | 400-450 | 2.0-4.5 | 1.5-3.5 |

**2.3.2. Fertilizer Material**

The compost used in this study to substitute the application of mineral fertilizer was mainly made of a pile of khat (*Catha edulis* Forsk) residues collected from the nearby market of Awaday, eastern Ethiopia. Well-decomposed and matured compost was air-dried and sieved. Composite random samples were taken for chemical analysis before application. The compost constituted organic carbon (8.01%), organic matter (13.80%), total nitrogen (0.69%), available phosphorus (234.80 mg kg$^{-1}$) and C:N ratio of 11.61. In the experiment, the compost was row applied to a depth of 10-15 cm at the rate of 8 t ha$^{-1}$ and mixed with the soil a week before maize planting and four weeks in 2012 and three weeks in 2013 before faba bean planting. Furrows were prepared by digging about 20 cm deep rows once the faba bean was planted and established as seedling, and rain water was made to stagnate.

**2.4. Treatments and Experimental Design**

Three on-farm based climate resilient cultural practices (crop diversification in the form of intercropping, moisture conservation as planting in furrows and soil nutrient management as compost application), two faba bean varieties and one open pollinated Melkassa-IV maize variety were used in this study. Thus, the treatments included faba bean-maize row intercropping, furrow planting, compost application and sole faba bean row planting, and sole maize row planting. The treatments were applied solely and in integration with each other (Table 3). A total of 17 treatments (for both faba bean varieties) were laid out in a randomized complete block design in a factorial arrangement with three replications. In a gross plot size of 4 m x 3.2 m, a 1 maize: 1 faba bean planting pattern of row intercropping was maintained by planting maize rows spaced 0.80 m apart and planting one row of faba bean between the two maize rows. In the row intercropping, 5 rows of maize were intercropped with 4 rows of faba bean variety each at the center of the two maize rows per plot. In addition, sole maize and sole faba bean row planting were included as experimental treatments, which were planted at 0.80 m x 0.40 m and 0.40 m x 0.10 m inter-row and intra-row spacing, respectively. In case of sole faba bean row planting there were 10 rows per plot. In the intercrops, maize was planted three weeks in 2012 and two weeks in 2013 prior to faba bean planting. The spacing between blocks was 1.5 meter and that between plots was 1 meter.

Table 3. Treatment combinations and their respective descriptions used for faba bean and maize field experiments at Haramaya during the 2012 and 2013 and at Arbarakate in the 2013 main cropping seasons.

| S.No. | Treatment | Treatment combination description |
|---|---|---|
| 1 | SP | Sole faba bean row planting (control) |
| 2 | FP | Furrow faba bean planting |
| 3 | CA | Faba bean planting using compost application (compost fertilization) |
| 4 | RI | Faba bean-maize row intercropping |
| 5 | FP + CA | Faba bean furrow planting with compost application |
| 6 | FP + RI | Faba bean furrow planting in faba bean-maize row intercropping |
| 7 | CA + RI | Faba bean planting using compost application in faba bean-maize row intercropping |
| 8 | FP + CA + RI | Faba bean furrow planting with compost application in faba bean-maize row intercropping |
| 9 | SMA | Sole maize row planting |

**2.5 Experimental Procedure**

Sowing of maize was done manually by planting two seeds per hill, which were later thinned to one plant per hill. The faba bean varieties were also manually planted. Maize was planted at Haramaya on 21 June 2012 and on 27 June 2013; and at Arbarakate on 3 July 2013. Faba bean was planted at Haramaya on 11 July 2012 and on 12 July 2013; and at Arbarakate on 16 July 2013. The crops were grown without application of any chemical fertilizer. Weeding and other agronomic practices were done properly and uniformly as per the recommendations to grow a successful crop.

**2.6. Data Collection and Measurement**

**2.6.1. Soil Moisture and Soil Temperature Assessment**

In the 2013 cropping season at Haramaya, weekly soil moisture (%) and temperature ($^oC$) from the most integrated climate resilient cultural practices (furrow planting with compost fertilization in row intercropping) treated and sole cropped plots of faba bean were recorded. Soil moisture was determined by gravimetric measurement. In the gravimetric method, measurement of soil moisture was made on soil samples of known weight or volume. Soil samples for moisture content were taken from 40 cm depths collected with soil auger starting from the fourth week of July. They were collected in air-tight aluminum containers. The fresh soil samples were weighed and dried in an oven at 105 $^oC$ for about 24 hours until all the moisture was driven off. After removing from oven, they were cooled slowly to room temperature and weighed again. The difference in weight was considered as the amount of moisture in the soil. The soil's moisture content was expressed as a fraction and as percentage on a gravimetric basis using a established formula of Lal and Shukla (2004):

$$\text{Gravimetric water (\%)} = [(\text{Wet weight} - \text{Dry weight})/\text{Dry weight}] \times 100 \quad (1)$$

The soil temperature was recorded by using soil thermometer. At the middle of each sole cropped and highly integrated climate change resilient cultural practice treated rows of plots, thermometers were inserted to the depth of 20 cm for about 5 minutes at 7:00 to 9:00 AM and 3:00 to 6:00 PM twice a week to measure diurnal soil temperatures. The weekly average for each temperature per plot was calculated.

**2.6.2. Assessment of crop growth and yield parameters**

Data on faba bean growth and yield parameters were recorded from each plot. The growth parameter included plant height (cm). Plant height was determined by measuring the mean height of ten randomly taken plants from the ground level to the apex of the matured plant. The yield parameters included number of pods per plant (NPPP), number of seeds per pod (NSPP), hundred seed weight (HSW) and grain yield. Grain yield (t $ha^{-1}$) was determined by estimating the total seed mass after threshing at harvest from the respective harvestable areas of each plot. Four middle rows were harvested for intercropped and eight rows were harvested for sole-cropped faba bean plots.

The faba bean grain yield was adjusted to 10% moisture level by using the formula: Yield at % moisture = W*C.F., where W was unadjusted grain weight and C.F was a correction factor which was obtained after oven drying of 100 g unadjusted grain sample at 100 $^{o}$C for 48 hours for complete drying. The C.F was determined using the table of Birru (1979) that gives a C.F. value for the corresponding dry weight of the 100 g sample. Percent moisture was taken after threshing pods using Draminski Grain Moisture Meter (Owocowa 17, 10-860 Olsztyn). NPPP were determined as the mean of ten randomly taken faba bean plants per plot and NSPP were also determined by taking the mean of seeds of ten randomly taken pods of plants per plot. HSW (g) was obtained by randomly counting and weighing 100 seeds per plot. Moreover, grain yield (t ha$^{-1}$) of maize was determined after shelling the dried cobs from each net plot area at harvest both from sole and intercropped plots. The maize grain yield was adjusted to 12.5% moisture level using the same formula used for faba bean. Percent moisture was taken using the same instrument as in faba bean grain yield.

The productivity of faba bean intercropping was evaluated using land equivalent ratio (LER) index (Mead and Willey, 1980), where LER is defined as:

$$LER = LA + LB = \frac{YA}{SA} + \frac{YB}{SB} \tag{2}$$

where LA and LB are the LERs for the individual crops (faba bean and maize, respectively). YA and YB are the individual crop yields in intercropping, where SA and SB are their yields as sole crops. The partial LERs are then summed up to give the total LER for the intercrop. When LER > 1 there is an intercropping advantage in improved use of environment resources for plant growth; when LER = 1 there is no intercropping advantage/disadvantage, with respect to sole crop; when LER < 1 there is a disadvantage to intercropping and implying that the resources are used more efficiently by sole cropping rather than by intercropping. To remove faults relating LER, the maximum monocropping yield was used.

### 2.7. Data Analysis

Analysis of variance (ANOVA) was run for each growth and yield parameter of faba bean to determine treatment effects across locations in each year. ANOVA was also run for both soil moisture and temperature data to determine effects of integrated climate change resilient cultural practices and sole cropping systems at Haramaya in 2013. ANOVA was computed using the SAS GLM Procedure (SAS Institute, 2001) and treatment mean separations were made using least significant difference (LSD) at 0.05 probability level. The two locations and seasons were considered as different environments because of heterogeneity of variances as tested using Bartlett's test (Gomez and Gomez, 1984) and the F-test was significant for most of the parameters studied. Thus, data were not combined for analysis.

## 3. Results

### 3.1. Soil Moisture

The soil moisture content was significantly ($P \leq 0.05$) influenced by intercropping integrated climate resilient cultural practices and sole cropping systems in most of the cropping months in both faba bean varieties at Haramaya in 2013 (Table 4). Higher soil moisture content was recorded in plots treated with the most integrated combination of climate resilient cultural practices over sole faba bean treatment in all cropping months. Soil moisture test data also revealed that moisture content consistently decreased during the cropping months where the lowest value was obtained in October for both faba bean varieties. The most integrated cropping system numerically increased soil moisture by 1.24 to 3.23% for Degaga and by 1.73 to 2.26% for Bulga-70 variety compared to sole cropped systems.

Table 4. Effect of climate change resilient cultural practices on monthly average soil temperature and soil moisture at Haramaya, Ethiopia, during the 2013 main cropping season.

| Treatment [1] | | Cropping months of faba bean | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | July | | August | | September | | October | |
| Cultural practice | Variety | Soil temp. (°C) | Soil moisture (%) | Soil temp. (°C) | Soil moisture (%) | Soil temp. (°C) | Soil moisture (%) | Soil temp. (°C) | Soil moisture (%) |
| SP | Degaga | 14.28[a] | 13.36[a] | 14.17[a] | 10.43[a] | 14.94[a] | 8.45[a] | 15.26[a] | 7.39[a] |
| FP+CA+RI | Degaga | 13.97[a] | 14.60[a] | 13.92[b] | 12.96[b] | 14.13[b] | 10.76[b] | 14.31[b] | 10.62[b] |
| SP | Bulga-70 | 14.20[a] | 13.01[a] | 14.28[a] | 10.95[a] | 15.12[a] | 9.69[a] | 15.20[a] | 8.93[a] |
| FP+CA+RI | Bulga-70 | 13.99[a] | 14.74[a] | 14.02[a] | 13.21[b] | 14.62[b] | 11.88[b] | 14.14[b] | 10.72[b] |
| LSD (0.05) | | 0.18 | 1.45 | 0.16 | 0.61 | 0.19 | 1.00 | 0.24 | 0.81 |
| CV (%) | | 0.92 | 7.35 | 0.78 | 3.66 | 0.92 | 6.96 | 1.15 | 6.15 |

*Note:* [1] *SP, sole planting; and FP + CA + RI, furrow planting with compost application in row intercropping. Means in each column followed by the same letter are not significantly different at 5% probability level.*

**3.2. Soil Temperature**

The monthly average soil temperature was also significantly ($P \leq 0.05$) influenced by intercropping integrated climate change resilient cultural practices and sole faba bean planting at Haramaya during most of the cropping months in 2013 (Table 4). However, the data depicted in the table clearly show that significant differences occurred for Bulga-70 only in September and October. Nonetheless, in all cases, the lower monthly average soil temperature was recorded for the most integrated climate change resilient cultural practices treated plots than for sole faba bean planting. Unlike soil moisture test data, soil temperature increased during the cropping months, with the highest being recorded in October. The most integrated treatment lowered and cooled soil temperature by 0.25 to 0.95 $^oC$ for Degaga and by 0.21 to 1.06 $^oC$ for Bulga-70. A similar trend was also observed for both monthly average minimum and maximum soil temperature data for the cropping months of both faba bean varieties (data not shown).

**3.3. Plant Height**

The data on faba bean plant height generally did not show significant variation among the climate resilient cultural practices used and as compared to the control treatment at Haramaya in 2012 and both at Haramaya and Arbarakate in 2013 (Tables 5 and 6). However, a significant ($P \leq 0.05$) difference in height was obtained between varieties at Arbarakate in 2013. Although not significant, intercropping and intercropping integrated with climate resilient cultural practice(s) treated plots (referring to furrow planting in row intercropping and/or compost application in row intercropping and/or furrow planting with compost application in row intercropping or intercropping integrated treatments hereafter) produced taller faba bean plants than sole faba bean planting at Haramaya in 2012 and both at Haramaya and Arbarakate in 2013 main cropping seasons. Taller Degaga faba bean plants were also recorded at Arbarakate than Bulga-70 during the 2013 cropping season.

**3.4. Faba Bean Yield Components**

Data on yield components are presented in Tables 5 and 6. Statistical analysis of the data showed that climate resilient cultural practices generally had significant ($P \leq 0.05$) effect on hundred seed weight of faba bean at Haramaya in 2012 and at both locations in 2013 main cropping seasons. However, a general non-significant trend on NPPP and NSPP of faba bean were observed at both locations and across the main cropping seasons. It was also observed that the variety Degaga had significantly heavier seed weights than the variety Bulga-70. Sole cropping treatments caused heavier faba bean seeds than their respective intercropping and intercropping integrated treatments at both locations and over seasons. Comparably, higher NPPP and 100-seed weights of faba bean were recorded at Haramaya and Arbarakate in 2013 than at Haramaya in 2012 main cropping season.

Heavier faba bean grains were obtained from plots where faba bean plants were planted with compost fertilization or planted in furrows with compost fertilization at both locations in 2013. In 2012, heavier faba bean grains were harvested from furrow planted or furrow planting with compost fertilized plots at Haramaya than from sole faba bean planting. However, lower 100-seed weights of faba bean were recorded in plots that were planted either in intercropping or intercropping integrated treated plots at both locations in 2013. The overall condition was a little bit different during 2012 as compared to 2013.

**3.5. Grain Yield**

The effects of climate resilient cultural practices and sole cropping on grain yield of faba bean are presented in Tables 5 and 6. There were significant ($P \leq 0.05$) differences in faba bean grain yield due to climate change resilient cultural practices at Haramaya in 2012 and at both Haramaya and Arbarakate during the 2013 cropping season. Significant differences were also found between Degaga and Bulga-70 at both locations in 2013 but not at Haramaya in 2012. Both faba bean varieties gave higher grain yield in the different treatments at both locations in 2013 than in the year 2012. The grain yield of faba bean obtained at Arbarakate was even higher than that of Haramaya. Thus, the faba bean overall mean grain yield was higher by 161.67% for Degaga and by 142.31% for Bulga-70 at Haramaya in 2013 than in 2012 main cropping season.

The highest grain yields were consistently obtained from non-intercropped (furrow planting and/or compost fertilization and/or furrow planting with compost application) and sole cropped plots at both locations and years. Among those treatments that produced higher faba bean grain yield at Haramaya, furrow planting with compost fertilization resulted in the highest (3.47 t $ha^{-1}$ in 2012 and 4.25 t $ha^{-1}$ in 2013) faba bean grain yield. Furrow planting with compost fertilization also produced the maximum (5.29 t $ha^{-1}$) faba bean grain yield at Arbarakate in 2013. It was followed by compost fertilization at both locations (4.14 t $ha^{-1}$ at Haramaya and 4.99 t $ha^{-1}$ at Arbarakate) in 2013. However, furrow and sole row planting resulted in production of the highest faba bean grain yields next to furrow planting with compost fertilization at Haramaya in 2012.

In both cropping seasons at Haramaya and Arbarakate, faba bean grain yields of each sole row planting were also greater than the grain yield of their respective intercrops. The lowest faba bean grain yield was recorded for either intercropped or intercropping integrated treated plots as compared to non-intercropped and sole cropped treatments. The grain yield obtained at Haramaya ranged from 0.96 to 1.22 t $ha^{-1}$ (in 2012) and from 2.48 to 2.67 t $ha^{-1}$(in2013). The grain yield of faba bean at Arbarakate ranged from 2.99 to 3.29 t $ha^{-1}$ in 2013. Among intercropping integrated treatments, compost fertilization in row intercropping treated plots gave the highest (2.67 t $ha^{-1}$ at Haramaya and 3.29 t ha$^{-1}$ at Arbarakate) faba bean grain yield in 2013. However, furrow planting with compost fertilization in row intercropping treated plots at Haramaya resulted in a higher (1.22 t ha$^{-1}$) faba bean grain yield than others in 2012.

Table 5. Effects of integrated climate change resilient cultural practices on growth and yield parameters of faba bean (*Vicia faba*) at Haramaya, Ethiopia, during the 2012 and 2013 main cropping seasons.

| Treatment [1] | Haramaya[2] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2012 | | | | | 2013 | | | | |
| | Height (cm) | NPPP | NSPP | HSW (g) | Yield (t ha$^{-1}$) | Height (cm) | NPPP | NSPP | HSW (g) | Yield(t ha$^{-1}$) |
| **Faba bean variety** | | | | | | | | | | |
| Degaga | 1.59$^{a}$ | 12.59$^{a}$ | 2.86$^{a}$ | 55.02$^{a}$ | 2.27$^{a}$ | 1.68$^{a}$ | 17.99$^{b}$ | 3.03$^{a}$ | 60.09$^{a}$ | 3.67$^{a}$ |
| Bulga-70 | 1.56$^{a}$ | 13.58$^{a}$ | 2.78$^{b}$ | 47.89$^{b}$ | 2.08$^{a}$ | 1.65$^{a}$ | 21.60$^{a}$ | 3.01$^{a}$ | 49.57$^{b}$ | 2.96$^{b}$ |
| LSD (0.05) | 0.03 | 1.72 | 0.08 | 1.05 | 0.35 | 0.04 | 1.74 | 0.08 | 1.02 | 0.18 |
| **Resilient cultural practice** | | | | | | | | | | |
| SP | 1.55$^{bc}$ | 16.02$^{a}$ | 2.93$^{a}$ | 51.94$^{abc}$ | 3.36$^{a}$ | 1.65$^{a}$ | 19.93$^{abcd}$ | 3.10$^{a}$ | 54.99$^{ab}$ | 3.93$^{a}$ |
| FP | 1.55$^{bc}$ | 15.67$^{a}$ | 2.75$^{bc}$ | 53.73$^{a}$ | 3.18$^{a}$ | 1.64$^{a}$ | 18.17$^{cd}$ | 2.97$^{a}$ | 55.27$^{ab}$ | 3.90$^{a}$ |
| CA | 1.54$^{c}$ | 13.03$^{abc}$ | 2.90$^{ab}$ | 50.35$^{c}$ | 2.92$^{a}$ | 1.66$^{a}$ | 18.67$^{bcd}$ | 3.03$^{a}$ | 55.77$^{ab}$ | 4.14$^{a}$ |
| RI | 1.58$^{abc}$ | 11.58$^{bc}$ | 2.75$^{bc}$ | 50.40$^{c}$ | 1.10$^{b}$ | 1.68$^{a}$ | 21.58$^{abc}$ | 2.97$^{a}$ | 53.80$^{b}$ | 2.48$^{b}$ |
| FP + CA | 1.55$^{bc}$ | 14.80$^{ab}$ | 2.78$^{abc}$ | 52.74$^{ab}$ | 3.47$^{a}$ | 1.66$^{a}$ | 17.57$^{d}$ | 3.03$^{a}$ | 56.92$^{a}$ | 4.25$^{a}$ |
| FP + RI | 1.64$^{a}$ | 11.63$^{bc}$ | 2.73$^{c}$ | 51.06$^{bc}$ | 1.22$^{b}$ | 1.69$^{a}$ | 22.17$^{a}$ | 3.07$^{a}$ | 53.77$^{b}$ | 2.55$^{b}$ |
| CA + RI | 1.62$^{ab}$ | 10.22$^{c}$ | 2.90$^{ab}$ | 50.59$^{c}$ | 0.96$^{b}$ | 1.68$^{a}$ | 18.63$^{bcd}$ | 2.97$^{a}$ | 54.25$^{b}$ | 2.67$^{b}$ |
| FP + CA + RI | 1.59$^{abc}$ | 11.73$^{bc}$ | 2.80$^{abc}$ | 50.83$^{bc}$ | 1.22$^{b}$ | 1.68$^{a}$ | 21.67$^{ab}$ | 3.00$^{a}$ | 53.86$^{b}$ | 2.60$^{b}$ |
| LSD (0.05) | 0.07 | 3.45 | 0.15 | 2.11 | 0.71 | 0.08 | 3.48 | 0.17 | 2.04 | 0.37 |
| CV (%) | 3.55 | 22.33 | 4.65 | 3.48 | 27.51 | 3.94 | 14.89 | 4.68 | 3.15 | 9.39 |

Note: [1]SP, sole planting; FP, furrow planting; CA, compost application; RI, row intercropping; FP + CA, furrow planting with compost application; FP + RI, furrow planting in row intercropping; CA + RI, compost apllication in row intercropping; and FP + CA + RI, furrow planting with compost application in row intercropping.

[2] *NPPP, number of pods per plant; NSPP, number of seeds per pod; and HSW, hundred seed weight.*

*Means in each column followed by the same letter are not significantly different at 5% probability level.*

Table 6. Effects of integrated climate change resilient cultural practices on growth and yield parameters of faba bean (*Vicia faba*) at Arbarakate, Ethiopia, during the 2013 main cropping season.

| Treatment [1] | Arbarakate[2] | | | | |
|---|---|---|---|---|---|
| | Height (cm) | NPPP | NSPP | HSW (g) | Yield (t ha$^{-1}$) |
| **Faba bean variety** | | | | | |
| Degaga | 1.67$^{a}$ | 20.30$^{a}$ | 3.03$^{a}$ | 60.10$^{a}$ | 4.26$^{a}$ |
| Bulga-70 | 1.64$^{b}$ | 21.21$^{a}$ | 3.01$^{a}$ | 49.36$^{b}$ | 3.71$^{b}$ |
| LSD (0.05) | 0.03 | 1.34 | 0.08 | 0.82 | 0.19 |
| **Resilient cultural practice** | | | | | |
| SP | 1.63$^{ab}$ | 20.60$^{ab}$ | 3.03$^{a}$ | 54.59$^{abc}$ | 4.79$^{b}$ |
| FP | 1.62$^{b}$ | 19.20$^{b}$ | 3.03$^{a}$ | 55.06$^{abc}$ | 4.34$^{c}$ |
| CA | 1.64$^{ab}$ | 21.47$^{ab}$ | 3.00$^{a}$ | 56.08$^{a}$ | 4.99$^{ab}$ |
| RI | 1.68$^{ab}$ | 21.97$^{a}$ | 2.97$^{a}$ | 53.82$^{c}$ | 3.14$^{d}$ |
| FP + CA | 1.63$^{b}$ | 19.97$^{ab}$ | 3.03$^{a}$ | 55.72$^{ab}$ | 5.29$^{a}$ |
| FP + RI | 1.67$^{ab}$ | 20.33$^{ab}$ | 3.10$^{a}$ | 54.07$^{c}$ | 2.99$^{d}$ |
| CA + RI | 1.69$^{a}$ | 20.33$^{ab}$ | 3.00$^{a}$ | 54.23$^{bc}$ | 3.29$^{d}$ |
| FP + CA + RI | 1.67$^{ab}$ | 22.17$^{a}$ | 3.00$^{a}$ | 54.29$^{bc}$ | 3.05$^{d}$ |
| LSD (0.05) | 0.06 | 2.68 | 0.16 | 1.64 | 0.39 |
| CV (%) | 2.98 | 10.95 | 4.43 | 2.54 | 8.29 |

Note: [1]SP, sole planting; FP, furrow planting; CA, compost application; RI, row intercropping; FP + CA, furrow planting with compost application; FP + RI, furrow planting in row intercropping; CA + RI, compost apllication in row intercropping; and FP + CA + RI, furrow planting with compost application in row intercropping.
*[2] NPPP, number of pods per plant; NSPP, number of seeds per pod; and HSW, hundred seed weight.*
*Means in each column followed by the same letter are not significantly different at 5% probability level.*

### 3.6. Land Equivalent Ratio (LER)

Evaluation of intercropping advantage was performed on the basis of LER of intercropping index and, hence, the significance of higher faba bean grain yield gain from sole and non-intercropping planted plots could be explained using LER. The total LER values computed for faba bean at Haramaya in 2012 and at both locations in 2013 are presented in Table 7. The total LER values for intercropped plots were more than one at both locations and years. The values at Haramaya ranged from 1.02 to 1.16 in 2012 and 1.63 to 1.76 in 2013. Similarly, LER values ranged from 1.55 to 1.76 at Arbarakate in 2013. Maximum grain yield advantages of 16% were obtained at Haramaya in 2012 and 76% at both Haramaya and Arbarakate areas in 2013. The highest (1.76) LER value was obtained when faba bean was row intercropped with maize at both locations in 2013, indicating grain yield benefit from 1.76 hectares of sole faba bean crop could be obtained from one hectare of intercropped faba bean and could increase productivity by 76% over the sole planting of each crop.

Table 7. Effects of intercropping systems on grain yield (t ha$^{-1}$) and total land equivalent ratio (LER) of faba bean at Haramaya and Arbarakate, Ethiopia during the 2012 and 2013 main cropping seasons.

| Treatment [1] | Haramaya | | | | | | Arbarakate | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2012 | | | 2013 | | | 2013 | | |
| | Grain yield (t ha$^{-1}$) | | Total LER | Grain yield (t ha$^{-1}$) | | Total LER | Grain yield (t ha$^{-1}$) | | Total LER |
| | Faba bean | Maize | | Faba bean | Maize | | Faba bean | Maize | |
| SP | 3.36 | 6.39 | | 3.93 | 2.61 | | 4.79 | 2.54 | |
| RI | 1.10 | 4.88 | 1.09 | 2.48 | 2.64 | 1.64 | 3.14 | 2.69 | 1.71 |
| FP+RI | 1.22 | 5.08 | 1.16 | 2.55 | 2.66 | 1.67 | 2.99 | 2.34 | 1.55 |
| CA+RI | 0.96 | 4.69 | 1.02 | 2.67 | 2.83 | 1.76 | 3.29 | 2.72 | 1.76 |
| FP+CA+RI | 1.22 | 4.89 | 1.13 | 2.60 | 2.54 | 1.63 | 3.05 | 2.48 | 1.61 |

Note: [1] SP, sole planting; RI, row intercropping; FP + RI, furrow planting in row intercropping; CA + RI, compost application in row intercropping; and FP + CA + RI, furrow planting with compost application in row intercropping.

## 4. Discussion

The study demonstrated that cropping systems significantly affected gravimetric soil moisture content and soil temperature at Haramaya during the 2013 main cropping season. The most integrated climate resilient cultural practices generally resulted in higher soil moisture and lower soil temperature than the sole planted faba bean. This present observation corroborates the findings of Choudhary *et al.* (2012) and

Naresh *et al.* (2014) who reported that higher soil moisture and lower soil temperature for maize-cowpea intercrops than for maize sole crop. Dahmardeh and Rigi (2013) found that maize-green gram intercrops had lower soil temperature than sole cropped maize. Similarly, El Naim *et al.* (2013) reported that sorghum-cowpea intercrops resulted in higher soil moisture content over a sorghum pure stand.

Increase in soil moisture and reduction in soil temperature due to the most integrated climate resilient cultural practices of maize-faba bean planting might be explained by high canopy cover and early enclosure of the ground and less light penetration in intercrops. This, in turn, might reduce soil temperature and rate of evaporation and, further, increase soil moisture. Similarly, Dahmardeh and Rigi (2013) and Ghanbari *et al.* (2010) noted that reduced soil moisture content in the sole crop of maize was due to high evaporation potential as a result of lower soil cover. There was more shading in the soil surface in intercropping at high ratio of planting that may have caused low evaporation and high moisture in soil causing low soil temperature (Ghanbari *et al.*, 2010). Olasantan and Babalola (2007) observed that mixed stands reduced soil temperature and increased soil moisture due to ground cover in melon-maize or cassava intercropping, which consequently led to reduction in solar radiation, diurnal soil temperatures, and evapotranspiration.

Plant height was strongly influenced by cropping systems both in 2012 and 2013. At both Haramaya and Arbarakate locations, intercropping and intercropping integrated treatments tended to have taller plants of faba bean, which might be due to severe competition between faba bean and maize to reach and capture light and shading of maize. Both faba bean varieties sown at both locations grew taller in 2013 than in 2012 since the latter cropping season was characterized by a relatively lower precipitation. Previous studies also indicated that plant height of faba bean increased when intercropped with safflower (Abo-Shetaia, 1990); taller faba bean plants were recorded for maize-faba bean row intercropping than sole cropping (Tilahun, 2003). Similarly, Peksen and Gulumser (2013) found that bean-maize row intercropping resulted in the growth of taller plants than sole bean cropping due to more competition for light in the latter. Megawer *et al.* (2010) also reported that lupine underwent shading of barley canopy as a result of interspecific competition for light and exhausted most energy in elongation in barley-lupine intercrops.

Lower grain yields of faba bean were harvested in 2012 than in 2013 possibly due to erratic distribution and early cessation of rainfall starting from the second week of September, which may have caused terminal stress in pod formation and pod filling growth stages of faba bean. Similar results were reported by Ali *et al.* (2013) who found that poor distribution and early termination of rainfall during the cropping season caused moisture deficit and adversely affected productivity. Ghassemi-Golezani *et al.* (2009) also pointed out that water deficit can reduce dry matter accumulation, crop growth rate and relative growth rate and, consequently, reduced grains per plant and grain weight of faba bean. The present data demonstrated that non-intercropped and sole cropped plots produced higher grain yield than other resilient cultural practices, implying intercropping strongly influenced faba bean grain yield. These treatments also generally gave heavier seed weights. Tilahun (2003) found in maize-faba bean intercropping that sole planting gave higher faba bean grain yield than maize-faba bean intercrops. In common bean-maize double intercropping, Tamado *et al.* (2007) showed that sole cropped common bean gave significantly higher seed yield than intercropped bean. Similar results were also reported by Fininsa (1997) in bean-maize mixed and row intercropping.

Possibly higher grain yields and heavier 100-seed weights of faba bean harvested from non-intercropped and sole planting plots in this study might be related to availability of more nutrients and less inter-specific competition in sole crops for available resources than the intercropping systems. In addition, maize plants might have shaded faba bean due to its stature in intercropping and reduced the amount of light transmission required for growth that would result in etiolated growth and poor pod setting in faba bean. In agreement with this current finding, Adeniyan *et al.* (2007) and Khan *et al.* (2012) identified that competition for nutrients, moisture, space and solar radiation was responsible for yield reduction in intercrops. Huaggaard-Nielsen and Jensen (2001) also reported greater competitive ability of barley when intercropped with pea, and wheat when intercropped with chickpea for resources may cause shading and, thereby, reduce growth in the legume resulting in low yields.

Earlier studies also revealed that light interception was one of the yield limiting factors in intercrops. Accordingly, Yilmaz *et al.* (2008) indicated that soybean-maize intercrops had lower light interception and, as a result, severe competition occurred. In maize-cowpea intercrops, Legwaila *et al.* (2012) reported that maize shadowed cowpeas and reduced the amount of light required to stimulate flower production in cowpeas; and Khan *et al.* (2012) reported a similar observation in maize-mungbean intercrops. Furthermore, the superiority of sole lupine over barley-lupine intercropping systems was due to shading and lupine exhausted most energy in elongation and vegetative growth and less during grain filling period (Megawer *et al.*, 2010).

The present findings revealed that furrow planting with compost fertilization gave the highest faba bean grain yield, followed by compost fertilization. Among intercropping integrated treatments, compost fertilization in row intercropping generally produced higher faba bean grain yield and lower relative grain yield loss than other treatments. These treatments also reduced both faba bean rust and chocolate spot severity (Terefe *et al.*, 2015; Terefe *et al.* submitted). In 2012, furrow planting integrated intercropping systems led to lower relative grain yield losses, suggesting the vital role of furrow planting in moisture stress areas and compost fertilization to maintain productivity. This could reduce crop failure and increase resilience to climate variability effects. Several authors also reported yield gains due to compost application on different crops. Riahi *et al.* (2009) showed that compost amendments gave greater total and marketable yields of tomato. In their study on the influence of organic fertilization on maize and legumes, Bilalis *et al.* (2012) reported the highest legume root diameter, density and dry weight under compost fertilization, where the faba bean had high biomass. Similarly, Adeyeye *et al.* (2014) reported that compost application had a significant effect on all yield parameters of soybean, which were higher than those with no compost.

The high faba bean grain yield due to furrow planting and compost fertilization could be attributed to moisture retention and slow and steady availability of nutrients throughout the crop growth period, which, in turn, might have boosted the faba bean grain yield. Moreover, this treatment might improve soil physico-chemical properties, which might have resulted in loose and friable soil conditions and enabled better yielding capacity. Similarly, Adeyeye *et al.* (2014) noted that an increase in all yield parameters of soybean due to compost application indicates essentiality of N nutrition as a starter for optimum soybean productivity. Bedada *et al.* (2014) indicated that application of compost helps in improving the physico-chemical properties of soil and provides a better soil environment for biological activity. Ngwira *et al.* (2013) also reported that compost use resulted in increases in soil organic C, total N, and available P and soil pH essential for optimum crop growth. This was what was observed from the applied compost in this study where high essential elements were found. Thus, compost fertilization could be an option to agricultural land management practice and climate change adaptation strategies. Studies by Bryan *et al.* (2013) on adaptive strategies by subsistence farmers to climate change also pointed out that composting or manure, intercropping, residues and soil bunds are the most common practices that can increase productivity, soil fertility and increase in water-holding capacity of the soil.

Furthermore, Zemánek (2011) proposed a positive influence of compost on soil water and soil moisture retention. On the other hand, Xiaoli *et al.* (2013) found an increase in soil moisture, grain yield and harvest index of corn and water use efficiency in an integrated furrow-applied mulching system. The system is likely to reduce soil evaporation loss. Hu *et al.* (2014) also reported that rainwater-harvesting through mulching, ridging and furrow planting increased water use efficiency and, hence, an increase in marketable potato yields. These systems in different orientations also accumulated higher dry matter and increased relative growth rate, gave the highest tuber yield and increased water use efficiency through reduced evapotranspiration (Qin *et al.*, 2014). Moreover, Feng *et al.* (2012) indicated that ridge-furrow planting system harvested more rain water and conserved soil moisture and, consequently, increased dry matter and grain yield of *Elymussibiricus*.

Faba bean grain yields from intercrops were lower than their respective sole planting, and the total land productivity was much higher in intercrops than in sole crops, which is supported by total LER values (observed to be more than one). The values computed in 2013 were even higher than the values from previous studies. This finding agrees with the results of Agegnehu *et al.* (2008) who found that in barley-faba bean intercropping, all intercrops had greater LER values than in sole crops of both components. Tilahun (2003), Minale *et al.* (2002) and Tilahun *et al.* (2012) also reported greater computed LER values than one in all the intercrops of maize-faba bean intercropping. Similarly, Dusa and Stan (2013) reported greater LER values in oat-pea or lentil intercropping systems, implying the efficiency of resource use in intercropping relative to sole crop. The high intercropping advantage during the specified cropping season could be due to resource use efficiency; decrease in diseases, pests and weed build-up (Jensen *et al.*, 2010); and soil moisture retention and cooled soil temperature as revealed by this study.

The overall results of the study revealed that faba bean performed better and produced relatively higher grain yield at Arbarakate than at Haramaya in 2013. This might be attributed to differences in the suitability of the two locations for growth and development of the crop. Thus, Arbarakate is characterized by extended period of rainfall, higher altitude and better soil conditions, which may have favored the growth and development of the crop over Haramaya. Tamene (2015) also reported that environmental effects accounted for 73.6% of the total yield variation among faba bean genotypes evaluated compared to genotype and genotype x environment interactions. Concurrent with the results of this study, an experimental location at higher altitude with high rainfall amount and even distribution resulted in higher grain yield and dry biomass weight in faba bean varieties tested compared to an experimental location with a relatively lower altitude (Ashenafi and Mekuria, 2015).

## 5. Conclusions

Intercropping integrated climate resilient cultural practices significantly increased soil moisture content by cooling the soil temperature and enhancing soil moisture content compared to sole faba bean planting. These practices also generally led to the production of higher faba bean grain yields per unit area. Sole planting and non-intercropping treatments produced significantly higher total faba bean grain yield than that of both intercropping and intercropping integrated treatments. However, the land productivity index indicated the advantages of intercropping of faba bean and maize. Among intercropping integrated treatments, compost fertilized systems produced the highest faba bean grain yield, particularly compost fertilization in row intercropping. Moreover, the overall faba bean grain yield obtained from compost fertilization along with furrow planting or in combination with other climate change resilient cultural practices enhanced productivity of faba bean in Hararghe highlands. It is, therefore, concluded that integrated climate resilient cultural practices are proved to be more productive than sole cropping of the two faba bean varieties tested and with promising capacity to mitigate effects of climate variability. Practicing the integrated climate resilient cultural practices may benefit farmers through increased productivity and can diversify produces and food resources via reduced inputs and non-chemical means in the face of climate variability. These practices are economical and eco-friendly for maintaining productivity and managing faba bean diseases. It is suggested to further directly investigate the effect of compost on yield and quality of crops as well as on soil physico-chemical properties.

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# Bean Quality Attributes of Arabica Coffees Grown in Ethiopia and the Potential for Discovering New Specialty Coffees

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**Abstract**: Coffee beans with unique flavour profiles that are produced in special geographical microclimates are known as specialty coffees. Specialty coffees have high niche markets and fetch premium prices. Bean quality attributes of coffees produced in Ethiopia are often determined based on results of green coffee bean assessment done on arrivals in the central market by Ethiopian Commodity Exchange (ECX) Company. This research was, therefore, conducted with the objective of studying bean quality attributes of coffees originating from distinct major and minor coffee growing regions in Ethiopia and to explore the potential for finding new specialty coffees using the methods employed by the Ethiopian Commodity Exchange (ECX) company and those employed by Efico (Belgian coffee company). Seventy coffee bean samples were collected from 24 locations representing four traditional coffee producing regions in Ethiopia (south-western, southern, western, and eastern regions) and one newly emerging (north-western) region. Red coffee cherries were collected by handpicking. The green coffee beans were sun-dried, hulled, and subjected to sensory evaluation using the aforementioned methods. The results revealed that location did not have significant effects on all coffee quality attributes (cup cleanness, acidity, body, flavour, total point, preliminary grade, aroma, aftertaste, balance, perfumed, and overall attributes) except hundred bean weight and bean moisture content. The preliminary quality attributes for the unwashed coffee samples indicated that more than 65% of the samples attained the grade point 2. Most of the specialty coffee quality attributes attained high score points for all regions. Thus, based on the cup quality test done by Efico, about 75.7% of the samples fitted specialty grade 1, 18.6% fitted specialty grade 2 (premium grade), and 5.7% fitted specialty grade 3 (commercial grade). Furthermore, based on this test, four additional specialty coffees, namely, Kabo, Kossa, Gore, and Anfilo were identified. However, based on the cup quality test done by Ethiopian Commodity Exchange (ECX) company, only 7% of the samples fitted specialty grade 1, 40.1% specialty grade 2, and the remaining 48.6% fitted specialty grade 3 (commercial grade). In conclusion, the study revealed that almost all coffee beans originating from the distinct coffee growing geographical regions in the country have comparably superior bean quality attributes, with about 3/4th of the samples falling in the category of the specialty grade, and there is high potential to discover new specialty coffees in the regions using the Efico method rather than the ECX method.

**Keywords**: Coffee origins; Coffee industry; Commercial grade; Cup quality test; Efico; Ethiopian Commodity Exchange (ECX); Specialty grade.

## 1. Introduction

A number of countries have expanded their coffee production and export volumes. Newly emerging coffee-producing countries have become strong competitors in the world coffee market. Thus, it does not seem feasible for developing countries like Ethiopia to overcome coffee marketing challenges and threats in the world only through expansion of production. Supplying high quality specialty coffees could be a viable option to persist in the competitive and fluctuating world coffee market for Ethiopia (Behailu *et al*., 2008).

Coffee market distinguishes exemplary, premium, and mainstream categories. Although between 80% and 90% of the coffee consumed worldwide is a mainstream quality, there are many other coffees, often of limited availability, with greatly varying taste characteristics that appeal to different groups of consumers, and are sold at a premium over the mainstream coffees (Donnet and Weatherspoon, 2006). Therefore, quality and availability determine whether a coffee can find a niche market under the influence of the international trade. The potential for specialty coffee consumption appears to be almost limitless. In fact, no more than 5% of green coffees could make specialty grade (ITC, 2011).

Arabica coffee, which originated in Ethiopia, has a long and well established root for which the country is most known for its tradition. In Ethiopia, more than 6000 Arabica coffee accessions have been collected and preserved by research centres, out of which 37 have been released (Taye, 2012). Recently, coffee research and development has been designed as a coffee growing area-based strategy with the initiative of multiplying and distributing specialty coffee varieties in their respective locality. Moreover, coffee quality testing and grading has been decentralized to keep up with growing area-specific traits. A study made in Ethiopia revealed significant

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variations due to location, genotype, and processing methods for most coffee quality traits, in which the overall quality was improved in a descending order of washed, semi-washed, and sun-dried coffees. Quality expression of genotypes was also found to be location-specific (Mekonen, 2009).

Ethiopia has already a number of specialty coffees with their own appellations such as Yirgachaffe Coffee, Harar Coffee, and Sidama coffee. However, the country is facing stiff competitions in the international market from increasing numbers of specialty coffees being discovered and produced in other countries (Dessie, 2008). Fortunately, Ethiopia possesses favourable agro-ecologies and microclimate to produce unique coffee types (Dessie, 2008). However, this potential has not yet been exploited to a desired level since little work has been done to identify and label specialty coffees in the main coffee growing regions of the country. Therefore, the country needs to explore and identify new specialty coffees rigorously to sustain and develop its coffee industry and foreign exchange earnings.

The information on the quality of coffee in Ethiopia is mostly based on assessment of green coffee beans on arrivals in the central market by Ethiopian Commodity Exchange (ECX) Company. Thus, systematic and rigorous tests on the profile of Ethiopian Arabica coffee quality attributes associated with origins of the coffees have not yet been done. Thus, the objective of this research was to determine the profile of Ethiopian Arabica coffee quality attributes based on origin by using both ECX methods and the methods employed by Efico (Belgian coffee company), and to identify specialty coffees. The study was also intended to compare the rigour of the two methods in discerning coffee bean quality attributes.

## 2. Materials and Methods

### 2.1. Site Selection and Sample Preparation

The study regions included the major coffee growing areas stretching between $30^0$ 30' to $14^0$ 55' North latitude and 330 to $48^0$ East longitude (Figure 1. and Table 1). The regions and locations in the regions were purposely selected considering the natural barriers and/or spatial location and agro climatic situation. Twenty-four coffee farms (Table 2) were selected from South-western (n = 33); Western (n = 9); Southern (n = 3); North-western (n = 12); and Eastern (n = 13) regions. Coded samples of green coffee beans with moisture contents ranging between 8.8 - 10% were used as an experimental material. A total of 70 coffee bean samples from the five regions were obtained by the dry or unwashed coffee processing method viz. red ripe cherries were handpicked, sun dried, and hulled. The coffee samples were carefully prepared and handed over to Ethiopian Commodity Exchange (ECX) (100 g), Jimma Centre and Efico (50g) in Belgium. A panel of 3-4 trained cuppers evaluated the coffee quality attributes in each case.

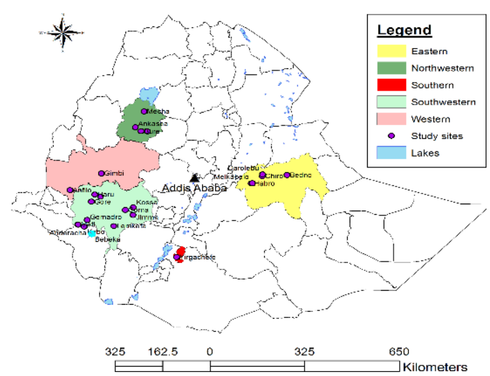


Figure 1. Map of coffee growing regions in Ethiopia from where the green coffee bean samples were collected.

Table 1. Mean annual weather data and altitudinal range of the geographical regions.

| Geographical Regions (Locations) | Climatic Factors | | | | | Altitude range (m a.s.l.) |
|---|---|---|---|---|---|---|
| | RF (mm) | MAX ($^0$C) | MIN ($^0$C) | RH (%) | Sunshine (HRS/day) | |
| Eastern (26 yrs) | 643.7 | 27.8 | 12.8 | NA | NA | 1874 - 2266 |
| North-western (23 yrs) | 1140.5 | NA | NA | NA | NA | 1774 - 2000 |
| Southern (30 yrs) | 1345.7 | 26.6 | 11.7 | 69 | 5.7 | 2091 |
| South-western (30 yrs) | 1564.9 | 26.1 | 13.2 | 73.3 | 5.4 | 1150 - 1820 |
| Western (28 yrs) | 1385.2 | 25.6 | 13.9 | 70.5 | 6.5 | 1800 - 1907 |

*Note: NMSA = National Meteorological Services Agency; NA = data not available; RF mm = rainfall in mm; MAX ($^0$C) = maximum temperature; MIN ($^0$C) = Minimum temperature; RH (%) = Relative humidity; HRS = hours; m a.s.l. = metres above sea level.*
*Source*: NMSA, Ethiopia (2010).

Table 2. Origins of unwashed green coffee bean samples in Ethiopia.

| Farm | N=70 | Location | Adm. Region | Adm. Zone | Latitude | Longitude |
|---|---|---|---|---|---|---|
| Bebeka | 3 | Southwest | SNNP | Benchmaji | 6.99442 | 35.5684 |
| Anderacha | 3 | Southwest | SNNP | Godere | 7.23987 | 35.3169 |
| Kabo | 3 | Southwest | SNNP | Godere | 7.24124 | 35.3197 |
| Meti | 3 | Southwest | SNNP | Godere | 7.32297 | 35.1288 |
| Gemadro | 3 | Southwest | SNNP | Sheka | 7.48639 | 35.4131 |
| Lemkefa | 3 | Southwest | SNNP | Kafa | 7.27274 | 36.2427 |
| Jimma | 3 | Southwest | Oromia | Jimma | 7.67884 | 36.8385 |
| Kossa | 3 | Southwest | Oromia | Jimma | 7.95452 | 36.8468 |
| Goma | 3 | Southwest | Oromia | Jimma | 7.85752 | 36.5885 |
| Yayo | 3 | Southwest | Oromia | Illuababora | 8.33601 | 35.8226 |
| Gore | 3 | Southwest | Oromia | Illuababora | 8.14905 | 35.5369 |
| Gimbi | 3 | West | Oromia | West Wollega | 9.17125 | 35.8359 |
| Haru | 3 | West | Oromia | West Wollega | 8.40717 | 35.6396 |
| Anfilo | 3 | West | Oromia | Kelem Wollega | 8.55386 | 34.8651 |
| Yirgachaffe | 3 | South | SNNP | Gedeo | 6.15848 | 38.1958 |
| Jabi | 3 | Northwest | Amhara | West Gojam | 10.6918 | 37.2665 |
| Bure | 3 | Northwest | Amhara | West Gojam | 10.7003 | 37.0668 |
| Ankasha | 3 | Northwest | Amhara | West Gojam | 10.8436 | 36.8914 |
| Mecha | 3 | Northwest | Amhara | West Gojam | 11.417 | 37.1557 |
| Chiro | 2 | East | Oromia | West Hararghe | 9.06989 | 40.8646 |
| Habro | 3 | East | Oromia | West Hararghe | 8.81697 | 40.5167 |
| Darolabu | 3 | East | Oromia | West Hararghe | 9.14549 | 40.8691 |
| Malkaballo | 2 | East | Oromia | East Hararghe | 8.82672 | 40.5499 |
| Badano | 3 | East | Oromia | East Hararghe | 9.11447 | 41.6335 |

*Note: Adm. = Administrative.*

### 2.2. Laboratory Analysis and Procedures

According to the Specialty Coffee Association of America (SCAA, 2009) protocol the raw and cup quality analyses were conducted and evaluated on 40% and 60%, respectively.

#### 2.2.1. Raw quality analysis

A green coffee bean sample weighing 100 g was used for the raw evaluation test before roasting, and primary and secondary defects, shape and make, colour, and odour of the coffee samples were assessed according to the procedure developed by Ethiopian standard, and based on the green coffee reference chart (QSAE 4257, 2000). The evaluation scores for the tested unwashed coffee are shown in Table 7. The weight of 100 beans (HBW) for each sample was measured using a sensitive balance. Moisture content (MC%) of the green coffee beans was determined with SINAR AP 6060 coffee moisture analyzer, UK.

#### 2.2.2. Roasting and brew preparation

Batch roaster equipped with a cooling system, in which air was forced through a perforated plate, capable of roasting up to 500 g of green coffee beans, was used for roasting the coffee beans. A 100 g of bean was used for each sample and the beans were carefully roasted at the temperature of 170 - 200 $^0$C to a medium brown roast colour (7 – 8 minutes).

The roasted beans were ground to a medium level using the Guatemala SB coffee grinder. Then, the powder was brewed. The water used for brewing contained 0.3 mmol to 1.2 mmol of calcium carbonate ($CaCO_3$), which was free from chlorine or other foreign flavour affecting factors. Using the preheating graduating cylinder, 150 ml of boiled water (93 $^0$C) was poured into a cup containing 12 g roasted coffee powder and the infusion was allowed to steep for approximately 4 minutes to settle. The cup was then evaluated for its aroma and the surface of the beverage skimmed off to remove foams after which the beverage was cooled down up to a comfortable temperature (55 $^0$C) for tasting (ISO, 1991).

#### 2.2.3. Cup quality analysis

Coffee bean samples were evaluated for all cup quality attributes and summed up to 60 out of 100%. A panel of trained, experienced and internationally certified (Q graders) cuppers took 6 to 8 cc of the brew from 5 cups using soupspoons and forcefully slurped it to spread evenly over the entire surface of the tongue and palate and then expectorated on to the spittoon. Cup cleanness, acidity, body, and flavour were evaluated in accordance with the standard method (ECX, 2009). The results are shown in Table 9. Finally, the preliminary grade assessment was made based on the scores of the raw and cup quality analyses.

With regard to specialty assessment by Efico, aroma, acidity, flavour, body, aftertaste, and balance attributes were evaluated. Then, the overall score was calculated as an average of the six attributes. Aftertaste has a preference rating on a scale of 1 to 10, ranging from "Very Poor" to "Outstanding." Flavour receives a preference rating on a scale of 1 to 10, ranging from "very poor" to "outstanding." Cuppers' Points (balance) are a critically important preference rating and are awarded on a scale of -5 to +5, in a range from "very poor" to "outstanding." Cuppers rank acidity according to its intensity, which ranges from 1 – "very flat," to 3 – "very soft," to 5 – "slight sharp," to 7 – "very sharp," to 10 – "very bright." Body is given an intensity ranking on a scale of 1 to 10, ranging from 2 – "Thin," to 4 – "light," to 6 – "full", to 9 – "heavy. "Fragrance/aroma is a preference rating, and ranges from Zero (not rated) to 10, and Plus 1 to Plus 5 means "very poor" to "average; " Plus 6 to Plus 10 means "good" to "outstanding" (Marsh and De Laak, 2006; SCAA, 2009).

### 2.3. Data Analysis

A one-way analysis of variance was conducted using SPSS 16 v2 software. Moreover, covariance analysis was done to distinguish percentage contribution of predictors to the variation in coffee quality attributes. In addition, the frequency distribution of coffee quality attributes with respect to score points was done.

## 3. Results

### 3.1. Hundred Seed Weight and Moisture Content

Locations did not have a significant influence on all coffee quality attributes except hundred bean weight (HBW). Coffee beans originating from the eastern region had significantly ($P < 0.001$) higher mean values of HBW than those from the north-western region. The hundred seed weights of coffee beans that originated from the other regions were all in statistical parity with the hundred seed weight of beans from both the eastern and north-western regions (Table 3).

The moisture content of coffee beans that originated from the north-western region was significantly higher than the one that originated from the southern region. However, the moisture contents of coffee beans from the other regions were all in statistical parity with the moisture content of bean obtained from both the north-western and southern regions (Table 4).

Table 3. Effect of growing region on preliminary coffee quality attributes (mean ± SE of the mean).

| Location | N | HBW | Primary Defect | Secondary Defect | Odour | Acidity | Body | Flavour | Total Point | Preliminary Grade | Specialty | Cup Cleanness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| South-western | 33 | 15.8±0.3 [ab] | 14.5±0.4 | 11.6±0.6 | 9.9±0.1 | 11.4±0.2 | 10.1±0.3 | 9.9±0.3 | 82.4±1.1 | 2.3±0.1 | 80.6±0.6 | 15±0.0 |
| Western | 9 | 15.8±0.4 [ab] | 14.7±0.3 | 11.0±1.0 | 10.0±0.0 | 11.3±0.4 | 10.0±0.5 | 11.3±0.7 | 83.3±1.9 | 2.1±0.2 | 81.9±1.2 | 15±0.0 |
| Southern | 3 | 14.9±0.2 [ab] | 15.0±0.0 | 15.0±0.0 | 10.0±0.0 | 12.0±0.0 | 10.0±1.0 | 10.0±1.0 | 87.0±2.0 | 1.7±0.3 | 80.5±2.0 | 15±0.0 |
| North-western | 12 | 14.1±0.2 [b] | 14.8±0.3 | 11.1±1.2 | 9.7±0.2 | 11.0±0.4 | 9.8±0.4 | 10.5±0.5 | 81.8±1.1 | 2.3±0.1 | 80.0±0.6 | 15±0.0 |
| Eastern | 13 | 16.8±0.5 [a] | 15.0±0.0 | 13.2±0.8 | 10.0±0.0 | 11.1±0.4 | 10.4±0.4 | 10.2±0.6 | 84.8±1.5 | 2.0±0.2 | 79.6±1.6 | 15±0.0 |
| P | | < 0.001 | 0.923 | 0.229 | 0.228 | 0.755 | 0.879 | 0.320 | 0.433 | 0.435 | 0.729 | 1 |
| SD | | 1.6 | 1.7 | 3.5 | 0.4 | 1.3 | 1.4 | 1.8 | 5.6 | 0.7 | 3.9 | 0.0 |
| CV% | | 10.3 | 11.7 | 29.2 | 4.1 | 11.5 | 14.4 | 17.6 | 6.7 | 31.4 | 4.9 | 0.0 |

*Note: Means followed by same letter (s) within a column are not significantly different (P> 0.05); SE = Standard Error; HBW = Hundred Bean Weight (g).*

Table 4. Effect of growing region on specialty coffee quality attributes (Mean ± SE of the mean).

| Location | N | MC | Aroma | Body | Acidity | Balance | Fruity | Perfumed | Flavour | Aftertaste | Overall |
|---|---|---|---|---|---|---|---|---|---|---|---|
| South-western | 33 | 9.3±0.1 [ab] | 5.5±0.2 | 5.5±0.2 | 6.3±0.2 | 5.5±0.2 | 4.8±0.3 | 4.3±0.3 | 4.5±0.3 | 5.2±0.2 | 5.2±0.2 |
| Western | 9 | 9.6±0.2 [ab] | 5.8±0.2 | 5.6±0.2 | 6.2±0.2 | 5.8±0.1 | 5.9±0.6 | 5.1±0.4 | 5.3±0.4 | 5.8±0.3 | 5.7±0.3 |
| Southern | 3 | 8.8±0.1 [b] | 5.7±1.3 | 5.7±0.9 | 5.5±0.8 | 5.3±1.2 | 6.3±1.8 | 5.7±2.3 | 5.7±1.9 | 6.2±1.6 | 5.8±1.4 |
| North-western | 12 | 10.0±0.3 [a] | 6.3±0.3 | 6.3±0.2 | 6.8±0.2 | 6.2±0.2 | 5.1±0.8 | 5.5±0.5 | 6.0±0.4 | 6.3±0.3 | 6.1±0.2 |
| Eastern | 13 | 9.0±0.2 [ab] | 5.9±0.2 | 6.1±0.2 | 6.6±0.3 | 5.9±0.2 | 6.0±0.3 | 5.2±0.3 | 5.2±0.3 | 5.7±0.3 | 5.8±0.2 |
| P | | 0.009 | 0.185 | 0.059 | 0.369 | 0.144 | 0.219 | 0.180 | 0.068 | 0.154 | 0.092 |
| SD | | 0.8 | 1.0 | 0.9 | 1.1 | 0.9 | 2.0 | 1.7 | 1.7 | 1.3 | 1.0 |
| CV% | | 8.4 | 18.2 | 16.2 | 17.3 | 16.5 | 37.0 | 34.8 | 33.0 | 23.7 | 18.9 |

*Note: Means followed by same letter (s) within a column are not significantly different (P= 0.05); SE = Standard Error; MC = Moisture Content (%).*

### 3.2. Effect of Location to Specialty Coffee

The covariance analysis indicated that the effect of location on the variation in both preliminary and specialty coffee quality attributes was by far higher than the effect due to farms (Figures 2 and 3).

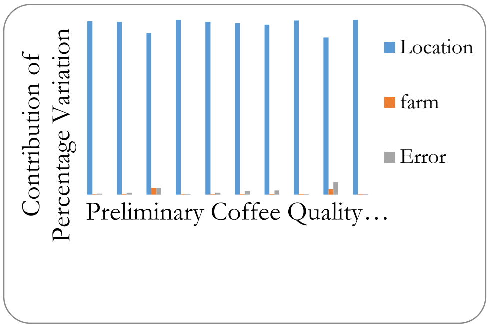


Figure 2. Percentage contribution of predictors for variation of preliminary coffee quality attributes; HBW = Hundred Bean Weight.

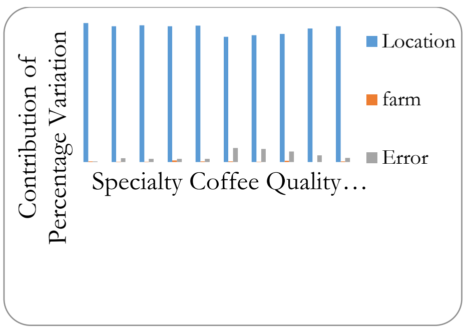


Figure 3. Percentage contribution of predictors for variation of specialty coffee quality attributes.

### 3.3. Distribution of Preliminary Quality Attributes

There were no differences among the coffee samples with respect to the cup-cleanness attribute. With respect to odour, 95.7% of the samples were invariably clean (10%) while 4.3%, were fairly clean. Samples could be grouped into two main categories based on acidity and body attributes (Figure 4). In both cases, the samples scored medium-pointed (75.5%) to medium (24.3%) for acidity, and medium-full (35.7%) to medium (64.3%) points for body. Moreover, 94.3% of the samples scored < 5 defects for the primary defect attribute while 4.3% and 1.4% scored 6% - 10% and 11% - 15% defects, respectively (Figure 4).

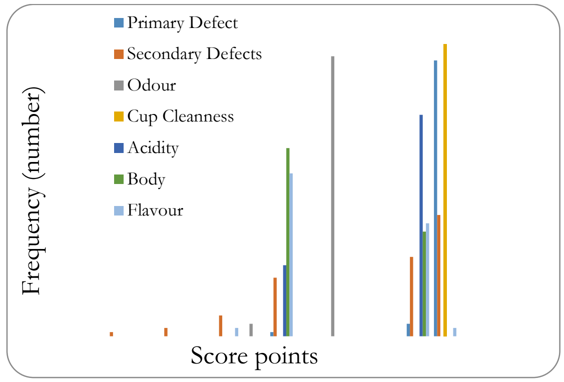


Figure 4. Distribution of preliminary quality attributes for unwashed coffee samples.

A distinction was made for the secondary defect weight attribute. With regard to this, 41.4% of the samples scored < 5% defects while 27.1% had < 10%. The remaining 20%, 7.1%, 2.9% and 1.4% of the samples scored <15%, <20%, <25% and >25% defect weights, respectively.

The most remarkable distinction was further observed based on the profile of flavour attribute in which micro-environmental factors may have played important roles. In this regard, it was noted that sub-farms (2.9%) of Anfilo and Kossa were sorted out with a score point of good while the remaining 38.6% of the samples had the score of fairly-good, 55.7% had average, and 2.9% had fair scores (Appendix Table 33). The distribution of the score values of preliminary quality attributes for the unwashed coffee samples indicated that 10% of the observed samples scored a preliminary grade of 1 while 65.8%, 21.4%, 1.4%, and 1.4% scored preliminary grade points of 2, 3, 4 and 5, respectively (Table 5). The distribution of the samples with respect to the preliminary grade assessment showed that one unit farm each at Kossa, Gore, Anfilo, Yirgachaffe, Chiro, Malkaballo, and Badano scored the grade 1 point. Farms including Meti, Gemadro (2 sub-farms), Lemkefa, Goma, Kossa, Gimbi (2 sub-farms), Bure (2 sub-farms), Mecha, Darolabu, Malkabelo, Bedeno and Ankasha scored grade 3 while the remaining samples from farms, namely, Bebeka, Anderacha, Kabo, Meti, Gemadro, Jimma, Kossa, Goma, Yayo, Gore, Gimbi, Haru, Anfilo, Yirgachaffe, Jabi, Bure, Ankasha, Mecha, Chiro, Habro, Darolabu and Badano scored the grade point of 2. The least preliminary grade was observed for coffee originating from Lemkefa, a semi-forest coffee farm. Re-evaluation for specialty by ECX gave 47.1% of the samples their Q1 and Q2 grades (Table 6).

Table 5. Preliminary grade distribution of unwashed coffee samples.

| Grade | Score points | Frequency | Percent |
|---|---|---|---|
| 1 | 91-100 | 7 | 10 |
| 2 | 81-90 | 46 | 65.8 |
| 3 | 71-80 | 15 | 21.4 |
| 4 | 63-70 | 1 | 1.4 |
| 5 | 58-62 | 1 | 1.4 |
| 6 | 50-57 | | |
| 7 | 40-49 | | |
| 8 | 31-39 | | |
| 9 | 20-30 | | |
| UG | 15 -19 | | |
| Total | | 70 | 100 |
| SD | | 0.69 | |

*SD = Standard deviation.*

Table 6. Specialty grade (by ECX) distribution of unwashed coffee samples.

| Grade | Frequency | Percent |
|---|---|---|
| Q1 | 5 | 7 |
| Q2 | 28 | 40.1 |
| Commercial 3 | 34 | 48.6 |
| Valid | 67 | 95.7 |
| Missing system | 3 | 4.3 |
| Total | 70 | 100 |
| SD | 3.904 | |

*SD = Standard deviation.*

**3.4. Distribution of Specialty Quality Attributes**

From the specialty cupping analysis point of view by Efico, all samples fitted the grade of 1 through 3 out of which 75.7% of the samples scored class 1 (specialty grade) while 18.6% and 5.7% scored class 2 (premium grade) and class 3 (commercial) grade, respectively (Table 7).

Table 7. Specialty grade (by Efico) distribution of unwashed coffee samples.

| Specialty grade | Frequency | Percent |
|---|---|---|
| 1 (Specialty) | 53 | 75.7 |
| 2 (Premium) | 13 | 18.6 |
| 3 (Commercial) | 4 | 5.7 |
| 4 (Below standard) | 0 | 0 |
| 5 (Off-grade) | 0 | 0 |
| Total | 70 | 100 |

Scoring by Efico indicated that 37.1% of the samples were below "good" for both aroma and body attributes (Figure 5). Coffee quality attributes, namely, acidity, balance, fruity, perfumed, flavour, and aftertaste contributed to 15.7%, 38.6%, 46.2%, 63%, 50% and 41.5% of the samples, respectively to score below "good" rating. Although "perfumed" and "flavour" attributes of most of the samples contributed to scores below "good" rating, most samples performed better with respect to "aroma", "body", "acidity", "balance", "fruity" and "aftertaste" quality attributes and hence were rated from "good' to "outstanding", which ultimately resulted in 94.3% of the samples attaining the specialty grades 1 and 2. In this regard, about 10% of the samples scored values less than 4 for aroma whereas about 10% scored values less than 5% rating while the 40% scored about 6% points for body. About 5.7% of the samples hade values less than 4 for acidity, and balance. With respect to flavour, about 50% of the samples showed poor rating (< 6%), while about 41.4% showed poor aftertaste (< 5%). Coffee samples from about 47.1% of the origins were fruity in their taste (< 5%), and about 58.6% of the origins were poorly perfumed (< 5%).

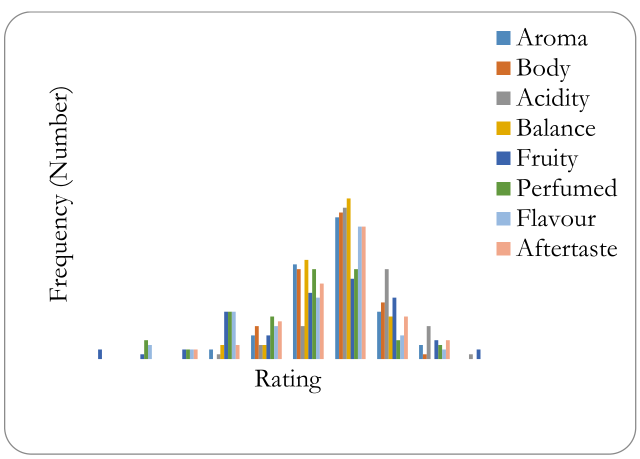


Figure 5. Distribution of specialty attribute of unwashed coffee samples.

As shown on Table 8 below, the trend for preliminary total points and grade scores showed increasing improvement from north-western to south-western to western to eastern to southern region. However, the trend for specialty (overall attribute) was improved from south-western to western to southern to eastern to north-western region.

Table 8. Trend for coffee quality by growing regions.

| Location | Overall specialty attribute (Efico) | Preliminary total point (ECX) | preliminary grade (ECX) |
|---|---|---|---|
| North-western | 6.1 | 81.8 | 2.3 |
| South-western | 5.2 | 82.4 | 2.3 |
| Western | 5.7 | 83.3 | 2.1 |
| Eastern | 5.8 | 84.8 | 2.0 |
| Southern | 5.8 | 87.0 | 1.7 |

## 4. Discussion

The differences observed in hundred bean weight among the locations could be due to differences in metabolism (physiology) of the coffee fruit development under the influence of moisture and temperature, which could be controlled by management, altitude, and soil moisture. That the highest bean weight was recorded for coffees originating from the eastern region could be ascribed to low temperature at the higher altitudes, which enhances slower fruit growth and better physiological maturity of the beans. This suggestion is consistent with that of Wrigley (1988) that the ultimate bean size is determined in the period of rapid fruit expansion following the pinhead stage and reflects the availability of soil moisture at this time. Similarly, Van der Vossen (1985) stressed that high altitudes are critical for the successful production of high quality Arabica coffees in equatorial regions. Lower temperatures, and their longer daily amplitudes, tend to induce slower growth and more uniform ripening of the berries, thereby producing larger and denser beans. Temperature reduces by $1^0$C for every 180 metres above sea level increment in altitude (Coste, 1992). A study by Srirat *et al.* (2007) at Agro-industry Kasetsart University indicated that uniform bean maturity enhances bean quality. Bean size and density is often correlated with aroma, flavour, and superior beverage quality. It is reported that the better quality of Arabica coffee at high altitudes is provided by the more intense UV radiation, which leads to the development of hard beans with more acidity in the taste (Alègre, 1959; Coste, 1992).

The variations in the green coffee bean moisture content could be attributed to the drying process, relative humidity of the drying site, and the warehouse used to store the coffee beans as well as physiological maturity of the bean. The moisture content of coffee beans is one factor to indicate that the coffee beans reached commercial standard quality (SCAA. 2009). The results revealed less variations in most of the preliminary and specialty coffee quality assessment scores among the locations and farms despite the variations in geography (climate, micro-environment, and soil), agronomic practices, genotypes, age of the coffee trees, and post-harvest management practices. Usually, coffee quality analyses are reported based on total points and grade scores not as statistical outputs. In this regard, subtle differences which might not have been captured in this study could likely cause considerable preferences by consumers for coffee taste. Observations at coffee auctions revealed that other factors not captured by the scoring protocols influenced the price of specialty coffees (Ferguson, 2006).

The findings of this study are inconsistent with the results of Mekonen (2009), who reported significant variations in the preliminary and specialty attributes of coffees originating from different locations in Ethiopia. The absence of variability in most of the coffee quality attributes are also partly in contrast to the report by Ferguson (2006) who stated the existence of natural variation in relation to differences in coffee varieties, soil, altitude and rainfall conditions, and cultivation and processing methods used by producers. However, concordant with the results of this study, Ferguson (2006) elaborated that coffee is a complex product with attributes that emerge from a combination of characteristics displaying a rich variability of individual types that cannot be totally decomposed. In accordance with this suggestion, Harar, Yirgachaffe, and Sidama brands have been already discriminated based on the distinctive characters (flavour and taste) of those origins (types), thereby inducing the international registration of these coffees to be recognised as property rights of Ethiopia. This has given the country the opportunity to get premium prices (Prodolliet, 2004; MoARD, 2008).

As a normal practice, coffees that got grade 1 to 3 in the preliminary assessment undergo a specialty assessment for cup quality to determine the potential of the coffees. Accordingly, the fact that the evaluation of 67 out of 70 unwashed coffee samples by the Ethiopian Commodity Exchange (ECX) for specialty showed only 7% of the samples fitting the specialty grade 1 (Q1), 40.1% the specialty grade 2 (Q2) and the remaining 48.6% fitting the commercial grade 3 leaves a lot to be desired, when compared with the high percentage of the coffee samples fitting the specialty grade category according to the evaluation done based on the methods of Efico. Thus, based on the results of the specialty grade evaluation, the perception by the exporter (ECX) (Ethiopia) and importer (Efico) (Belgium) showed distinctions in that Efico was able to separate 94% of the samples in specialty grades in contrast to the amount done by ECX for the same replicates of coffee samples, which amounted only to 47%. This means ECX has been underestimating the specialty coffee grades in the country, resulting in lower payment to the primary producer (farmers) and the country as well as inability to discover new specialty coffees in the country. This signifies that ECX should revise and re-invigorate its procedure of grading specialty coffees in the country.

## 5. Conclusion

The results of this study have demonstrated no significant variations in most of the preliminary and specialty coffee quality attribute scores among the locations. Furthermore, four more specialty coffees were identified, namely, Kabo, Kossa, Gore, and Anfilo. The results of the study have also revealed an enormous difference in the testing rigour between Efico and ECX methods. Thus, the Efico method identified that about 75.7% of the coffee bean samples fitted specialty grade 1, but only 18.6% fitted specialty grade 2 (premium grade), and 5.7% fitted specialty grade 3 (commercial grade). However, for the same coffee bean samples, the ECX method identified that only 7% of the samples fitted specialty grade 1, but as much as 40.1% fitted specialty grade 2, and as much as 48.6% fitted specialty grade 3 (commercial grade). This implies that the grading of Ethiopian coffee for premium prices as well as the potential of obtaining new specialty coffees could be improved by using better coffee cup quality testing methods such as that of Efico rather than the current possibly rudimentary and inferior ECX methods. Further studies involving multi-year and multi-location sampling and better coffee bean cup quality testing methods should be conducted for enhanced grading of coffee beans as well as to discover new specialty coffees, thereby boosting foreign exchange earnings and livelihoods of coffee farmers in the country.

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# Role and Problems of Coffee and Enset Dominant Home gardens for Enhanced Livelihood and Food Security in Dilla District, Southern Ethiopia

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**Abstract:** Home gardens are one of the most complex and diverse agroforestry systems in Gedeo, southern Ethiopia and it has played an important role in the improvement of livelihood and food security of households. The study was conducted with the objective of investigating the role and problems of Coffee (*Coffea arabica* L) and Enset *(Ensete ventricosum (Welw.) Cheesman)* dominated home gardens for improved livelihoods and food security in the study area. A purposive random sampling method was used to obtain a study population of 120 households. Primary data were collected through structured and semi-structured interviews, questionnaires, and direct observations. Data were analyzed using descriptive statistics by generating frequency distribution and percentages. Pearson correlation analysis was used to determine relationships between household age, educational level, household family size, home garden, and food security indicators. The results revealed that out of a total 75 different plant species, 40% were food crops, 17.3% were cash crops, 13.3% were medicinal plants, 17.3% were plants used as live fence, 20% were plants used for construction and fuel, 10.6% were used for home made furniture and utensils, 4% were used as spices crops, 5.3% were stimulants, 10.6% were used as ornamentals and 20% were used as shade trees. It was found that about 36.2% of the household income was contributed by home gardening in the surveyed area. The Pearson correlation coefficient results have showed that home gardening was positively and significantly correlated with household food security with respect to the number of meals eaten per day (0.281 at $P < 0.01$), home garden crops owned (0.716 at $P < 0.01$) and heads of livestock owned (0.223 at $P < 0.05$). However, no significantly positive correlation was observed between home gardening and household educational level. From the result, it was concluded that majority of plant in home gardens were food crops and contributing for food security. Households, therefore, should be aware and encouraged to use technologies to improve their practice of home gardening to realize food security.

**Keywords:** Agroforesry; Ensete ventrocosum (Welw.) Cheesman; Coffea arabica L.; Food security; Home garden; Livelihood.

## 1. Introduction

Home gardens are one of the most complex and diverse agro ecosystems worldwide and have played an important role in the development of early agriculture and domestication of crops and fruit trees process (Abdoellah *et al*., 2006). Home gardens are commonly defined as a piece of land with a definite boundary surrounding a homestead, being cultivated with a diverse mixture of perennial and annual plant species, arranged in a multilayered vertical structure, often in combination with raising livestock, and managed mainly by household members for subsistence production (Vorgelegt, 2007). The role of home gardens in improving rural livelihoods is well appreciated and documented throughout the world (Fernandes and Nair, 1986; Soemarwoto, 1987; Nair, 2006; Allen, 1990; Musvoto and Campbell, 1995). They were ancient forms of agriculture, and with the current issues of growing population, scarce resources and food crises, home gardens can provide many people with improved livelihoods (Chris, 2011). Plants grown in home gardens and agricultural fields provide rural families with income, nutritious food for humans feed for animas, etc. This helps communities to achieve food self-sufficiency (Ndaeyo, 2007). Moreover, crop plants, tree, and tree products from home gardens play an important role in the household food security, as it is a sustainable source of food, fruits, and vegetables (Uddin and Mukul, 2004).

Extensive areas of traditional agroforestry home gardens exist in the south and southwestern parts of Ethiopia (Bashir Jama *et al.,* 2006). Most of these gardens are located at altitudes of 1500-1300 meters above sea level where moisture and temperature are favorable for agriculture (Tadesse Kippie, 2002). Zerihun Kebebew *et al.* (2011) found that smallholder farmers appreciated the significance of their home gardens for attaining food security and about 96.9% of the households agreed on the impact of home garden on improving their livelihood. Gedeo 'agroforests' are among ensete - coffee based systems in Ethiopia. The enset-coffee home gardens have been stable agricultural systems for centuries, supporting very dense populations of up to 500 persons per square kilometer (Tadesse Kippie, 2002). However, the contributions of these enset-coffee based home gardens for food security, at household levels have not yet been investigated in the study area. Therefore, this study was conducted to elucidate the roles coffee and enset

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dominant home gardens play in the livelihoods of smallholder famers and the problem the system faces in the study area.

## 2. Materials and Methodology

### 2.1. Description of the Study Area

The study was conducted in Dilla Zuriya district, which is one of the six districts in the Gedeo Zone, Sothern Nations Nationalities and People's Regional State (SNNPRS), Ethiopia. The district has a total area of 12764 hectares and it is geographically located between 5°84"−6°43" North latitude and 38°08"-38°44" East longitude. It is located at the distance of 359 km south of Addis Ababa and 90km from the regional, Hawassa. It is bordered by Sidama zone in the north, Oromiya Regional State in the South and Northeast, and Wonago district of the Gedeo Zone in the south.

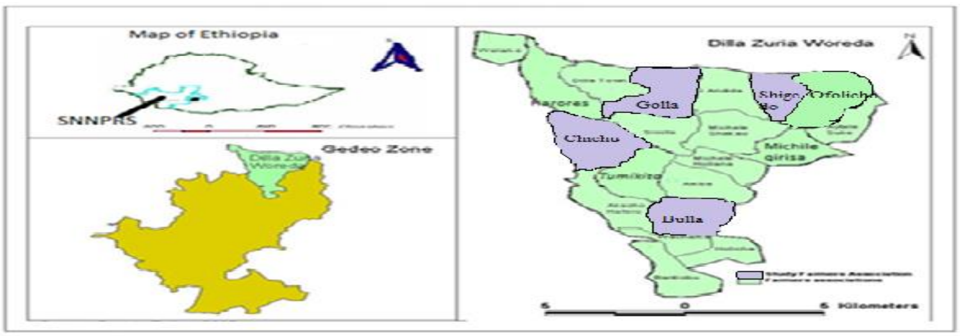


Figure 1. The map of study area.

### 2.2. Climate

Dilla Zuriya district ranges from 1350 to 2600 meters above sea level. Regarding the agro-climatic zones, the district is predominantly *Woynadega* (70%) while *Dega* and *Kola* constitute 23 and 7.0% of the total area of the district, in that order. The mean annual temperature of the discrict ranges between 18-27°C and the mean annual rainfall ranges between 1400−1800 mm (DZWAoRDP, 2011).

### 2.3. Population

The Gedeo Zone is the most densely populated area in Ethiopia and the second most densely populated region in Africa. Thus, Dilla district has an approximate population density of 579.5 inhabitants per kilometer square (PHEEC, 2010). The 2007 census conducted by the Central Statistical Agency of Ethiopia revealed that the Woreda has a total population of 98,439, of whom 49,413 are men and 49,026 are women with a population growth rate of 2.9%. A total of about 20,436 households inhabit the district according to the agricultural office of the district. The average landholding size of each household is about 0.5 hectares (DZWAoRDP, 2011).

### 2.4. Data Collection and Measurement

This study was conducted between January and August 2012. From a total of 17 Kebeles in the study area, only four Kebeles (Golla, Chichu, Bulla and Shigedo) were selected purposely. The choice of the Kebeles was based on their proximity to the capital of Gedeo Zone, Dilla, and the type of home garden practices, in which enset or coffee crop is dominant. Accordingly, the two Kebeles, Chichu and Golla, are relatively near the capital of Gedeo Zone, Dilla, and are only about 0.5 and 1.5km away from it, respectively, whereas Bulla and Shigedo are located at the distances of 13.5 km and 15 km away from the town. Similarly, the home garden types of Chichu and Golla are coffee dominated whereas that of Bulla and Shigedo is enset dominated.

### 2.5. Interview and Survey

Various tools of data collection methods were employed to gather data. Primary data were collected through structured and semi-structured interviews and direct observation. In the structured interview the selected informants were asked to categorically list plant species in their home gardens by vernacular names that helped to characterize variation in gardening knowledge and production practices among the owners of the home gardens.

In the semi-structured interview, all interviewees were asked the same standard questions in Amharic using open- and close-ended questionnaires. The questionnaire consisted of four parts. The first part contained socioeconomic characteristic like age, gender, and educational background of the selected household member of the home garden owners. The second part contained questions related to home garden function: for what purpose people in the study area use home gardens (household food supply, income generation, medicine, construction or building, shade and ornamentation, fuel wood production etc). The third part consisted of questions related to food security and livelihood systems. The forth part of the questionnaire was concerned with income survey and constrains that affect home garden productivity.

***Household Survey***

**Income survey***:* Information on household income from the home gardens was obtained by asking the respondents, how much income he/she earned from sale of home garden produces in the previous year. This enabled to calculate the proportion of total income earned from the home gardens. Net annual income of sampled households from the home gardens, farmland, and off-farm activities was also determined in order to compute the percentage contribution of the home gardens to household annual income.

**Food security status***:* The household food security status presented in this study are based on a measure of food security determined from responses given by respondents to a series of questions about conditions known to characterize households having difficulty meeting basic food needs. Each households were asked about whether insecurity condition has occurred at any time during the previous 12 months and required specifying any lack of food availability or money to obtain food. Using standard scoring methods, households were placed into 2 categories: food secure or food insecure as indicated by Nord *et al.* (2009). In addition, households were asked to recall their number of meal per day in previous three days prior to the interview. The amounts of food obtained from their home garden in the daily consumption were also estimated. The households that have three and more meals per day and obtain greater than 20% for daily meal from their home gardens were considered as food secure whereas those who have meals less than three meals in a day and obtain less than 20% from their home gardens as food insecure.

***Market survey:*** In addition to vegetation data collection in home gardens, a market survey was also conducted to record varieties and amounts of food and other plant products that have market values in the local market in the study area by interacting with producers, sellers and consumers.

### 2.6. Data Analysis

The data were analyzed using SPSS (Statistical Package for Social Sciences) version 16 (SPSS Inc., 2007). Descriptive statistics were used to generate frequency distribution and percentages. Pearson Correlation coefficients were used to determine the relationship between household age, educational level, household family size, home garden and food security indicators. Households were also asked to recall socioeconomic factors that hinder their garden productivity.

## 3. Results and Discussion

### 3.1. Household Characteristics

The study revealed that the average age of the respondents was 47.7 with minimum of 31.0 and a maximum of 75. The age of the majority of the respondents (53.3%) fall between 40 to 60 years while the age of 34.2% and 12.5% of the respondents were between 25 and 40 and above 60 years, in that order. Out of the 120 surveyed households, 15% were female-headed whereas the reaming ones were male-headed. The average family size in the study Kebeles was 6.76 persons per household with a range of 2.0-13 persons. The total land size of each household consists of the farmland and home garden. Of the 120 households, 75% have farm size ranging between 0.5 - 1.0 hectare.

### 3.2. Plants in the Home Gardens and their Utility

In the present study, twenty-four plants with high value to meet household food consumption and income were identified from a total of 75 species based on farmers' opinions (Table 1).

Table 1. Highly valuable plant species, their frequency distribution and purpose of production.

| Plants Species | Frequency (N=120) | Percentage | Purpose of Production (%) | | |
|---|---|---|---|---|---|
| | | | Consumption | Sale | Both |
| *Allium cepa* L | 33 | 27.5 | 83.4 | 4.4 | 12.2 |
| *Annona reticulata* | 61 | 50.8 | 43.5 | 51.2 | 5.3 |
| *Brassica carinata* Braun | 120 | 100 | 92.6 | 0.0 | 7.4 |
| *Brassica oleracaea* L | 41 | 34.2 | 41.9 | 3.3 | 54.8 |
| *Capsium frutescens* L | 54 | 45 | 89.3 | 2.5 | 8.2 |
| *Carica papaya* L | 69 | 57.5 | 34.7 | 26.2 | 39.1 |
| *Coffea arabica* L | 120 | 100 | - | 98.9 | 1.1 |
| *Collocasia esculenta* (L) Schott | 120 | 100 | 99.3 | - | 0.7 |
| *Cucuribiata pepo* L | 85 | 70.8 | 100 | - | - |
| *Dioscorea alata* L | 120 | 100 | 97.8 | - | 2.2 |
| *Ensete ventricosum* (Welw.) Cheesman | 120 | 100 | 98.1 | - | 1.9 |
| *Ipomoea batatas* (L) Lam | 58 | 48.3 | 91.5 | 0.7 | 7.8 |
| *Mangifera indica* L | 78 | 65 | 23.8 | 47.7 | 28.5 |
| *Manihot esculenta* Crantz | 54 | 45 | 63.2 | 13.5 | 23.3 |
| *Musa paradisiacal* L | 115 | 95.8 | 19.1 | 13.5 | 67.4 |
| *Persea americana* Mill | 88 | 73.3 | 32.6 | 11.3 | 55.1 |
| *Phaseolus lunatus* L | 93 | 77.5 | 88.2 | 9.4 | 2.4 |
| *Phaseolus vulgaris L* | 107 | 89.2 | 89.6 | 4.2 | 6.2 |
| *Pitcairnia feliciana* (Chev.) | 47 | 39.2 | 21.8 | 67.5 | 10.7 |
| *Psidium guajava L* | 43 | 35.8 | 39.3 | 48.3 | 12.4 |
| *Saccharum officinarum L* | 52 | 43.3 | 12.1 | 73.4 | 14.5 |
| *Solanium americanum* Mill | 36 | 30 | 52.0 | 17.3 | 30.7 |
| *Sorghum bicolor* (L.) Moench | 44 | 36.7 | 93.6 | 1.4 | 5.0 |
| *Zea mays* L | 105 | 87.5 | 94.4 | 4.3 | 1.3 |

*Note: Frequency of occurrence does not imply abundance. It is used here as a potential indicator of importance to the farmer.*

Enset *(Ensete ventricosum* (Welw.) Cheesman) was the main staple crop in the study district and 100% of the inventoried homegardens maintained this crucial food crop. Taro (*Collocasia esculenta)* is shade-tolerant and was found planted in the home gardens. It is mainly planted under enset, coffee and trees species. It does not compete for space and alleviates the problem of land shortage. From the total respondents, 100% were cultivating Taro in their home gardens during the study. The study revealed that 99.3% of the sampled households produced Taro for household consumption whereas 0.7% produced it for both home consumption and sale. This shows that Taro is one of the important crop plants in the study area. Yem (*Dioscorea alata* L) is another root crop that has been produced across all home garden systems in the district. From the surveyed sample households, 100% of them grew *yem* in their home garden and 97.8% of them used it as food. The remaining 2.2% produced the crop for both home consumption and sale.

Banana is one of the major plant components in the home gardens in the agroforestry system in the study area. Of the 120 households, 19.1% grew banana for home consumption, 13.5% for earning income and 67.4% for both home consumption and income generation.

Mango is one of the dominant fruit trees in the surveyed home gardens, particularly in two sites (Golla and Chichu). From the total respondents, 23.8% produced mango for home consumption, 47.7% for sale in nearby markets and 28.5% produced the crop for both home consumption and income generation.

Coffee is the major source of income for the households in the study area. All the 120 (100%) of the surveyed home garden households possessed coffee shrubs in large numbers indicating that it is an essential cash crop for them. The main purpose of its production is for income generation (98.9%) and 1.1% households produced the crop for both income and home consumption. None of the respondent cultivated coffee only for home consumption purpose.

The home garden plants observed in the home gardens were kept for both food and non-food purposes. However, the proportions of the food plants in the home gardens were much higher than the proportion of non-food plants. The food plants of the home gardens included fruits, roots/tuber/bulb, vegetables, cereals, spices, and pulses.

Table 2. Uses and species composition of home garden plants in the study area.

| Plant use types | | | |
|---|---|---|---|
| Food plants | No. of Species (%) | Non-food plants | No. of Species (%) |
| Fruits | 16 (21.3) | Income | 13 (17.3) |
| Root/tuber/bulbs | 7 (9.1) | Medicinal | 10 (13.3) |
| Vegetables | 11 (14.7) | Ornamental | 8 (10.6) |
| Cereals | 2 (2.7) | Building/fuel | 15 (20) |
| Spices | 3 (4) | Stimulants | 4 (3.3) |
| Pulses | 1 (1.3) | Shade | 15 (20) |

The study revealed that fruits accounted for 21.3% of the total plant species in the home gardens followed by vegetables (14.7%), root/tuber/bulb crops (9.1%), spices (4%), cereals (2.7%) and pulses (1.3%) species in the food plant groups. In non-food groups, plants that are indirectly used to fill food shortage gaps that are used for construction/fuel and shade share the largest part (20%). These were followed by cash crops (17.5%), medicinal plants (13.3%), ornamental plants (10.6%), and stimulants (3.3%).

Different parts of the food plants are processed for use as food. Fruit, root/tuber/bulb crops, leaves, stems, seeds and flowers are the parts of the plant that are used for food from the home garden crops.

The study revealed that 16 or 53.4 % of the plant species were fruits, which were utilized as food in the home gardens followed by root/tuber/bulb food plant species (23.3%). The root/tuber/bulb food crops comprised 7 food plant species that accounted for 23.3% of the total food plant species (Figure 1). The major crops in this category were Enset (*Ensete ventricosum*), Yem (*Dioscorea alata*), taro (*Colocasia esculenta*) and Sweet potato (*Ipomoea batata*). Those root crops were mainly grown for household consumption. Crops that their seeds are utilized as food source accounts 10% and most of them are cereals and pulses (*Zea mays*, *Sorghum bicolor* and *Phaseolus lunatus*). Leaves of two crop plants are used as food (10%). These are *Brassica carinata* and *Brassica oleracaea.* Stem of one plant species (*Saccharum officinarum*) was used for food (3.3%).

### 3.3. Income Generated from Home Gardens and Livelihood Improvement

#### 3.3.1. Home garden crops with market value

Home gardens serve as a reserve bank for food and cash for farmers. The households subjected to the study give priorities to 13 cash crops for their financial needs (Table 2).

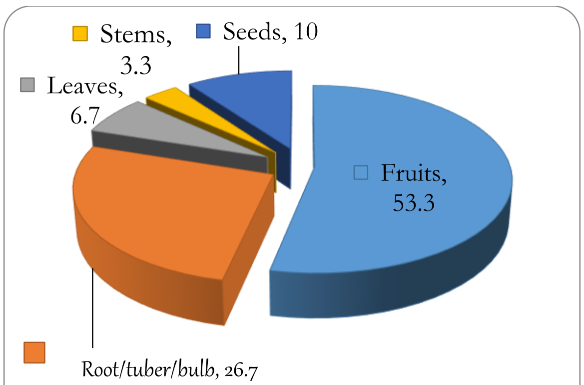

Figure 2. Parts of plant used as a source of food

Table 3. Income generated from crops produced in the home gardens of the study area.

| Homegarden Crops | Chichu | Golla | Bulla | Shigedo | Total | % |
|---|---|---|---|---|---|---|
| Coffee | 37,792 | 41,265 | 31,379 | 34,746 | 145,182 | 57.5 |
| Fruits | 14,147 | 15,824 | 2,679 | 3,964 | 36,614 | 14.5 |
| Root and tuber crops | 4,721 | 3,518 | 2,838 | 3,483 | 14,560 | 5.8 |
| Leafy vegetables | 2,136 | 2,871 | 2,246 | 1,321 | 8,574 | 3.4 |
| Trees | 11,743 | 17,277 | 6,165 | 8,392 | 43,577 | 17.3 |
| Animals | 1,061 | 945 | 893 | 994 | 3893 | 1.5 |
| Total | 71,600 | 81,700 | 46,200 | 52,900 | 252,400 | 100 |

*Coffee (Coffea arabica)* is the main cash crop in all study Kebeles. 57.5% of the annual income derived from home gardens came from this crop. The highest income from coffee was obtained in Golla. The reason for this was that a number of households at Golla had larger sized home gardens planted to coffee than the other sites. Trees accounted for 17.3% of the total income followed by fruits (14.4%). The tree plant species that were used for income generation included *Eucalyptus comaldulesis*, *Eucalyptus globulas, Cordia africana*, *Croton macrostachys, Juniperus procera* and *Millettia ferruginea*. Fruit crops, namely, mango (*Mangifora indica)*, avocado (*Persea americana)*, banana (*Musa paradisiacal)*, guava (*Psidium guajava)*, cherimoya (*Ananas comosus)*, Casmir (*Casamiria edulis)* and papaya (*Carica papaya)* are the major income sources in the study area. Root or tuber crops and vegetables sold in local markets as sources of income comprises 5.8% and 3.4%, respectively. Livestock or livestock products add only 1.5% to the total income from home gardens. In two of the study sites, Chichu and Golla, the market access enabled farmers to produce more cash crops like *Mangifora indica*, *Persea amercania*, *Musa paradisiaca* and pineapple (*Annanas comosa)* for sale. These home garden products are sold fresh. It was observed that farmers who have medium sized home gardens intensively cultivated different crops. Giving priority to a few profitable cash crops might be the reason for getting more income from their home gardens.

### 3.3.2. Contribution of home gardens to household income

Household benefits from home gardens are not confined to obtaining food. In many cases, sale of crops produced in home gardens significantly add an extra income to improve the households' financial status. Home gardens are cost effective since they are managed by all household members. The average annual costs of running home gardens from four assessed Kebeles are illustrated in the Table 4 below.

Table 4. Annual expenditures in running home gardens of four study Kebeles in Dilla district in 2013.

| Cost | Chichu | Golla | Bulla | Shigedo | Total | Average |
|---|---|---|---|---|---|---|
| Management cost | 875 | 747 | 566 | 639 | 2827 | 23.56 |
| Transport cost | 629 | 693 | 993 | 877 | 3192 | 27.43 |
| Seed/seedling | 1932 | 1688 | 1273 | 1491 | 6384 | 53.2 |
| Household labor cost | 3904 | 4072 | 2162 | 2833 | 12977 | 108.14 |
| Total | 7340 | 7200 | 5000 | 5840 | 25380 | 211.5 |
| Average | 244.6 | 240 | 166.6 | 194.6 | | |

*Note: Household labor cost: time spent in home garden converted into price (8hr/day=40ET Birr). This is equivalent to 1hr = 5 ET Birr during the study.*

The total average costs spent by the households in each study Kebeles for management, transport of home garden product to the market, buying of seeds or seedlings and labor cost in the home gardens was found to be 211.5ET Birr (Table 4). This shows that home gardens were cost effective. The entire family members were involved in its management and there were no money spent for applying inorganic fertilizers.

Table 5. Average income generated from home garden, farmland and off farm of the study Kebeles.

| Types of homegarden | Study Kebeles | No. | Source of income | Total | Average | % |
|---|---|---|---|---|---|---|
| Coffee based | | | HG | 71600 | 2386.7 | 36.05 |
| | Chichu | 30 | Farmland | 122300 | 4076.7 | 61.57 |
| | | | Off farm | 4731 | 157.7 | 2.38 |
| | | | HG | 75500 | 2723.3 | 36.75 |
| | Golla | 30 | Farmland | 136700 | 4556.7 | 61.5 |
| | | | Off farm | 3893 | 129.8 | 1.75 |
| Enset based | | | HG | 52900 | 1763.3 | 34.07 |
| | Shigedo | 30 | Farmland | 99350 | 3311.7 | 63.98 |
| | | | Off farm | 3024 | 100.8 | 1.95 |
| | | | HG | 75000 | 1540.0 | 31.20 |
| | Bulla | 30 | Farmland | 99100 | 3303.3 | 66.92 |
| | | | Off farm | 2786 | 92.9 | 1.88 |

The household may sell products produced in the home garden, including coffee, fruits, vegetables, animal products and other valuable materials such as fuel wood in the local markets. The most important plant species found in the home gardens that contributed to the household income were *Coffea arabica, Mangifera indica*, *Persea americana* and *Musa paradisiaca.* Of these, the main income source in the study area is Coffee (*Coffea arabica)* because 98.9% of the interviewed households cultivate it as a cash income (Table 1).

The average incomes from enset dominant home gardens in Shigedo and Bulla were 1763.3 and 1540 ET Birr, respectively. The cost to the home garden averages 194.67 ET Birr. The average farmland income in Shigado Kebele was 3311.7 ET Birr (63.98%). Similarly, the average incomes obtained from coffee dominant home garden in Chichu and Golla were 2386.7 (36.05%), and 2723.3 (36.75%), respectively. The result revealed that the average income in enset based home garden (Shigedo and Bulla) is lower than that of coffee based home gardens (Chichu and Golla). The possible reason for this was the decrease in fruit crop diversity in Shigedo and Bulla sites since they have higher elevation, 2048m and 2132m, respectively. These home gardens are dominantly occupied by enset crop which is staple food source for the family rather than income. There is also variation in cost in home garden and income from farmland. In Shigedo, the average cost is 194.67 ET Birr, in Bulla it is 166.7 ET Birr. However, in Chichu, it is 244.67 ET Birr and in Golla it is 240 ET Birr. The farmland average income in Shigedo, Bulla, Chichu and Golla are 3311.7, 3303.3, 4076.7 and 4556.7 ET Birr, respectively (Table 5). The off-farm average was higher in Chichu than the other three Kebeles since it is more close to the capital city of the Zone, Dilla that many households earn income from many activities like wage labor, small businesses etc. The increasing access to the market has gradually created more opportunities for off farm activities and intensification of cropping pattern to produce more marketable livestock products.

The total average income of the surveyed household from the home garden was 2103.3 ET Birr. The costs to the garden averages 211.5 ET Birr and income from farmland accounts an average of 3812.1 ET Birr.

Table 6. Annual total average income, expenditure, net average and total percent of the study area.

| Income Source | Average income | Average expenditure (cost) | Net average income | % total income |
|---|---|---|---|---|
| Homegarden | 2103.3 | 211.5 | 1891.8 | 36.2 |
| Farmland | 3812.1 | 478.8 | 3333.3 | 63.7 |
| Off-farm Business | 117.3 | 111.3 | 6.0 | 0.1 |
| Total | 6032.7 | 801.6 | 5231.1 | 100 |

The net total income from the home garden the study area was 1891.8 ET Birr. It was calculated by subtracting the total cost in to the home garden from the total average income obtained. The study showed that the total percentage of the income derived from home garden in the study site was 36.2%. The finding agrees with Maria *et al.* (2008) who reported that home gardens generate a monetary contribution that can be significant for domestic economies. This contribution oscillates from 10 to 100% and in Nicaragua, it represents from 10 to 100% with the average being 35%. In addition, Mendez (2000) in Honduras reported that the contribution of home garden varies between 10 and 26%. Beside the home garden and farmland income, small and marginal households access seasonal off farm employment opportunities in the form of labor. About 0.1% of the total household income is derived from off-farm employment opportunities (Table 6) mainly from business trade and labor. The income generated is used to maintain or improve living conditions especially to purchase household materials, crop seed, cover health, education and clothing costs.

### 3.3.3. The significance of home gardens to livelihood

Agriculture was the major livelihood strategy in the study site. This is followed by non-agricultural sources of income including wage labor and small amount of commerce (0.1%). Home gardens were one of the agricultural systems. Within home gardens, crop-based livelihood activities were diversified but depended mainly on root/tuber, cash crops, fruits and small amount on livestock. Food crops supply food for family and fruits and vegetables provides nutrient essential for the health condition. Cash crop, *Coffea arabica* , production was the major source of income for livelihood improvement in most visited households, perhaps because coffee were the major source of cash for people at these sites. In addition, home gardens provide tree plant species that are used to construct houses and produce materials utilized in home. Furniture like tables, beds, chairs and doors are mainly made from *Cordia africana*. Others, 15 plant species (20%) are used as firewood. Trees and shrubs are very important components of home gardens, as they play multiple roles in the systems.

### 3.3.4. The Importance of home gardens to food security

Home gardens maintain the diverse mixtures of crops that are harvested at different times, and thus constant supply of food in some form or the other is available from these home gardens at all times of the year.

Table 7. Food security status of the study area.

| Variables of food security study | Food Secure | No. | Food insecure | No. |
|---|---|---|---|---|
| Shortage of food in the last12-month | 1-2months | 23 | 3-5 months | 17 |
| Number of meal/day in 3days | 3 meals/day | 19 | 2 meal/days | 21 |
| Yearly income from HG | >3000ET Birr | 14 | < 3000ET Birr | 9 |
| Home garden supply to daily meal | >20% | 11 | < 20% | 6 |
| Total number (120); No. (%) | | 67 (55.8) | | 53 (44.2) |

The result revealed that 55.8% households were food secured while 44.2% were food insecure. From the food secured households, 34.44% were faced only 1-2 month of food shortage in 12 months prior to this study (Feb. 2011 to Feb. 2012) and 28.38% households had three meals per day. The percentage of the home garden supply to the daily consumption of household varied from 0-20% to 41-60%. Of the total surveyed households in the food secure group, 16.4% indicated that their home garden supplied more than 20% of their daily meal and 20.9% obtained more than 3000 ET Birr from their home gardens annually. The 44.2% of the households of the study area faced food shortage in different times of the year (Table 7) and regarded as food insecure. In this category, 25.4% households faced insufficient availability of food for three to five months within the last 12 months prior to the interview and 31.34% households ate two times per day in last three days prior to the interview. Similarly, in food secure category, majority of the households (84.2%) obtain greater amount of food for family consumption from home garden and 15.8% purchase from nearby market. For the food secured households, their home gardens were largely occupied by *Ensete ventricosm*, which is found at different stage (mature, medium and seedling stages) that can be harvested for household consumption.

To determine the significance of home garden in the households' food security, the Pearson correlation coefficient was computed between household age, educational level, household family size, home garden and food security indicators (Table 8).

Table 8. Pearson correlation coefficient between household characteristics by study factors ($N = 120$).

| Correlation | Educational level | Family size | Home garden size | No. of meals per day | No. of livestock | Home garden crops |
|---|---|---|---|---|---|---|
| Household age | -.417** | .068 | .378** | .219* | .174 | .215* |
| Household education level | | .249** | -.073 | .087 | -.058 | .013 |
| Family size | | | .118 | .104 | .097 | .138 |
| Home garden size | | | | .281** | .223* | .716** |
| No. of meals per day | | | | | .208* | .265** |
| No. of livestock | | | | | | .244** |

*Note: ** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed).*

Results of the Pearson Correlation Coefficient in Table 14 showed that the household age and educational level exhibited highly significant negative correlation at ($p < 0.01$). This reveals that as the age of household increase the educational level decreases. Such relationship could be due to the general condition in the rural area where individuals often dropout of school shortly after few years of attending school. On the other hand, size had highly significant ($p < 0.01$) positive correspondence ($r = 0.378$) with the age of household. This indicates that households with increased age have large sized home gardens because of a corresponding change in size of land. The home garden sizes of young aged households were small because they have taken the farm land from their parents and the corresponding home garden size would be small. There was a significant correlation (0.219) between age of household and number of meals eaten daily ($p < 0.05$) and household age and home garden crops (0.215) at $p < 0.05$. This also shows that households with higher age possessed increased land size for home gardening and produce high yield which increases their daily meal. They can grow large number of food crops in their home gardens. The result revealed that there was no significant relation ($p > 0.05$) between household age, family size and number of livestock at 0.068 and 0.174, respectively. The household educational level and family size at 0.249 was highly significant ($p < 0.01$). However, results of the correlation between home garden size and household education was negative ($p > 0.05$) with a correlation of (-0.073), indicating that minimal changes in home garden size was because of increases in educational level. There was no significant association ($p > 0.05$) between educational level and the number of available home garden crops with a correlation of 0.013. Similarly, there was no significant relationship ($p > 0.05$) between family size and home garden size, number of meal per day, number of livestock and home garden crops with a correlation of 0.118, 0.104, 0.097 and 0.138, respectively. Home garden size was strongly and significantly correlated (0.281) with the number of meal per day ($p < 0.01$) implying that higher number of meal was due to the large size of home garden that provide high food stock for the households. The correlation between the size of home garden and number of livestock at 0.223 was significant ($p < 0.05$). This shows that when the size of home garden increases it maintain high amount of fodder for livestock. Again, the correlation between the size of home garden and home garden crops was highly significant at 0.716 ($p < 0.01$). This tells that the change in home garden crops is due to the corresponding change in the size of home garden. There was a significant correlation (0.208) between the numbers of meals per day and the numbers of livestock ($p < 0.05$). The number of meals per day was also significantly correlated with the home garden crops at 0.265 ($p < 0.01$). Finally, there was highly significant correlation (0.224) between numbers of livestock and home garden crops ($p < 0.01$). This implies that increase in the number of livestock provides organic manure for the soil fertility that support high crop in the home garden.

#### 3.3.5. Factors affecting diversity and productivity of home gardens

Main factors affecting the productivity and diversity of crops in home gardens of the study area as reported by respondents are size of the land (home garden), lack of access to water, weeds, pests and diseases, monkeys and availability of better seeds.

Table 9. Informant's response on factors affecting productivity of homegarden ($N = 120$).

| Factors | Number of respondents No. (%) |
|---|---|
| Size of land | 109 (90.8) |
| Water (weather) | 63 (52.5) |
| Weeds | 52 (43.3) |
| Disease and pests | 88 (73.3) |
| Monkey/baboon | 48 (40.0) |
| Availability of better seeds | 73 (60.8) |
| Market access | 43 (35.8) |

Land or more specifically plot size is the major factor influencing productivity of home gardens. The result shows that 90.8% of the respondents said the size of land takes the biggest part in controlling the productivity of home gardens. This means that households with larger land size have large sized home gardens, cultivate more diversified crop species and produce more food. On the other hand, households with small land size have small sized home garden with few crop plants and producte less.

The availability of water or the lack of water is another constraint in growing home garden crops in the study area. According to the informants, a little over half (52.5%) of home gardens in the study area are primarily rain fed and home garden crop diversity highly decreases in the dry season due to lack of water. Particularly, plants at the lower layer like *Collocasia esculenta, Dioscorea alata and Brassica carinata* are less resistance to shortage of water and their production decreases in dry season. Shortage of water or rain also affects the productivity of coffee. During its flowering time, coffee needs much water. The second major factor, as indicated by 73.3% respondents, was diseases. Diseases mainly affect enset and banana crops and less frequently coffee. The diseases of these crops are locally known as 'Kollera'. The households have their own knowledge to manage these diseases; they remove as soon as the disease infects the plant. As told by 40% of the informants, wild animals especially apes destroy garden crops in two study sites, Bulla and Shigedo. They may feed on maize when it mature and destroy the others. Lack of better seed also reduces productivity of home gardens.

## 4. Conclusion

This study reveals that the home gardens of the study area ranges from 250 m$^2$ (small) to 2000 m$^2$ (large) with mean of 665.42 m$^2$. The home gardens display three vegetation layers making them typical agroforestry systems. Home gardening could result in tangible benefits for the household, including increased food for family consumption, extra income, and food reserves for emergencies and special occasions, enhanced traditional varieties and ultimately improve family food security and nutrition. Access to fresh homegrown vegetables, fruits and livestock not only ensures a more balanced diet for families with limited purchasing power, but also increases their self-reliance. Results of present study have shown that home gardening plays a role in household food security with respect to household age, size of home garden, number of meals per day, home garden crops and number of livestock but not with family size and household educational level.

Home gardens also have the potential to generate income. The economic gain from selling home garden products varied greatly depending on the size of the home garden, the needs of the household, and plant diversity. More than 36.2% of the household income was contributed by home gardening in surveyed area. However, the major problems associated with home gardening in the study area were insufficient land (home garden), lack of access to water, weeds, diseases, monkey and shortage of better seeds and seedlings. Home gardens are distinctive agricultural spaces, near to home, with significant potential in raising the food security, nutrition, and livelihood of the rural people. It was observed that home gardening could be an effective tool in enhancing the nutritional intake of the farmers, increasing household food supply through enhancing the food security. The promotion and improvement of home gardens requires special emphasis.

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# Registration of "*Addis-01*" Finger Millet Variety

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**Abstract:** The name *Addis-01* was given to the finger millet (*Eleusine coracana* sub spp. *coracana)* variety with the pedigree of Acc-203544, which was developed by Addis Ababa University in collaboration with Bako Agricultural Research Center between 2011 and 2015. The *Addis-01* and the other pipeline finger millet genotypes were evaluated against two standard checks (*Gute and Taddesse*) across four environments (Arsi Negele, Assosa, Bako, and Gute) in 2012 and 2013 main cropping seasons. Additive main effect and Multiplicative Interaction (AMMI), Genotype and Genotype by Environment interaction (GGE) biplot analysis, and Eberhart and Russell model revealed that Acc. 203544 is stable and high yielding (3.16 ton $ha^{-1}$) with a yield advantage of 13.7% over the best standard check, Gute (2.78 ton $ha^{-1}$), and thus was released in 2015.

**Keywords:** Additive main effect and multiplicative interaction (AMMI), Finger millet (*Eleusine coracana* subsp. *coracana)*, Genotype by Environment Interaction (GEI), *Magnaporthe oryzea*

## 1. Introduction

Finger millet (*Eleusine coracana* subsp. *coracana*) represents one of the critical plant genetic resources for agriculture and food security of farmers inhabiting arid, infertile and marginal lands (Barbeau and Hilu, 1993). Lack of stable and high yielding varieties is one of the major bottlenecks for production and productivity of finger millets in Ethiopia. The consequences of phenotypic variation depend largely on the environment. This variation is further complicated by the fact that not all genotypes react in a similar way to changes in the environment and no two environments are exactly the same. Therefore, identification of adaptable, stable, and high yielding genotypes under varying environmental conditions prior to release is the first and foremost steps for plant breeding and this has direct bearing on the adoption of the variety, its productivity, and total production of the crop.

## 2. Varietal Origin and Evaluation

Addis-01 (Acc. 203544) was originally introduced from Kenya through the Ethiopian biodiversity Institute. This and the other pipeline finger millet genotypes were evaluated against the standard checks, Taddesse and Gute, across 4 environments (Arsi Negele, Assosa, Bako and Gute) for two years (2012 and 2013).

## 3. Agronomic and Morphological Characteristics

The released variety, *Addis-01* (Acc. 203544) has light brown seed color, average plant height of 77.14cm and average thousand grain weight of 2.5 grams. The detailed agronomic characters of the newly released variety are indicated in Table 1.

## 4. Yield Performance

Addis-01 (noted as genotype No.6 or G6) produced the best average yield (3.16 ton $ha^{-1}$) (Fig 2). As observed from multi-location and multi-year evaluation records, it has a stable and high yield performance under blast disease stressed environment such as Assosa (average yield of 2.75 tons $ha^{-1}$) and non-stressed or conducive environment such as Arsi Negele (4.4 ton tons $ha^{-1}$ s/ha). Besides, *Addis-01* gave an average grain yield ranging from 2.5-3.1 tons $ha^{-1}$ on farmers field and 2.6-4.2 tons $ha^{-1}$ in verification plots grown in Arsi Negele, Assosa and Gute districts in 2014 (Table 1).

## 5. Stability and Adaptability Analysis

Eberhart and Russell (1966) model revealed that the best yielding variety, Addis-01 (G6), showed regression coefficient ($b_i$) closer to unity (1.08) and thus stable and widely adaptable variety than the remaining genotypes (Fig 2). Both environment-focused biplot and genotype-focused comparison of the tested genotypes revealed that Addis-01 (G6) fell in the central circle, indicating its high yield potential and relative stability compared to the other genotypes (Fig 1). Generally, GGE biplot analysis, AMMI and Eberhart and Russell model revealed that Addis-01 (Acc- 203544) was a stable and high yielding (3.16 ton $ha^{-1}$) variety with 13.7% yield advantage over the best standard check Gute (2.78 ton $ha^{-1}$) and therefore, officially released and recommended for production under wiser environmental conditions.

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## 6. Reaction to Major Diseases

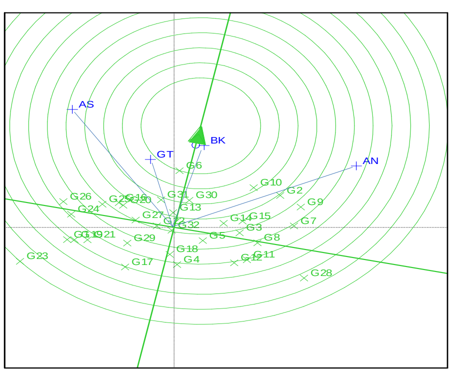
Addis-01 is moderately resistant to major diseases particularly blast (*Magnaporthe oryzea),* a devastating disease that affect all above ground parts of the plant.

## 7. Conclusion

The *Addis-01* finger millet variety is hereby released for its high yield, stability, and wider adaptability. Therefore, smallholder farmers and other finger millet producers inhabiting Southern Ethiopia (Arsi Negelle, Shashemene and Alaba districts) and western Ethiopia (Bako, Nekemt, Bambasi and Assosa districts) and areas with similar agro-ecologies can double or triple finger millet yield by growing Addis-01 variety with its full agronomic and other management recommendations.

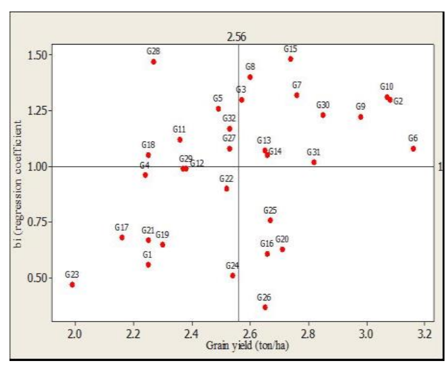
Table 1. Agronomic/morphological characteristics of finger millet variety, *Addis-01*.

| Agronomic characteristics of finger millet variety | |
|---|---|
| Varietal name | *Addis -01* |
| Adaptation area | Adaptation area: Southern Ethiopia (Arsi Negelle, Shashemene and Alaba districts) and western Ethiopia (Bako, Nekemt, Bambasi and Assosa) and areas with similar agro-ecologies<br>Altitude (masl):1400-2200m<br>Rainfall (mm): 1200 – 1300 |
| Days to heading | 95-110 |
| Days to maturity | 145-155 |
| 1000 seed weight (g) | 2-3 |
| Plant height (cm): | 77.14 |
| Seed color | Light brown |
| Growth habit | Erect |
| Grain yield (ton/ha) | On farmers field: 2.5-3.1<br>On station: 2.6-4.2 |
| *M. oryzea* disease reaction | Moderately resistant |
| Year of release | 2015 |
| Breeder/maintainer | Addis Ababa University (AAU) and Bako Agricultural Research Center (OARI/BARC) |




Key: AN=Arsi Negelle, AS= Assosa, BK=Bako, GT= Gute, G=genotype number.

Figure 1: GGE biplot analysis showing the stability of genotypes and test environments.




Key: G = genotype

Figure 2. Matrix plot of genotypes mean grain yield (tons ha$^{-1}$) versus regression coefficient ($b_i$) indicating Stability and yield performance of the test genotypes.

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