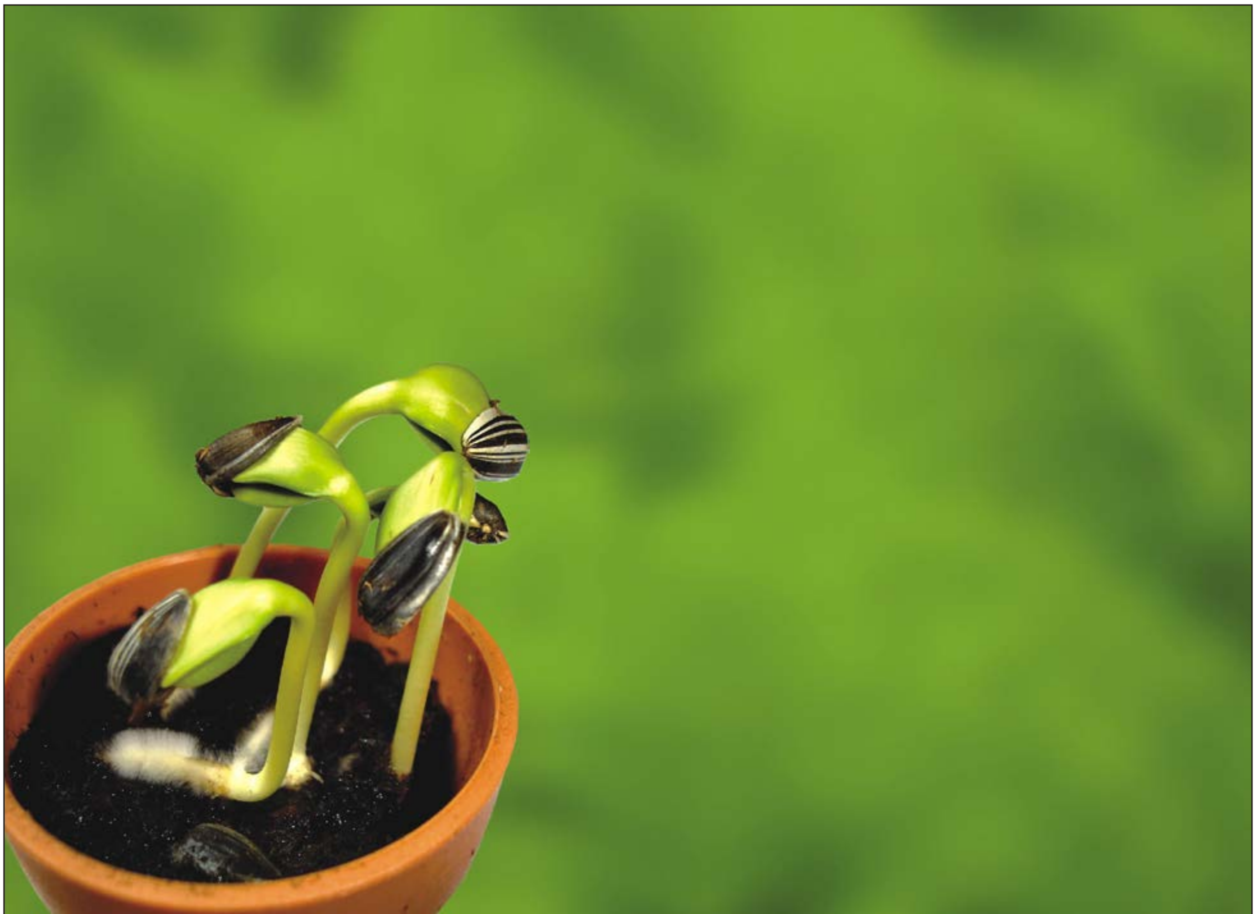

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Variability and Association of Quality and Biochemical Attributes in Some Promising *Coffea arabica* Germplasm Collections in Southwestern Ethiopia

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ABSTRACT
The overall aim of this study was to study the extent of genetic variation and association among bean physical, organoleptic and biochemical quality traits. Twenty-one native coffee germplasm collections were evaluated for 16 quality traits in randomized complete block design at the Jimma Research Center. Variances component method was used to estimate genetic variation, broad sense heritability and genetic advance. Association of traits was also estimated using standard method. The genotypes differ significantly ($p<0.01$) for most coffee quality and biochemical attributes. Coffee collections from Sheko, Dizi and Meanit manifested high variability for sensorial and biochemical characters as compared to those from other origins. Aromatic intensity, flavour, bitterness, shape and make, average bean weight, dry matter, ash, protein and fat had expressed high heritability. The relationships between the attributes were observed to vary in patterns and magnitudes both at phenotypic and genotypic levels. The good cup quality parameters had reverse relationships with caffeine, bitterness and astringency at phenotypic level, indicating that coffee breeding strategy within and among geographical areas may provide quality improvement with known origin quality profile. It can be concluded that the promising coffee germplasm collections were diverse in terms of most quality traits and biochemical constituents due to genetic factors. Thus, selection of superior coffee cultivars requires careful evaluations and characterizations for yield, disease resistance and quality traits under various field management and processing techniques across major coffee producing locations in the country.

Key words: Biochemical composition, variability, heritability, correlation, quality traits in coffee

INTRODUCTION
Ethiopia is believed to be the primary centre of origin and genetic diversity for Arabica coffee (*Coffea arabica*). The total area of land devoted to coffee production is estimated at 662,000 hectares, of which 496,000 hectares are estimated to be productive. The majority of coffee production (90%) comes from the smallholders, while the rest is produced by large-scale producers (state farms and investors). In Ethiopia, coffee can grow in a wide range of agroecology from 550 m above sea level (m.a.s.l) to 2000 m.a.s.l (Paulos and Teketay, 2000). The diversity of coffee, soil and climate, production and processing methods, among others, enable the country to produce

and supply the de facto organic coffees (Taye and Tesfaye, 2002). Ethiopian coffee is processed and exported in two processing techniques, namely, natural sun-dried (70%) and washed (30%) coffees (Atero *et al*., 2008).

With regard to coffee germplasm, about 5175 accessions have been collected from the different coffee growing areas of the country through the national coffee collection program and maintained at the Jimma Agricultural Research Center and its sub-centers (Bayetta and Labouisse, 2006). In addition, the Biodiversity Conservation Institute of Ethiopia preserved over 4000 accessions in *ex-situ* coffee gene bank at Choche biodiversity unit in Jimma Zone, Southwest Ethiopia (Paulos and Teketay, 2000). Now this increased to a total of 11691 arabica coffee germplasm accessions that have been collected and *ex-situ* conserved at the Jimma Agricultural Research Centers (5960 accessions) and Institute of Biodiversity Conservation (5731 accessions) field gene banks (Kufa, 2010). The Jimma Research Center has developed and released 37 new coffee cultivars (34 pure lines and 3 hybrids). The new varieties are high yielding, resistant to diseases and possess unique quality profile. This include the known Ethiopian coffee brands (Sidama, Yirgacheffe and Harar) and other identified potential areas (Wellega/Gimbi, Kaffa, Illu Aba Bora, Bebeka/Tepi and others) with unique specialty coffee types in the country. Hence, coffee research has played a pivotal role in safeguarding the coffee sub-sector and improving coffee productivity and foreign exchange earnings in the country (Girma *et al*., 2008).

The existences of genetically diverse strains of this crop plant in this country led botanists and scientists to agree that Ethiopia is the centre for origin, diversification and dissemination of the coffee plant (Bayetta and Labouisse, 2006). Nonetheless, the country is not yet fully utilizing its coffee genetic resources as expected in terms of improving coffee productivity and the life style of the rural community due to several constraints. The increasing population pressure, deforestation, expansion of large-scale farms, competition from other crops, settlement programmers, financial crisis and climate change, among others, threatening coffee forest areas and genetic diversity (Paulos and Teketay, 2000; Gole *et al*., 2000). The limited use improved technologies has also contributed to the low national coffee yield and quality performances of Arabica coffee as compared to other coffee producing countries (Girma *et al*., 2008), suggesting the need for their scaling up of best practices in the major coffee growing areas.

Though quality is an inherent factor, environment and genetic diversity can play the major roles in determining coffee physical, organoleptic and bean biochemical quality attributes expression (Leroy *et al*., 2006). Despite this, little effort has been made on quality of *Coffea arabica* L. development through selection and breeding with high yielding cultivars. Much work has not been done to characterize germplasm on basis of their quality characters especially based on biochemical and organoleptic characters, largely due to limited capacity (Kufa, 2010). Currently, it is crucial to focus on environmental sustainability and coffee diversity (Kufa, 2010) to mitigate the risks of genetic erosion at their country of origin. This would promote effective and efficient utilization of Arabica coffee genetic resources and improve the livelihoods of million rural people in Ethiopia and elsewhere. It is therefore imperative to compare the patterns and magnitudes of genetic diversity and identify suitable coffee genotypes with desirable traits, including quality attributes and profile mapping. Thus, the objectives of the current research project was to estimate the extent of variability, heritability (in the broad sense) and the genetic advance expected under selection of some arabica coffee germplasm collections with regard to bean physical quality, biochemical compositions and organoleptic characteristics, ii) to examine the relationships between these quality attributes and iii) to see heritability of physical quality, biochemical composition and organoleptic characteristics in Arabica coffee germplasm collections in Ethiopia, its birth country.

MATERIALS AND METHODS

Description of study site: The experiment was carried out in 2009/10 at the Jimma Agricultural Research Center (JARC) (7°46' N latitude and 36°0' E longitude, 1753 m), southwest Ethiopia. JARC is the national coffee research coordinating center where there are live coffee collections. The center is located at 350 km away from Addis Ababa, 8 km away from the Jimma town in the direction of south western part. The center is located within the Tepid to cool humid highlands agro-ecological zone of the country. The area receives adequate amount of rainfall with the total mean annual rainfall of about 1529 mm. The mean maximum and minimum air temperatures of 26.3 and 11.6°C, respectively. The driest season lasts between December and January. The soil type of the center is dominated by Nitosol or Eutric nitosol, reddish-brown or darkish-brown, clay or clay loam texture and slightly acidic (Paulos and Teketay, 2000).

Experimental materials: Twenty-one *Coffea arabica* germplasm genotypes have been collected from the major coffee growing areas in southwestern Ethiopia (Table 1). Out of the several collections, this batch was selected based on the evaluations and promising performances with regard to coffee berry disease resistance, quality and yield as compared to other national collections between 1977 and 1997. The selected promising coffee accessions were advanced to variety trial and reestablished at the Jimma Agricultural Research Center field gene banks in 2002. Therefore, this experiment was conducted from 2002-2010.

Experimental design and sampling: A randomized complete block design of three replications was used for field planting of coffee trees. Each genotype was planted in a single row of eight trees per plot using a spacing of 2×2 m. All pre-and post-field management best practices were uniformly

Table 1: Geographical origin of the coffee genotype used for the study

Genotype	Region	Zone	Woreda	Site	Altitude
23000	SNNP	Benchmaji	Dizi	Garo	1326
23002	SNNP	Benchmaji	Sheko	Aybera	1634
23004	Oromia	Jimma	Goma	Choche	1634
23006	SNNP	Benchmaji	Meanit	Shasha	1324
23008	Oromia	Jimma	Goma	Choche	1771
23011	SNNP	Benchmaji	Dizi	Bero	1349
23013	SNNP	Benchmaji	Dizi	Bai	1439
23015	SNNP	Kaffa	Gimbo	Boka	1711
23017	SNNP	Benchmaji	Dizi	Bero	1349
23019	Oromia	Jimma	Goma	Choche	1735
23022	SNNP	Benchmaji	Dizi	Bai	1443
23024	SNNP	Benchmaji	Dizi	Bai	1552
23026	SNNP	Benchmaji	Sheko	Sanka	1677
23028	SNNP	Benchmaji	Dizi	Bero	1347
23030	Oromia	Jimma	Goma	Choche	1769
23041	SNNP	Benchmaji	Dizi	Garo	1336
23042	SNNP	Benchmaji	Sheko	Aybera	1667
23045	Oromia	Jimma	Seka Chekorsa	Melko	1751
23046	SNNP	Benchmaji	Sheko	Gizmeret	1613
23047	SNNP	Keffa	Gimbo	Boka	1712
23050	SNNP	Benchmaji	Sheko	Gacheb	1679

applied as per recommendations of the center (IAR, 1996). For this study, healthy and ripe red coffee cherries were selectively handpicked from 7-year-old coffee trees during a peak harvesting season. Fully ripe coffee berries were harvested from 8 plants of each accessions of individual accession per replications. The fresh coffee samples were carefully prepared using the washed processing method (pulping, fermentation and drying) as described by Clark (2005).

Data collection and analysis: Data on physical parameters (seed moisture content, average bean weight, green bean size and shape and make) were determined from the so prepared coffee samples according to ISO (2004). Further, uniform coffee beans were prepared from each accession by passing through a sieve size of 14 inch. Then, the standard procedures (ISO, 2004) were followed for organoleptic quality analyses (aromatic intensity, aromatic quality, acidity, body, bitterness, flavour and overall standard). Moreover, the samples were prepared and chemical compositions of green arabica coffee beans (caffeine, crude protein, sucrose, fat, dry matter and crude mineral) were determined according to AOAC (1990). Finally, the data collected for physical, organoleptic quality and biochemical were subjected to Analysis of Variance (ANOVA) in a randomized complete block design with three replications using SAS version 9.2 (SAS, 2001). For significantly different attributes, treatment means were compared and separated according to Tukey's test at 5% probability level.

Data analysis: Genotypic and phenotypic component of variances were estimated from the analysis of variance estimated as suggested by Singh and Chaudhary (1977) with general linear model (GLM) procedure of SAS version 9.2 (SAS, 2001). Moreover, heritability in broad sense for characters was computed using the formula suggested by Allard and Bradshaw (1964). Genetic advance expected assuming selection of the superior 5% of the genotypes was estimated in accordance with the methods illustrated by Allard and Bradshaw (1964). Again, genetic advance (as % of mean) was computed to compare the extent of predicted genetic advance of different traits under selection.

RESULTS AND DISCUSSION

The ANOVA results revealed highly significant difference ($p<0.01$) among the genotypes for all the physical quality, organoleptic attributes and biochemical compositions, except overall standard, body and sucrose content, respectively (Table 2). Similar finding were reported by several authors (Silvarolla *et al*., 2000; Clifford, 1985; Yigzaw *et al*., 2007) in arabica coffee. In addition, Parthiban *et al*. (2011) found variability in Jatropha for some character studied. And Gichimu and Omondi (2010) studied on morphological characterization of five newly developed lines of Arabica coffee and two commercial cultivars in Kenya and they reported non significant difference for internodes length. However, Dar and Sharma (2011) obtained highly significant difference among the genotypes for all the quality traits studied in tomatoes.

Physical quality of genotypes: The results depicted highly significant ($p<0.01$) differences among coffee genotypes for physical quality attributes, except over screen (Table 2). The highest score (17.17) for average bean weight was recorded by genotype 23030 and the lowest score (11.66) was recorded by genotype 23028. Interestingly, five- genotypes 23045, 23024, 23019, 23002 and 23008 performed best with significantly the highest average value (15.00) for shape and make (Table 3). The rest six-genotypes (23017, 23011, 23022, 23006, 23030 and 23015) had the lowest

Table 2: Analysis of variance (mean squares) for physical, organoleptic and biochemical quality attributes in Arabica coffee genotypes

Characters mean squares	Block (df = 2)	Genotype (df = 20)	Error (df = 40)
Physical			
SM	0.01	20.57**	0.11
OVS	0.19	1.21ns	0.29
ABW	0.03	7.44**	0.05
Organoleptic			
AI	0.19	1.44**	0.09
AQ	0.19	1.21**	0.11
BO	0.30	1.45ns	0.24
AC	0.19	1.21**	0.11
FL	0.01	4.11**	0.03
BT	0.02	2.58**	0.02
OVAS	0.19	1.21**	0.11
Biochemical			
DM	0.02	4.94**	0.02
CAF	0.01	0.07**	0.01
PRO	0.01	0.67**	0.0001
ASH	0.11	1.42**	0.07
SUC	0.19	1.21ns	0.11
FAT	0.03	7.45**	0.05

**Significant at $p<0.01$ probability level. ns: non significant ($p>0.05$). DM: Dry matter, CAFP: Caffeine, SUC: Sucrose, PRO: Protein, AI: Aromatic intensity, AQ: Aromatic quality, AC: Acidity, BO: Body, BT: Bitterness, FL: Flavour, OVAS: Overall standard, SM: Shape and make, OVS: Over screen, ABW: Average bean weight

Table 3: Mean values of the physical quality attributes in the studied coffee genotypes

Genotype	ABW	SM
23045	15.26^{cd}	15.00^{a}
23026	15.54^{bc}	12.00^{b}
23050	14.42^{e}	12.00^{b}
23024	17.13^{a}	15.00^{a}
23017	12.85^{gh}	8.00c
23011	12.28^{hi}	8.00c
23028	11.66^{i}	12.00^{b}
23041	12.72^{gh}	12.00^{b}
23000	12.42^{gh}	12.00^{b}
23013	14.79^{de}	12.00^{b}
23022	15.30^{cd}	8.00^{c}
23006	13.62^{f}	8.00^{c}
23030	17.17^{a}	12.00^{b}
23008	14.55^{e}	15.00^{a}
23004	15.48^{bc}	8.00^{c}
23019	15.69^{bc}	15.00^{a}
23042	16.06^{b}	12.00^{b}
23002	15.79^{bc}	15.00^{a}
23046	14.51^{e}	12.00^{b}
23047	13.04^{fg}	12.00^{b}
23015	15.31^{cd}	8.00^{c}
Mean	14.55	11.57
CV (%)	1.50	2.87

Mean values followed by the same letter(s) in a column are not significantly different from each at $p<0.01$. ABW: Average bean weight and SM: Shape, make

Table 4: Mean values of organoleptic quality attributes in the studied coffee genotypes

Genotype	AI	AQ	AC	FL	AS	BT	OVAS
23045	3.00[cd]	3.00[bc]	3.00[ab]	5.00[a]	1.00[a]	0.00[d]	3.00[bc]
23026	4.00[b]	4.00[ab]	2.00[bc]	4.00[b]	0.00[b]	0.00d	4.00[ab]
23050	3.00[cd]	3.00[bc]	3.00[ab]	4.00[b]	0.00[b]	0.00[d]	3.00[bc]
23024	4.00[b]	4.00[ab]	2.00[bc]	3.00[c]	0.00[b]	0.00[d]	4.00[ab]
23017	3.00[cd]	3.00[bc]	3.00[ab]	2.00[d]	1.00[a]	2.00[b]	3.00[bc]
23011	4.00[b]	4.00[ab]	2.00[bc]	4.00[b]	0.00[b]	0.00[d]	4.00[ab]
23028	5.00[a]	4.67[a]	1.33[c]	2.00[d]	0.00[b]	1.00[c]	4.67[a]
23041	5.00[a]	5.00[a]	1.00[c]	3.00[c]	0.00[b]	1.00[c]	5.00[a]
23000	3.00[cd]	3.00[bc]	3.00[ab]	4.00[b]	1.00[a]	0.00[d]	3.00[bc]
23013	2.33[d]	2.67[c]	3.33[a]	4.00[b]	1.00[a]	0.00[d]	2.67[c]
23022	3.00[cd]	3.00[bc]	3.00[ab]	3.00[c]	1.00[a]	0.00[d]	3.00[bc]
23006	3.33[bc]	3.33[bc]	2.67[ab]	2.00[d]	1.00[a]	1.00[c]	3.33[bc]
23030	4.00[b]	4.00[ab]	2.00[bc]	1.33[ef]	1.00[a]	2.00[b]	4.00[ab]
23008	3.00[cd]	3.00[bc]	3.00[ab]	2.00[d]	1.00[a]	2.00[b]	3.00[bc]
23004	3.33[bc]	3.33[bc]	2.67[ab]	1.00[f]	1.00[a]	3.00[a]	3.33[bc]
23019	3.00[cd]	3.00[bc]	3.00[ab]	2.00[d]	1.00[a]	1.00[c]	3.00[bc]
23042	3.00[cd]	3.00[bc]	3.00[ab]	3.00[c]	1.00[a]	0.00[d]	3.00[bc]
23002	3.00[cd]	3.00[bc]	3.00[ab]	5.00[a]	1.00[a]	0.00[d]	3.00[bc]
23046	3.00[cd]	3.00[bc]	3.00[ab]	3.00[c]	1.00[a]	0.00[d]	3.00[bc]
23047	3.00[cd]	3.00[bc]	3.00[ab]	1.67[d]	1.00[a]	0.00[d]	3.00[bc]
23015	3.00[cd]	3.00[bc]	3.00[ab]	2.00[d]	1.00[a]	1.00[c]	3.00[bc]
Mean	3.38	3.38	2.62	2.91	0.76	0.79	3.38
CV (%)	8.89	9.68	12.49	6.29	0.41	15.88	9.68

Mean followed by the same letter in rows are not significantly different according to Tukey's test at $p<0.05$. AI: Aromatic intensity, AQ: Aromatic quality, AC: Acidity, FL: Flavour, AS: Astringency, BT: Bitterness, OVAS: Overall standard

shade and make value. The genotype 23030 had the highest bean weight and lowest shape and make. This indicates varying performance of the same genotype for different physical quality traits. But, genotype 23024 had high results for both bean weight and shape and make. The variation in the genotypes implies possibility for the genetic improvement of the crop through ingenious selection and cross breeding. This is in line with other findings that indicated diversity in *Coffea arabica* L. varieties in bean physical characters (Yigzaw *et al*., 2007).

Oragnolepic quality: The result showed highly significant ($p<0.01$) differences among genotypes for sensorial quality attributes, except for body (Table 2). Consequently, the average results ranging from 2.33-5.00 for aromatic intensity, 2.67-5.00 for aromatic quality, 1.00-3.33 for acidity, 1.00-5.00 for flavour, 0.00-1.00 for astringency, 0.00-3.00 for bitterness and 2.67-5.00 for overall standard. The genotypes that showed high value (5.00) for aromatic intensity were 23028 and 23041 as opposed to the lowest (2.33) result for genotype 23013. Except the genotypes 23026, 23024, 23011, 23028 and 23041, the remaining genotypes manifested very lightly astringent quality character. The highest (5.00) and lowest (2.67) aromatic quality results were determined from genotypes 23041 and 23013, respectively. The latter genotype had also high acidity (3.33). In contrast, the low acidity (1.00) and high overall standard (5.00) were determined from genotype 23041. The maximum average result (5.00) for flavour was obtained from genotypes 23045 and 23002. This was lowest for 23004 that had high mean value (3.00) for bitterness (Table 4). Similar result was reported by Silvarolla *et al*. (2000), Clifford (1985) and Yigzaw *et al*. (2007) in arabica

Table 5: Variations in biochemical quality attributes in the studied coffee genotypes

Genotype	DM	CAF	PRO	ASH	FAT
23045	92.91^{de}	1.07r	3.69^{s}	3.66b^{cd}	13.28^{b}
23026	92.57^{e}	1.12^{o}	3.86^{p}	3.56^{bcde}	13.18^{bc}
23050	91.99^{fgh}	1.00^{s}	4.17^{l}	3.47^{bcde}	12.75^{bcd}
23024	95.06^{a}	1.22^{l}	4.21^{k}	4.02^{ab}	13.20^{b}
23017	91.03^{j}	1.41^{e}	4.86^{e}	1.99^{g}	12.69^{bcd}
23011	90.93^{jk}	1.13^{n}	3.89^{n}	2.03^{g}	12.66^{bcd}
23028	90.55^{k}	1.31^{g}	4.52^{g}	2.83^{f}	12.68^{bcd}
23041	90.67^{jk}	1.24^{k}	4.28^{j}	3.47^{dce}	12.77^{bcd}
23000	90.97^{j}	1.11^{p}	3.83^{q}	3.63^{bcd}	12.20^{cd}
23013	92.00^{fg}	1.18^{m}	4.07^{m}	3.30^{def}	13.25^{b}
23022	92.01^{fg}	1.26^{j}	4.35i	3.59^{bcde}	13.15^{bc}
23006	91.59^{hi}	1.39^{f}	4.79^{f}	2.21^{g}	13.17^{bc}
23030	94.90^{a}	1.46^{c}	5.04^{c}	3.55^{bcde}	13.17^{bc}
23008	91.98^{fgh}	1.44^{d}	4.97^{d}	2.87^{f}	12.72^{bcd}
23004	92.08^{fg}	1.51^{a}	5.24^{a}	3.94^{abc}	12.75^{bcd}
23019	93.00^{d}	1.39^{f}	4.79^{f}	4.03^{ab}	12.75^{bcd}
23042	94.04^{b}	1.29^{h}	4.45^{h}	3.84^{abc}	12.10^{d}
23002	93.61^{c}	1.09^{q}	3.76^{r}	3.81^{abcd}	12.22^{cd}
23046	91.70^{ghi}	1.27^{i}	4.38^{i}	2.22^{g}	12.61^{bcd}
23047	91.523	1.48^{b}	5.11^{b}	4.22^{a}	14.98^{a}
23015	92.11^{f}	1.31^{g}	4.52^{g}	3.10^{ef}	13.00^{c}
Mean	92.25	1.27	4.42	3.30	12.92
CV (%)	0.14	7.87	0.23	8.02	1.73

Mean values followed by the same letter in a column are not significantly different at $p<0.05$ (Tukey's test). DM: Dry matter, CAF: Caffeine, ASH: Ash, PRO: Protein, SUC: Sucrose, FAT: Fat

coffee. This also concurs with Walyaro (1983) and Van der Vossen (2005) who observed variations in cup quality characters among varieties and crosses of *Coffea arabica* L. The results indicate great variability among coffee genotypes and thus, one can develop varieties with different organoleptic quality profiles as per the preference of the consumers. For example, Germans and Swedes prefer lighter and more acidic coffees than Italians (Leroy *et al.*, 2006).

Biochemical composition: The performance of the coffee genotypes was highly significant ($p<0.01$) for all biochemical quality attributes, except for sucrose (Table 5). The average values 90.55-95.06 for dry matter, 1.00-1.51 for caffeine, 1.99-4.22 for ash, 3.69-5.24 for protein and 12.10-14.98 for fat content. Coffee genotypes 23024, 23004, 23047, 23004 and 23047 had the respective high mean values for bean dry matter (95.06), caffeine (1.51), ash (4.22), protein (5.24) and fat (14.98) content as compared to other genotypes (Table 5). In this study, the caffeine content and acidity were directly correlated with the elevation of the collection areas of the coffee germplasms (Table 1). This variability is in agreement with several findings (Getu, 2009; Ky *et al.*, 2001; Silvarolla *et al.*, 2000) that showed the presence of significant variations among genotypes of arabica coffee in biochemical compositions. Furthermore, Alsemaan *et al.* (2011) reported the existence of genetic diversity within *Rosa damascene* in oil contents.

Genotypic and phenotypic variations: The estimates of range, mean and components of variances for 17 quality characters of arabica coffee genotypes are presented in Table 6. And the

Table 6: Estimate of range, mean, components of variance and heritability for physical, organoleptic and biochemical quality attributes in the study coffee genotypes

	Range mean		Components of variance		
Characters	Min	Max	Vg	Vp	H^2(%)
Physical					
SM	8.00 15.00	11.57	6.86	6.94	98.78
OVS	67.60 99.30	11.57	0.01	0.15	6.38
ABW	11.66 17.16	14.55	2.46	2.51	98.01
Organoleptic					
BO	3.00 4.00	3.04	0.04	0.17	23.33
AC	1.00 3.33	2.62	0.37	0.48	77.08
FL	1.00 5.00	2.91	1.36	1.39	97.84
AI	2.33 5.00	3.38	0.45	0.54	83.33
AQ	2.66 5.00	3.38	0.36	0.47	76.59
AS	0.00 1.00	0.76	0.25	0.48	52.08
BT	0.00 3.00	0.79	0.85	0.87	97.70
OVAS	2.66 5.00	3.38	0.36	0.47	76.59
Biochemical					
DM	90.54 95.05	92.25	1.64	1.66	98.79
CAF	1.00 1.51	1.27	0.02	0.03	76.92
ASH	1.99 4.22	3.30	0.45	0.52	86.53
PRO	3.69 5.24	4.42	0.22	0.23	95.65
SUC	6.40 9.06	7.57	0.06	0.18	10.91
FAT	14.98 12.10	12.92	0.42	0.49	85.71

vg: Genotypic variance, Vp: Phenotypic variance, H^2: Broad sense heritability, BO: Body, AC: Acidity, FL: Flavour, AI: Aromatic intensity, AQ: Aromatic quality, AS: Astringency, BT: Bitterness, OVAS: Overall standard, SM: Shape and make, OVS: Over screen, ABW: Average bean weight,, DM: Dry matter, PRO: Protein, CAF: Caffeine, SUC: Sucrose

differences between the minimum and maximum mean values for all the traits were quite considerable. Consequently, the results showed range of 3.00-4.00 for body, 1.00-3.33 for acidity, 1.00-5.00 for flavour, 2.33-5.00 for aromatic intensity, 2.66-5.00 for aromatic quality, 2.66-5.00 for overall standard (Table 6).

Moreover, genotypic variances ranged between 0.01 for over screen and 6.86 for shape and make. The phenotypic variances ranged between 0.03 for caffeine and 6.94 for shape and make. Shape and make was among physical quality characters that showed higher phenotypic variance. Among the organoleptic and biochemical attributes, phenotypic variance was higher (1.36) for flavor and dry matter, respectively. The genotypic and phenotypic variances are almost closer each other, indicating that the genotype could be reflected by the phenotype and the effectiveness of selection based on phenotypic performance for these characters. Regarding the genotypic and phenotypic coefficient of variations, the estimates of genotypic and phenotypic coefficient of variations ranged from 1.29 for over screen to 40.52 for flavor, respectively. Genotypic coefficient of variation also ranged from 0.08 for over screen to 40.08 for flavour. According to Deshmukh *et al.* (1986), Phenotypic Coefficient of Variation (PCV) and genotypic coefficient of variation (GCV) values greater than 20% are considered to be high. Whereas, values less than 10% are considered to be low and values between 10 and 20% to be medium. High phenotypic and genotypic coefficients of variations were recorded for acidity, flavour, astringency, shape and make and ash. High genotypic and phenotypic coefficient of variation indicated the selection may be effective based on these characters and their phenotypic expression would be a good indication of the genotypic potential (Singh and Singh, 2004).

Table 7: Estimate of coefficient of variation and expected genetic advance for physical, sensorial and biochemical quality attributes in the studied coffee genotypes

	Coefficient of variation		Genetic advance	
Characters	GCV	PCV	K = 5 %	as of % mean
Physical				
SM	22.64	22.64	16.96	146.59
OVS	0.08	1.29	0.01	0.07
ABW	10.78	10.89	17.73	121.86
Organoleptic				
BO	1.32	5.59	0.34	11.18
AC	23.22	26.44	3.71	141.60
FL	40.08	40.52	5.28	181.44
AI	19.85	21.74	4.63	136.98
AQ	17.75	20.26	4.47	132.25
AS	28.15	31.64	1.51	198.68
BT	11.52	11.61	2.66	336.71
OVAS	17.75	20.28	4.47	132.25
Biochemical				
DM	1.38	1.39	94.70	102.66
CAF	11.68	12.69	1.52	119.69
ASH	20.33	21.85	4.58	138.79
PRO	10.61	10.88	5.36	121.27
SUC	0.79	2.38	0.81	10.70
FAT	5.02	5.42	14.15	109.52

GVC: Genotypic coefficient of variation, PCV: Phenotypic coefficient of variation, BO: Body, AC: Acidity, FL: Flavour, AI: Aromatic intensity, AQ: Aromatic quality, AS: Astringency, BT: Bitterness, OVAS: Overall standard, SM: Shape and make, OVS: Over screen, ABW: Average bean weight, DM: Dry matter, PRO: Protein, CAF: Caffeine, SUC: Sucrose

Moreover, aromatic intensity, aromatic quality and overall standard are coffee quality attributes that fall in range of high Phenotypic Coefficient of Variations (PCV) while their Genotypic Coefficient of Variation (GCV) remain in range of medium. Dry matter, over screen, fat, sucrose and body were the coffee quality character that fall in range of low genotypic and phenotypic coefficient of variations. According to Panse (1957), characters that demonstrated low genotypic and phenotypic coefficient of variations would offer less scope of selection as they were under the influence of environment.

Broad sense heritability: Estimate results of heritability in the broad sense (H^2) ranged from 6.38% for over screen to 98.79 for dry matter (Table 6). Very high estimate of heritability (H^2) in the broad sense was obtained for flavour (97.84), bitterness (97.70), shape and make (98.78), dry matter (98.79), protein (95.65), fat (85.71), ash (86.53), aromatic intensity (83.33) and average bean weight (98.01), indicating the possibility of progress from selection. Burton and Devane (2003) described that genotypic coefficient of variation along with heritability estimates would give a better idea about the prediction of progress through selection. Moderately high estimate of heritability values were recorded for acidity (77.08), aromatic quality (76.59), overall standard (76.59) and caffeine content (76.92).

According to Singh (2003), if the heritability of a character is very high ($\geq$80%) improvement of such a character could be easily achieved through selection. This is because of the existence of a close correspondence between genotype and phenotype variance due to a relatively smaller contribution of environment to phenotype (Singh, 2003). However, for the characters with low heritability, say less than 10% (such as over screen) selection may be difficult due to the masking effect of environment over the genetic effect.

Expected Genetic Advance (GA): The expected GA values for 17 characters in arabica coffee are presented in Table 7. The progress that could be expected from selecting the top 5% of the genotypes varied from 0.07% for over screen to 336.31% for bitterness as percent of mean (Table 7). Increases of 94.70% for dry matter, 17.73 for average bean weight and 16.96 for shape and make could made from selection and the least increases of 0.01, 0.34 and 0.81% could be made for over screen, body and sucrose in that order.

Regarding this, Burton (1952) suggested that genetic coefficient of variation together with heritability values would give the best estimates of the amount of the genetic advance to be expected from selection. Since, heritability estimate show only the effectiveness of selection of genotypes based on phenotype, their utilities can increase when used only with estimates of genetic advance (Allard and Bradshaw, 1964). Of all the good cup quality attributes, flavour and aromatic intensity appeared to combine relatively high values of heritability and genetic advance as percent of mean. This indicated that effective and satisfactory individual plant selection for practical improvement of their important character is possible. Nevertheless, to ascertain this further studies across locations and years are suggested.

Correlation analysis

Phenotypic associations: The phenotypic correlation coefficient among physical quality, organoleptic and biochemical compositions in arabica coffee genotypes ranged from r = -0.01 to 0.99 (Table 8). The range of phenotypic associations for physical quality attributes among each other and with other (organoleptic and biochemical composition) quality attributes were from -0.76 to 0.99 and these values were statistically significant.

Table 8: Phenotypic correlation coefficient among coffee quality attributes

Characters	ABW	SM	OVS	PRO	ASH	DM	SUC	CAF	FAT	BT	AS	AC	B0	AQ	AI	FL	OVAS
ABW		0.04	0.08	0.14	0.26	0.78**	0.13	-0.34*	0.07	-0.24	-0.01	0.15	0.43**	0.19	0.11	0.06	0.20
SM			0.01	-0.04	0.12	0.25	0.23	-0.14	0.04	-0.11	-0.06	0.01	0.28	0.22	0.02	0.14	0.20
OVS				0.06	0.01	0.16	0.12	-0.22	0.05	-0.09	-0.06	0.18	0.34*	0.07	0.21	0.04	0.02
PRO					-0.14	-0.22	0.03	0.09	0.18	0.55**	0.28	-0.05	-0.02	-0.18	-0.11	-0.38*	-0.20
ASH						0.27	0.19	-0.20	0.27	0.61**	0.68**	0.25	-0.06	0.11	-0.65**	0.20	-0.06
DM							-0.13	-0.36*	0.28	-0.11	-0.18	0.30*	-0.10	0.14	0.18	0.16	0.23
SUC								0.15	-0.27	-0.12	-0.03	0.12	0.21	0.01	0.15	0.22	-0.11
CAF									-0.21	0.56**	0.20	-0.32*	-0.12	-0.67**	-0.59**	-0.61**	-0.52**
FAT										0.13	0.13	0.17	0.65**	0.17	0.27	0.18	0.22
BT											0.12	-0.21	-0.60**	-0.10	-0.19	-0.54**	-0.65**
AS												-0.31*	-0.72**	-0.67**	-0.52**	0.15	-0.25
AC													0.61**	0.81**	0.76**	0.79**	0.99**
B0														0.59**	0.63**	0.23	0.02
AQ															0.98**	0.81**	0.85**
AI																0.79**	0.88**
FL																	0.99**
OVAS																	

*, **: Significant at 0.05 and 0.01 probability level, respectively. DM: Dry matter, CAF: Caffeine, ASH: Ash, SUC: Sucrose, FAT: Fat, PRO: Protein, A I: Aromatic intensity, AQ: Aromatic quality, AC: Acidity, BO: Body, AS: Astringency BT: Bitterness, FL: Flavour, OVAS: Overall standard, SM: Shape and make, A BW: Average bean weight

Table 9: Genotypic correlation coefficient among coffee quality attributes

Characters	ABW	SM	OVS	PRO	ASH	DM	SUC	CAF	FAT	BT	AS	AC	B0	AQ	AI	FL	OVAS
ABW		0.15	0.69**	0.01	0.22	0.24	0.04	-0.55**	0.09	-0.34*	0.12	0.03	0.02	0.82**	0.21	0.03	0.26
SM			0.31*	0.05	0.23	0.03	0.07	-0.01	0.12	-0.11	0.22	0.19	0.03	0.03	0.03	0.24	0.01
OVS				-0.15	0.04	0.16	0.06	-0.23	0.13	-0.12	0.12	0.26	0.32*	0.04	0.41**	0.03	0.23
PRO					-0.14	0.16	0.22	0.79**	0.15	0.27	0.01	-0.22	0.79**	-0.22	-0.11	-0.18	0.13
ASH						0.23	0.06	0.13	0.04	0.77**	0.07	0.78**	0.55**	0.07	-0.05	0.14	0.27
DM							0.19	-0.55**	0.11	0.21	-0.01	0.67**	0.18	0.01	0.24	0.16	-0.02
SUC								-0.23	-0.03	0.03	0.11	0.11	0.10	0.09	0.14	0.23	0.13
CAF									-0.12	0.77**	-0.07	-0.29*	-0.25	-0.14	-0.22	-0.03	-0.15
FAT										-0.45**	0.17	0.19	0.27	0.19	0.55**	0.65**	0.66**
BT											-0.05	0.04	-0.23	-0.22	-0.55**	-0.53**	-0.61**
AS												-0.01	-0.99**	-0.76**	-0.26	-0.73**	-0.55**
AC													0.91**	0.97**	0.81**	0.86**	0.95**
B0														0.24	0.89**	0.66**	0.94**
AQ															0.88**	0.99**	0.95**
AI																0.99**	0.95**
FL																	0.61**
OVAS																	

*, **: Significant at 0.05 and 0.01 probability level, respectively. DM: Dry matter, CAF: Caffeine, ASH: Ash, SUC: Sucrose, FAT: Fat, PRO: Protein, AI: Aromatic intensity, AQ: Aromatic quality, AC: Acidity, BO: Body, AS: Astringency, BT: Bitterness, FL: Flavour, OVAS: Overall standard, SM: Shape and make, A BW: Average bean weight

Average bean weight was positively and significantly associated with dry matter. Similarly, Vaast *et al*. (2004) reported the existence of significant relationship between average bean weight and dry matter in arabica coffee. While average bean weight associated negatively and significantly with caffeine, the negative association of average bean weight with caffeine indicated simultaneous improvement in the two traits seam to be practically difficult. The associations of physical quality attributes and organoleptic quality attributes were positive except with astringency and bitterness. Moreover the association of body with average bean weight and over screen was positive and significant. Positive association of physical quality attributes among themselves and other good quality attributes is a good opportunity to improve both good characters simultaneously.

All good cup quality attributes (aromatic intensity, aromatic quality, acidity, flavour and overall standard) except body associated highly significantly and positively among each other (Table 9). Similarly, Yigzaw (2005) reported the presence of highly significant and positive association among good cup quality attributes of arabica coffee. Overall standard associated highly significantly and positively with acidity, aromatic intensity, aromatic quality and flavour. This relationship indicated that selection for overall standard is responsive to the improvement of all the traits. Overall standard associated significantly and negatively with caffeine, bitterness, indicating that improvement for overall standard could result in negative selection for caffeine and bitterness. The association of flavour and acidity with overall standard was stronger than any other organoleptic quality attributes, thus beyond the improvement of overall standard selecting genotypes for improvement of acidity and flavour could improve other good cup quality attributes since flavour and acidity had positive association with all good cup quality attributes. Similarly, Yigzaw (2005) reported flavour can serve as a single determinant character for genotype selection of arabica coffee. Also, Agwanda *et al*. (2007) reported that flavour is the all important combination of aroma, acidity and body that creates an overall impression. The same authors concluded that flavour rating is the best selection criterion for the genetic improvement of liquor quality in arabica coffee.

Bitterness and astringency associated with good cup quality attributes negatively in different level of significant. Such kind of inverse associations between good cup quality (aromatic intensity, aromatic quality, body, acidity, flavour and overall standard) and poor quality attributes (bitterness and astringency) have a great important for best variety development through selecting superior genotypes for good cup quality attributes since selection of genotypes for good cup quality attributes could result in negative selection of bitterness and astringency. When we select the superior genotypes for good cup quality attributes we could keep bitterness and astringency low.

Good cup quality attributes associated positively with biochemical compositions except caffeine and protein which associated negatively with all good cup quality attributes, of which the association of protein with favour was significant, on the other hand, caffeine associated highly significantly with aromatic quality, aromatic intensity, flavour and overall standard. However, ash associated negatively and weakly with aromatic quality, body, flavour and overall standard. Similarly, protein associated weakly and negatively with acidity, body, aromatic intensity, aromatic quality and overall standard. Bitterness associated positively and significantly with protein, caffeine and ash. Moreover, the association of Caffeine and protein turned out to be positive which is a lead to the associated response of these characters to improvement.

Sucrose associated negatively only with dry matter but associated positively and weekly with other biochemical quality attributes. Similarly, Decazy *et al*. (2006) indicated the absence of strong associations among fat, sucrose and sensorial quality attributes.

Genotypic associations: The genotypic correlation coefficients of quality attribute of physical, organoleptic and biochemical compositions in arabica coffee genotypes studied during 2009/10 cropping season ranged from r = -0.01 to 0.99 and are depicted in Table 9. Over screen associated highly significantly and positively with average bean weight and significantly with shape & make. Also shape and make associated positively with average bean weight. Hence, these positive associations among physical quality attributes are good indicator for simultaneous improvement of physical quality attributes through selection. All physical quality attributes associated positively with good cup quality attributes and biochemical compositions (except caffeine). Therefore, the positive association of physical quality attributes with good cup quality attributes and biochemical composition indicating possibility of simultaneous improvement of all the quality attributes through selection of genotypes in the absence of other technologies like cup testing and biochemical analysis. Overall standard turned to have non significant association with physical quality attributes at genotypic and genotypic levels, indicating that selection could made for the desired physical quality attributes with out changing the level of overall standard, since the lack of significant association between characters is caused by independent genetic control.

Interesting association was observed with regard to good cup quality attributes (acidity, body, flavour, aromatic intensity, aromatic quality and overall standard). Overall standard associated highly significantly and positively with acidity, body, flavour, aromatic intensity and aromatic quality. This result is in agreement with the finding of Decazy *et al.* (2006) who reported the presence of highly significant and positive association of overall standard with acidity, body, flavour, aromatic intensity and aromatic quality in arabica coffee. The result revealed that the possibility of best variety development targeting selection program on either of good cup quality attributes (acidity, body, flavour, aromatic intensity, aromatic quality and overall standard) will improve overall standard quality attributes.

All good cup quality attributes were highly significantly and positively associated with each other at genotypic level except the association between body and aromatic quality. Moreover, all good cup quality attribute associated positively with fat. Flavour and overall standard are among good cup quality attributes that associated highly significantly and positively with fat. Larcher (2005), reported the presence of highly significantly positive association of fat with organoleptic characteristics such as aroma, body, acidity, flavor, aromatic intensity, aromatic quality and preference. Also Decazy *et al.* (2006) found that fat content was associated with acidity and beverage preference. Further, Avelino *et al.* (2005) indicated that the presence of association between fat and sensorial qualities attributes. Therefore, selection of arabica coffee germplasm for superior performance of fat would improve good cup quality attributes.

Good cup quality attributes associated positively with all biochemical composition quality attributes except caffeine and protein. The association of fat and sucrose was negative and weak. This result is in harmony with Avelino *et al.* (2005) who reported the absence of strong association between fat and sucrose. Sucrose associated negatively with caffeine; positively with ash and protein. This demonstrates that the importance of analytical chemistry because there would be some bean chemical composition quality attributes that had positive significant association with important organoleptic quality attributes. Nikhila *et al.* (2008) reported that length of primary branches , number of primary branches, intermodal length and bush spread are the character that should be given premium importance while carrying out crop improvement programmes in robusta coffee.

CONCLUSION

The findings of the study demonstrate the existence of diversity among the Ethiopian coffee germplasm collections in bean physical, organolepic and biochemical quality attributes. The influence of geographical origin on these traits was also evident, strengthening our current local landrace coffee research and development strategy. Hence, sustainable production and export of superior quality coffees demand, *inter alia,* identification of the right cultivars with desirable traits including low caffeine under specific environments, field management and processing techniques. Moreover, molecular, physiological, quality and biochemical analyses should be undertaken to further characterize the germplasm and develop quality profile mappings with the views to ensure effective utilization, conservation and traceability of the great coffee genetic wealth in the country.

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