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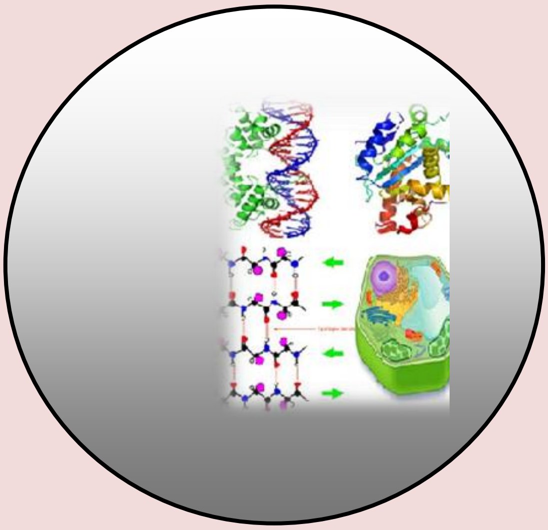

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RESEARCH PAPER

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Variation and Genotype X Environment Interaction for Quality Characters among Selected Coffee Hybrids under Mid-Lowland Environments in Ethiopia

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ABSTRACT
An experiment to determine the extent of quality variation in selected hybrid of Arabica coffee was conducted at two different sites at two locations in South-western region of Ethiopia. Genetic variation, genotype × environment interaction of 11 quality (three green bean and eight organoleptic cup quality characters were studied in 15 Arabica coffee hybrids and two standard checks across four environments. The randomized complete block design was used in each environment. Coffee quality assessment result showed that high and low genetic variation for green bean physical characteristics and organoleptic attributes as expressed by their respective high (h^2_{bs}>0.70) and low to moderate (h^2_{bs}=0.05 to 0.50) line mean-basis broad sense heritability estimates. The consequence of these lower heritablities for organoleptic cup quality attributes and the method to increase the heritability estimates were discussed. Genotypes exhibited lower genotype interaction with environment / location/ year demonstrating that selection can be performed at any of location or year for higher or lower score. The study indicates the presence of low to moderate variation for coffee quality characters among the tested hybrid genotypes.
Keywords: Broad sense heritability, Cup quality characters, Green bean characters, GxE effect, Hybrid coffee (Coffea arabica L.).

INTRODUCTION
Coffee, as export commodity, plays key role in national economies of nearly 80 developing world countries (Mishra and Slater, 2012). *Coffea arabica* L. represents 70% of the commercial coffee of the world. It is prominent by presenting quality attributes superior to Robusta coffee and thus more valued in the market (Pereira *et al.,* 2010). The coffee product of Ethiopia is solely Arabica coffee with diverse and unique aroma and flavor characteristics.
The quality of coffee beans is affected by genetic characteristics, edapho-climatic conditions, post-harvest and roasting process and the final preparation of coffee brews (Leroy *et al.,* 2006).

The breeding has the objective to transfer resistance genes from robusta coffee to Arabica interspecific hybrid (Bertrand *et al*., 2008) and/or within Arabica coffee, interaspecific hybrid (Mesfin and Bayetta, 1984). Besides conferring resistance to pests and diseases and an improvement of agronomic characteristics, these crosses may also affect the bean compositions and sensory quality of the coffees (Kitzberger *et al*., 2012) suggesting the need of monitoring the quality status of the newly developed crosses in regular basis in the breeding program.

Cup quality (Beverage quality), often referred to as liquor quality is an important attribute of coffee and acts as yardstick for price determination (Agwanda *et al*., 2003; Kathurima *et al*., 2009). Production and supply of coffee with excellent quality is therefore important for coffee exporting countries (Abadiga, 2010). Moreover, success of a new variety of Arabica coffee depends to a great extent on its bean and beverage quality (Agwanda *et al*., 2003). Consequently, many coffee producing countries consider assessment of coffee quality as critical as disease resistance and productivity in their coffee variety development programmes (Abadiga, 2010).

New Arabica coffee cultivars with better quality, higher yield potential and resistance to diseases have started to replace the traditional varieties on a large scale in several countries (Van der Vossen, 2001). For instance, the current coffee breeding strategy in Ethiopia which considered bean quality in addition to increased yield and resistance to diseases is taken as new but complimentary strategies initiated in early1980 had led identification of some elite hybrids derived from three coffee diversity groups viz., Harar, Sidamo and Southwestern Ethiopian coffee (Behailu *et al*., 2008) . However, the magnitude of genetic variability for green bean physical and cup quality characters has not yet been ascertained in these hybrids across environments. Genetic variability in arabica coffee for quality (organoleptic and/or green bean physical) characters has been studied by several workers (e.g., Walyaro, 1983; Gichimu *et al*., 2012; Gimase *et al*., 2014; Abrar *et al*., 2014). All investigators reported the presence of high variability among coffee genotypes for various characters studied. However, most of the above studies were run in a single environment and there is also little information on how those quality traits interact with the environment, e.g., genotype by environmental (G x E) interactions. Commonly, given resource requirement, the intensive evaluations activities will proceed in a single environment and possible modification of genetic potential by local growing environments (G x E interaction) are ignored. As such it is essential to determine the heritability estimates and magnitude of G x E interaction for *arabica coffee* breeding program to be effective. There is dearth of information especially on studies that included a site effect in genetic parameter estimation of coffee quality to estimate the effect of GxE. Therefore, the objectives of this study were to: (i) determine the extent of variation in coffee green bean physical and organoleptic cup quality characters in a group of seventeen hybrids coffee genotypes; (ii) determine the heritable components of the overall variability with the help of suitable genetic parameters; and (iii) estimate genotype x environment interaction to determine the stability of trait expression in various coffee quality characters of seventeen coffee genotypes across four mid land and low land coffee environments in South-Western Ethiopia.

MATERIAL AND METHODS

Description of the study sites and germplasm

The study was conducted at two different locations for two production seasons in South-western region of Ethiopia, namely at Jimma Agricultural Research Center (JARC) and Tepi National Spice Research Center (TNSRC). The Jima site represents the midland and Tepi represent lowland humid coffee growing agro-ecologies. The Jima research center is situated at $7^0$40'N latitude, $36^0$47'E longitude and an altitude of 1753 m above sea level (m.a.s.l) with mean total annual rain fall of about 1572 mm. Average daily minimum and maximum temperatures are about 11.6 and 26.3^{o}c, respectively. The Tepi research center is situated at $7^0$11'N latitude, $35^0$25'E longitude and an altitude of 1220 m above sea level (m.a.s.l) with mean total annual rain fall of about 1594 mm. Average daily minimum and maximum temperatures are about 15.7 and 29.9^{o}c, respectively. The bulk of the soil in the South-west coffee growing region in general is described as Eutric Nitosol and deep red fertile and well drained, with P^H of 5-6 medium to high in exchangeable cation (Paulos and Tesfaye, 2000).

The study used fifteen experimental coffee hybrids that were originally developed by crossing among germplasm primarily collected for their resistance to coffee berry disease (CBD) (Table 1).

The hybrids were and selected from previous screening trials for showing better resistance to major coffee diseases (CBD and CLR, coffee leaf rust), desirable cup quality and high yielding potential (Behailu *et al.*, 2008). Two commercial checks Ababuna (Hybrid check, here after referred as HYCK) selected from long-term hybridization program was planted at both locations, while the other variety check (VCK) was F-59 (Desu) planted at Jima and Geisha at Tepi were included in the trial for comparison.

Table 1. Description of the coffee hybrids and commercial checks used for the study.

#	Code-name	Germplasm Composition*	Cross categories†
1	HC-1	SW X Harrar	CBD res x Harrar +HY
2	HC-2	SW X Harrar	CBD res x Harrar +HY
3	HC-3	SW X Harrar	CBD res x Harrar +HY
4	HC-4	SW X Harrar	CBD res x Harrar +HY
5	HC-5	SWX Harrar	CBD res x Harrar +HY
6	HC-6	SW X SW	CBD res x CBD res +Q
7	HC-7	SW X Harrar	CBD res x Harrar +HY
8	HC-8	SW X SW	CBD res +Q xCBD res +Q
9	HC-9	SWX Sidama	CBD res x Sidama +HY
10	HC-10	SWX Sidama	CBD res x Sidama +HY
11	HC-11	SWx Sidama	CBD res x Sidama +HY
12	HC-12	SWx Sidama	CBD res x Sidama +HY
13	HC-13	SW X SW	CBD res x high yielder
14	HC-14	SW X SW	CBD res x high yielder
15	HC-15	SWx Sidamo	CBD res x Sidama +HY
16	Aba-Buna (HYCK)	SW X SW	CBD res x high yielder
17	F-59 (at Jimma)	SW	HY + wide adaptable
18	Geisha (at Tepi)	Introduced variety	Lowland adaptable + rust resistance

*SW=South-western Ethiopian coffee type; Harrar= Harrar coffee type; Sidamo= Sidamo coffee type
†CBD res = CBD resistant; Q = good quality; HY=high yielder; HC =Hybrid coffee, HYCK=hybrid check

Experimental design and field management

The hybrids were established using a Randomized Complete Block Design (RCBD) with three replications at each site in July, 2008. Each plot comprised of sixteen coffee trees planted in two rows for each genotype. The spacing between rows and trees within the rows were 2 m by 2 m. Fertilizer and crop management practices were uniformly applied at both sites throughout the trial periods as recommended. Samples were taken from all the sixteen trees and bulked to give one sample per replication.

Preparation and evaluation of green coffee bean

Coffee cherry samples were picked during the peak harvesting period of October to December both in 2013/14 and 2015/16 in both sites. The ripe coffee samples were carefully prepared using wet processing method (pulping, fermentation, and drying) and prepared for green bean physical quality evaluation as described by Abrar *et al*. (2014) was adopted, which evaluates physical quality characters based on bean size for above screen 14 (5.60 mm) in percentage, shape and make in 1 to 5 scale (1=small and 5=very good), and color in 1 to 5 scale (1=faded and 5=bluish).

Qrganolepitc /Cup quality sample preparation and evaluation

The standard procedure of green coffee bean sample preparation for cup quality evaluation which involve green bean roasting, grinding and brewing described by Abrar *et al*. (2014) was followed. Five cup quality attributes namely: Aromatic Intensity, Aromatic Quality, Acidity, Astringency, Bitterness, Body, Flavor and Overall Cup Quality were assessed by three experienced and internationally certified Q-grader professional panelist of Jima Agricultural Research Center (JARC) and rated on a 0 to 5 point scale (0=nill and 5=very strong), according to the intensity present in the samples.

Each panelist gave his/her independent judgment for each sample unit of the treatment. Finally, the average results of all panelists for both green bean physical and cup quality attributes were used for data analysis across four environments (2 sites and 2years combination).

Data analysis

The quality data (green bean and cup quality characters) were subjected to Analysis of Variance (ANOVA) using ProcGLM with the MIXED procedure of SAS (SAS Institute, 2008). For purpose of testing the significance of variation due to genotypes, genotype x environment, genotypes were considered fixed effects. Environment and replications within environments were considered random effects. The components of variance were estimated for each character separately with the restricted maximum likelihood (REML) method of SAS PROC MIXED (SAS Institute, 2008) considering all effects except the overall random mean.

Heritability on an entry-mean basis and its approximate standard error across environments were estimated for each characters using SAS Proc MIXED model of SAS after Holland *et al.* (2003). Data were being balanced in present study for which the REML based variance component estimates were comparable with ANOVA (Shaw, 1987), for this reason the genotypic mean, phenotypic and genetic variances from REML analysis were used to estimate phenotypic and genotypic coefficient of variation according to the formula given by Burton (1952).

The magnitude of the G x E interaction relative to the genetic variance was determined from REML variance component estimates of each quality attributes using the ratio σ^2ge/σ^2g.

RESULTS AND DISCUSSION

Analysis of variance and phenotypic variations

Combined analysis of variance for green bean and cup quality traits are given in Table 2. The environment (location and year combinations) effect was non-significant for all quality characters except bean size (SC14%). Such lack of differences explained by the same processing procedures was being followed every year at each location. The non-significant environmental effects on quality characters indicate selection and characterization in one environment can be extrapolated to other environments.

Analysis of variance revealed highly significant ($p<0.01$) and significant ($p<0.05$) differences among genotypes for all green bean physical characteristics (Screen size, shape and make, and Color) and some cup quality (aromatic intensity, aromatic quality and overall quality) attributes (Table 2). Non-significant genotypic differences were observed for other five cup quality characters (Table 2). The experimental CV∈ (CV∈ given as a percentage) values were also low–for all observed quality characters, except astringency and bitterness (greater than 30%) which is mainly attributed to the existing wide variations among the observations which increased the magnitude of error variances of these two cup quality attributes. However, other studies have reported significant differences among genotypes for cup quality attributes (Walyaro, 1983; Van der Vossen, 1985; Roche, 1995), all expect body (Gichimu, *et al*., 2012); bean physical and cup quality attributes (Abrar *et al*., 2014). On other hand, studies have reported lack of clear difference among the tested coffee types, bean physical and cup quality attributes (Owuor, 1988), sensory attributs (Bertrand *et al*., 2006). Significant to highly significant GxE interaction ($P < 0.05$ to $P < 0.01$) effects were detected in seven out of eleven characters, however, four of which also lack significant genotypic differences implying the complexity of the interactions for these characters (Table 2). Low or lack of significant GxE effect on quality characters have been reported by various authors in coffee (Moschetto *et al*., 1996) in robusta coffee, (Walyaro 1983; Van der Vossen, 1985; Roche 1995) in Arabica coffee, On other hand, other studies have reported significant GxE effect on quality attributes in Arabica coffee (Agwanda *et al*. 2003; Getu, *et al.,* 2009; Gichimu, *et al*., 2012) which are relatively similar to the present study. Such discrepancy could be attributed to the variation in coffee genotypes and test environments used in different studies. Phenotypic variations for 11 quality traits of coffee Arabica were estimated and are presented in Table 3. Generally, low variability ranges were observed in each quality characters. Ranges in analyzed characters were larger across genotypes than across environments, only for three green bean characters, aromatic intensity, and aromatic quality tastes indicating the greater genetic contribution than environments for observed variations among the genotypes for these characters (Table 3).

Table 2. Mean squares green physical bean and organoleptic characters in fifteen hybrids and two commercial check varieties evaluated over four environments.

Characters	Source of variation					CVЄ (%)
	Environment (E)	Reps (E)	Genotypes (G)	G x E	Error	
Green bean physical						
SC14%	53.227**	4.438**	23.071**	2.132**	1.046	1.08
SM	1.251	0.649**	0.407**	0.113	0.107	7.64
Color	1.065	0.854**	0.463**	0.125	0.090	7.00
Organoleptic quality						
AI	0.285	1.721**	0.416*	0.229	0.296	14.47
AQ	1.410	2.525**	0.496*	0.251**	0.137	10.05
AC	2.587	0.829**	0.268	0.169**	0.073	7.48
AS	3.640	3.471**	0.379	0.283**	0.118	44.91
BI	4.804	4.763**	0.376	0.356**	0.124	47.40
BO	1.759	0.841**	0.127	0.109	0.089	8.25
FL	2.459	0.945**	0.190	0.153**	0.085	8.23
OAQ	2.421	0.896**	0.289*	0.162**	0.074	7.64
DF	3	8	16	48	128	

* and ** Significant at the 0.05 and 0.01 probability levels, respectively; DF =Degree of freedom; SC14% = percent of above screen 14(5.60mm), SM = Shape and make, AI =Aromatic Intensity, AQ =Aromatic Quality, AC = Acidity, AS= Astringency, BI= Bitterness, BO = Body, FL = Flavor and OAQ = Overall Quality

Table 3. Variability ranges of genotypes and environment mean values for coffee green bean physical and organoleptic quality characters of seventeen coffee genotypes evaluated at Jima-Tepi environments.

Characters	Ranges				Mean	CV (%)
	Genotype n=17	CV%	Environment n=4	CV%	n=68	
Green bean physical						
SC14%	93.24-98.53	1.43	95.78-98.15	1.06	97.01	1.83
SM	3.86-4.63	4.29	4.04-4.36	3.69	4.27	6.53
Color	4.00-4.64	4.51	4.12-4.44	3.39	4.29	6.64
Organoleptic quality						
AI	3.44-4.21	4.93	3.66-3.83	1.98	3.76	8.06
AQ	3.33-4.06	5.52	3.48-3.84	4.50	3.68	9.42
AC	3.40-3.92	4.17	3.38-3.83	6.10	3.61	8.67
AS	0.48-1.04	23.36	0.40-1.04	34.90	0.76	51.05
BI	0.46-1.00	23.98	0.46-1.09	41.45	0.74	58.22
BO	3.45-3.85	2.86	3.35-3.74	5.05	3.60	6.83
FL	3.33-3.75	3.51	3.27-3.74	6.09	3.53	8.30
OAQ	3.33-3.92	4.45	3.30-3.74	6.01	3.55	8.74

SC 14% = percent of above screen 14(5.60mm), SM = Shape and make, AI =Aromatic Intensity, AQ =Aromatic Quality, AC = Acidity, AS= Astringency, BI= Bitterness, BO = Body, FL = Flavor and OAQ = Overall Quality

The variations across environments were notably larger than across genotypes for astringency and bitterness as shown high CV% value indicating the strong influence of environments over genetics for detected variations among the tested hybrids and existing check cultivars.

Likewise, low genotypic variation among arabica coffee genotypes tested across varied environments for most of liquor quality characteristics have also been reported by Walyaro (1983). The magnitude of phenotypic variation does not reveal the relative amount of genetic and non genetic components of variation. These were ascertained with the help of genetic parameters such as genotypic coefficient of variation, heritability estimates, and expected genetic advance.

Estimation of genetic parameters and genotype-environment interaction

Estimation of genetic parameters was done by partitioning of variance components as given in Table 4. Partitioning of variance into genotypic, interaction and error variance components has shown that much of the observed phenotypic variance (σ^2p) was due to the error variance component (σ^2e). The genotypic variance (σ^2g) was lower in magnitude than the pooled error variance for all characters except screen size and aromatic quality, and greater than the genotype x environment interaction variance for the three green bean physical characteristics (bean size, shape and make, color) and only for aromatic quality among organoleptic quality characters. The extent of heritability estimate was also relative to these proportions of variance explained by genotype from the total variance as well as from interaction components (Table 4). Accordingly, moderate to high broad sense heritability on an entry-mean basis was estimated for bean size (0.94±0.04) followed by color (0.73±0.11), and shape and make (0.72±0.11) and low to moderate for aromatic intensity (0.33± 0.25), acidity (0.37±0.26), overall quality (0.44±0.23) and aromatic quality (0.50±0.20), and very low that ranged from 0.05±0.39 for bitterness to 0.25±0.30 for astringency tastes.

Like in present study, low heritability for most liquor quality characteristics and high for coffee bean quality characters (though which were not measured by screen size) have been reported by Walyaro (1983). Lerroy *et al*. (2006) also reported significant values for heritability were observed for most bean characteristics leading to the achievement of significant genetic gains for bean size.

Table 4. Variance components, genotypic and phenotypic coefficients of variation, genetic advance and heritability (its standard error) estimates of physical bean and organoleptic quality of, fifteen hybrids and two commercial check varieties evaluated over four mid-lowland environments.

Characters	σ^2G	σ^2GE	σ^2e	h^2_{bs} entry mean-basis	PCV (%)	GCV (%)	GA (%)	σ^2ge/σ^2g
Green bean physical								
SC14%	1.75	0.35	1.10	0.94(0.04)	1.84	1.36	3.56	0.20
SM	0.02	0.002	0.11	0.72(0.11)	3.62	0.54	12.65	0.08
Color	0.03	0.01	0.09	0.73(0.11)	3.90	0.54	12.63	0.43
Organoleptic quality								
AI[1]	0.01		0.28	0.33(0.25)	2.79	0.37	9.72	
AQ	0.21	0.04	0.14	0.50(0.20)	12.29	0.63	17.22	0.18
AC	0.01	0.03	0.07	0.37(0.26)	2.48	0.26	7.10	4.00
AS	0.01	0.06	0.12	0.25(0.30)	11.71	0.22	28.69	6.88
BI	0.002	0.08	0.12	0.05(0.39)	6.03	0.05	6.26	38.50
BO	0.002	0.01	0.09	0.14(0.35)	1.24	0.09	2.49	3.00
FL	0.003	0.02	0.09	0.19(0.33)	1.55	0.13	3.70	7.67
OAQ	0.01	0.03	0.07	0.44(0.23)	2.95	0.31	8.62	2.64

SC 14% = percent of above screen 14(5.60mm), SM = Shape and make, AI =Aromatic Intensity, AQ =Aromatic Quality, AC = Acidity, AS= Astringency, BI= Bitterness, BO = Body, FL = Flavor and OAQ = Overall Quality

[1]Unable to calculate σ^2GE due to negative variance components

However, sometime high heritability is not indication of high genetic advance. It is therefore suggested by various researchers (Johanson *et al*., 1955; Khaliq *et al*., 2009) that high magnitude of h^2_{bs} should be combined with genetic advance in the prediction of phenotypic expression of traits.

In the present investigation, characters that combine relatively moderate to high heritability with high genetic advance was obtained for shape and make, color and aromatic quality, on other hand, character that combine high heritability with low genetic advance was bean size (percent bean retained above screen 14), the progress in selection would be high in former case and lower in the latter case according to Panse (1957). Generally organoleptic attributes exhibited low heritability with low genetic advance. Such low heritability have also been reported by Walyaro (1983) and Agwanda, *et al*. (2001), which indicate that genotype selection based on these quality characters is not reliable strategy. This low heritability could be explained by the high proportion of error variance though most of the quality attributes exhibited low experimental coefficient of variation (CVЄ<10.00%) (Table 2), suggesting the need of reducing residual variance which were dependent on the skill of the liquor technicians. Therefore one way to reduce variance is to refine liquor quality assessment technique and/or upgrade to scientific methods apart from increasing the genetic diversity level of the test materials. On other hand, GxE interaction also was under trait complex with large σ^2ge/σ^2g ratio (Table 4) other than the three bean physical characteristics and aromatic quality suggesting breeding for elevated cup quality attribute is complex and requires information about the causes of GxE interactions.

CONCLUSION

The present study revealed the presence of low to moderate levels of variations for most of the studied cup quality characters among the fifteen hybrids along with two check varieties. Bean physical characters (bean size, color and shape and make) exhibited high and significant line mean based broad sense heritability estimates and should respond to phenotypic selection. Jima maintained higher score than Tepi for most of the quality attributes indicating the important of location/site effects to realization of superior quality in Arabica coffee. Genotypes exhibited lower genotype interaction with environment/location/year demonstrating that selection can be performed at any of location or year for higher or lower score. This study indicated the presence of low levels of genetic variation among the genotype for evaluated cup quality characters.

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