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Variation and genotype x environment interaction for quality characters among selected coffee hybrids under highland environments in Ethiopia

Fekadu Tefera[1*], Sentayehu Alamerew[2], Dagne Wegary[3]
[1] Jimma Agricultural Research Center, P.O. Box, 192, Jimma, Ethiopia
[2] Jimma University, College of Agriculture and Veterinary Medicine, P. O. Box, 307, Jimma, Ethiopia
[3] CIMMYT-Ethiopia, ILRI Campus, P.O. Box 5689, Addis Ababa, Ethiopia

Abstract
An experiment to determine quantitatively the extent of morphological and quality variation in selected hybrid of Arabica coffee was conducted at two different sites around Gera district in South-western region of Ethiopia. Genetic variation, phenotypic diversity, genotype × environment interaction of 11 quality (three green bean and eight organoleptic cup quality) characters were studied in ten arabica coffee hybrids including two standard checks across four highland local environments (location-by-year combinations). The randomized complete block design was used in each environment. The quantitative phenotypic data were analyzed and partitioned into components using mixed model methodology through SAS.
Coffee quality assessment result showed that genetic variation for most of quality attributes was low as expressed by the low to moderate line mean-basis broad sense heritability (<0.50). Moderately high heritability were estimated by two physical bean characteristics, bean size (0.91), shape and make (0.72), and two organoleptic quality characters, acidity (0.67) and overall quality (0.55). The G x E effect of these characters was also not severing. Thus, selection for bold, very good shaped bean and desirable cup quality (balanced acidity) should be possible at single location. 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.)

1. Introduction

Coffee is the most cultivated stimulant crop in the world. Of the two most economically important species in the genus *Coffea* L., *Coffea arabica* L. and *Coffea canephora*, *Coffea arabica* L. is prominent by presenting quality attributes superior to Robusta coffee, and thus more valued in the market (Pereira *et al.*, 2010) [27]. 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) [20]. The breeding has the objective to transfer resistance genes from robusta coffee to arabica interspecific hybrid (Bertrand *et al*., 2008) [6] and/or within arabica coffee, interaspecific hybrid (Mesfin and Bayetta, 1984) [5]. 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) [18] 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) [3, 17]. Production and supply of coffee with excellent quality is therefore important for coffee exporting countries (Abadiga, 2010) [1]. Moreover, success of a new variety of Arabica coffee depends to a great extent on its bean and beverage quality (Agwanda *et al*., 2003) [4]. 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) [1].

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) [29]. 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 early 1980 had led identification of some elite hybrids derived from their Southwestern Ethiopian coffee parental (Behailu *et al*., 2008) [5]. However, the magnitude of genetic variability for green bean physical and cup quality characters has not yet been ascertained in these hybrids across highland 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; Olika *et al*., 2011; Gichimu *et al*., 2012; Gimase *et al*., 2014; Abrar *et al*., 2014) [31, 24, 12, 13, 2]. 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 cup quality characters in a group of ten 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 ten coffee genotypes across four highland local environments

2. Material and Methods

Ten hybrid coffee (*Coffee arabica L.*) varieties including two standard check varieties (Table 1) were tested at two different sites for two production seasons in Gera district of the South-western region of Ethiopia. The study sites represent the highland humid coffee growing agro-ecology and are well known as hot spot for coffee berry disease (CBD). The sites were Gera Research Station and on-farm location around the station. The experimental material was laid out in a Randomized Block Design (RBD) with three replications and established in July, 2008 at both sites with comprising of sixteen coffee trees of each genotype in each plot. Recommended cultural practices were followed and observations were made on the green bean physical and organoleptic cup quality parameters for two seasons (2014 and 2016). The coffee sample preparation procedures for quality analysis and data collection techniques for three green bean physical and eight organoleptic cup quality characteristics as described by Abrar *et al.* (2014) [2] and elaborated by Fekadu *et al.* (2019) were adopted.

Analysis of variance was performed with the MIXED procedure of SAS version 9.2 (SAS, 2008). For the purposes of estimating hybrid means and comparing check entries with experimental hybrids, checks were considered fixed effects. Environment and replications were considered random effects. To estimate genetic components of variance, the genotypes were considered random effects and variance components for genotypes and genotype x environment interaction were estimated with the SAS MIXED procedure. Heritability and its approximate standard error for each trait were estimated for each trait using mixed model of SAS across environments after Holland *et al.* (2003) [15]. Heritability on a entry-mean basis estimated as $h^2_{bs=}$ $(\sigma^2 g)/[\ \sigma^2 g + \sigma^2 ge/e + \sigma^2 e/re]$, where $\sigma^2 g$ is the estimate of genotypic variance, $\sigma^2 ge$ is the estimate of genotype x environment variance, $\sigma^2 e$ is the estimate of error variance, r is the number of replication per environment and e is the number of environments. 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) [8]. 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 $\sigma^2 ge/\sigma^2 g$.

Table 1: Description of the hybrids and commercial checks included in this study

Code- name	Germplasm Composition*	Cross categories†
HC¶1	SW X SW	CBD res +Q x CBD res +Q
HC2	SW X SW	CBD res +Q x CBD res +Q
HC3	SW X SW	CBD res +Q x CBD res +Q
HC4	SW X SW	CBD res +Q x CBD res +Q
HC5	SW X SW	CBD res +Q x CBD res +Q
HC6	SW X SW	CBD res +Q x CBD res +Q
HC7	SW X SW	CBD res +Q x CBD res +Q
HC8	SW X SW	CBD res +Q x CBD res +Q
Ababuna (Hybrid check)	SW X SW	CBD res x high yielder
74110 (Variety check)	SW	CBD res

*SW=South-western Ethiopian; † CBD res= CBD resistant; Q =quality; HY=high yielder; ¶HC =Hybrid coffee

3. 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 (year and location combinations) effect was non-significant for all quality characters. Such lack of differences explained by the similarity of the two sites and the same processing procedures was being followed every year at each location. This was further confirmed in separate analysis that the lack of year and location effects in eight and nine out of eleven green bean physical and cup quality characters, respectively (data not shown). Therefore, 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 three cup quality (acidity, flavor and overall quality) attributes (Table 2). Non-significant genotypic differences were observed for one green bean physical characteristics (bean color) and other five cup quality characters (Table 2). Furthermore, the lack of genotype interaction with year and location for most of quality attributes allowed the reliable comparison can be made based on their average performance. The test hybrids were found to be better or similar to the two existing commercial cultivars in green bean physical and cup quality attributes (data not shown). However, other studies have reported significant differences among genotypes for cup quality attributes (Walyaro, 1983; Van der Vossen, 1985) [31, 30], all expect aromatic intensity, astringency, body, and bitterness (Olika *et al*., 2011) [24], all expect body (Gichimu, *et al*., 2012) [12]; bean physical and cup quality attributes (Abrar *et al*., 2014) [2]. This is likely due to the limited number of varieties and a more narrow set of hybrid used in the present study. On other hand, studies have reported lack of clear difference among the tested coffee types, bean physical and cup quality attributes (Owuor, 1988) [25], sensory attributes (Bertrand *et al*., 2006) [7] which are partly support the present result. The experimental CVЄ (CVЄ given as a percentage) values for observed quality characters were low, 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 (Table 2).Significant to highly significant GxE interaction ($P < 0.05$ to $P < 0.01$) effects were detected in five out of eleven characters, however, three 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) [23] in robusta coffee, (Walyaro 1983; Van der Vossen, 1985) [31, 29] in Arabica coffee which are relatively similar to the present study, 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) [12]. Such discrepancy could be attributed to the variation in coffee materials and test environments used in different studies.

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

Characters		Source of variation				CVЄ (%)
	Environment (E)	Reps(E)	Genotypes (G)	G x E	Error	
Green bean physical						
SC14%	0.542	2.883**	32.088**	3.005**	0.648	0.83
SM	0.686	0.849**	0.621**	0.172**	0.080	6.31
Color	0.100	0.002	0.135	0.163	0.105	6.98
Organoleptic quality						
AI	0.061	0.413**	0.072	0.077	0.100	7.99
AQ	0.340	1.067**	0.237	0.154	0.131	9.03
AC	0.230	0.747**	0.295*	0.099	0.074	7.21
AS	1.097	2.479**	0.102	0.225**	0.097	48.89
BI	0.802	1.994**	0.173	0.140**	0.054	50.21
BO	0.032	0.916**	0.041	0.076*	0.043	5.49
FL	0.228	0.775**	0.200*	0.105	0.069	7.07
OAQ	0.202	0.731**	0.212*	0.095	0.070	7.12
DF	3	8	9	27	72	

* 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

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. Likewise, low genotypic variation among arabica coffee genotypes tested across varied environments for most of liquor quality characteristics have also been reported by Wolaryo (1983). Ranges in all analyzed characters except astringency and bitterness, were larger across genotypes than across environments though its magnitudes low indicating the greater genetic contribution than environments for observed variations among the genotypes for these characters (Table 3). This was in line with the estimated high CVЄ values for these two liquor quality attributes. 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.

Table 3: Variability ranges of genotypes and environment mean values for coffee green bean physical and organoleptic quality characters of ten coffee genotypes evaluated at Gera environments

Characters	Ranges				Mean	CV (%)
	Genotype n=10	CV%	Environment n=4	CV%	n=40	
Green bean physical						
SC14%	94.05-98.69	1.69	96.8-97.11	0.14	96.99	1.84
SM	4.11-4.72	5.15	4.31-4.63	3.38	4.49	7.28
Color	4.42-4.78	2.22	4.59-4.70	1.31	4.65	4.79
Organoleptic quality						
AI	3.88-4.10	1.85	3.92-4.02	1.17	3.96	3.98
AQ	3.81-4.31	3.48	3.91-4.12	2.69	4.01	6.26
AC	3.44-3.96	4.12	3.67-3.87	2.35	3.75	6.02
AS	0.50-0.79	14.88	0.40-0.80	30.82	0.62	47.74
BI	0.33-0.75	26.02	0.30-0.67	35.40	0.46	56.06
BO	3.68-3.86	1.45	3.73-3.78	0.70	3.76	3.75
FL	3.42-3.88	3.41	3.60-3.78	2.12	3.70	5.71
OAQ	3.44-3.92	3.49	3.59-3.76	2.15	3.69	5.56

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

Estimation of genetic parameters and genotype-environment interaction

Estimation of genetic parameters was done by partitioning of variance components and presented 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 error variance for all characters except bean size (screen size), and greater than the genotype x environment interaction variance only for bean size, shape and make, acidity and overall quality characters (Table 4). Accordingly, moderate to high broad sense heritability on an entry-mean basis was estimated for bean size (h^2_{bs}=0.91±0.05) followed by shape and make (h^2_{bs}=0.72±0.05) and low to moderate ranged from h^2_{bs}=0.36±0.35 for aromatic quality to h^2_{bs}= 67±0.18 for acidity and very low for bitterness taste (h^2_{bs}= 0.20±0.44) and a negative estimate of genetic variance with incalculable heritability estimate was observed for bean color and three cup quality traits which lack genetic variations among the genotypes. This low heritability could be explained by the high proportion of error variance in relative to the total variance for these quality attributes (Table 4). Low heritability therefore indicates that likely little progress will be made for those characters. In similar manner, Wolaryo (1983) and Olika *et al*. (2011) [24] reported that low and low to moderate heritability for most liquor quality characteristics with the exception of overall standard and aromatic quality, respectively. The present estimates for bean size are consistent with those reported elsewhere (Montagnon *et al*., 1998; Lerroy *et al*., 2006) [22, 23].

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) [19] 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 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) [26].

Generally, organoleptic attributes exhibited low to moderate heritability with low genetic advance. Walyaro (1983) [31] and Agwanda, *et al*. (2001) [4] have also been reported that low heritability of organoleptic attributes which is ascribed to subjectivity of its evaluation technique according to Charrier (1983) [4] though most of the quality attributes exhibited low experimental coefficient of variation (CV€ <10.00%) which describe the consistency of the sensory panel in present study, in addition to that the environmental and processing factors (Leroy, *et al*., 2006) [22] would also deserve special mention for low estimate of the genetic parameters. On other hand, Gopel (1997) [14] remarked that organoleptic procedures will continue to be the backbone of liquor quality evaluation; however, it needs to be complemented with biochemical techniques and electronic approaches to detect finer differences between the breeding lines and the traditional cultivars. The magnitude of the components of variances gives information about the importance of the GxE interactions. The results showed that the estimate of σ^2GE was low and relative to the GxE effect presented in Table 2. The σ^2 ge/σ^2g ratio also confirmed that the G x E interaction effects was low for all traits except bitterness taste (Table 4).

The interaction of bitterness attributes was also under trait complex which lacks important genetic variance differences. Though the GxE effect was low, the low to moderate heritablity estimate (h^2_{bs}=0.20-0.48) exhibited by most of cup quality characters and bean color except two bean physical characters(bean size and shape and make) and three cup quality(acidity and overall quality). This low to moderate heritability could be explained by the high proportion of error variance though most of the quality attributes exhibited low experimental coefficient of variation (CV€ <10.00%) other than astringency and bitterness tastes (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 refining the liquor quality assessment technique apart from increasing the genetic diversity level of the test materials to increase the heritability estimates of these quality characters.

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, eight hybrids and two commercial check varieties evaluated over four highland 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%	2.44	0.73	0.65	0.91±0.05	2.02	1.61	3.23	0.30
SM	0.04	0.03	0.08	0.72± 0.05	8.56	4.34	10.85	0.79
Color[1]		0.02	0.11		7.49			
Organoleptic quality								
AI[1]			0.09		7.65			
AQ	0.007	0.0069	0.13	0.36±0.35	9.52	2.09	6.03	0.99
AC	0.020	0.01	0.07	0.67±0.18	8.35	3.38	9.85	0.50
AS[1]		0.03	0.10		57.47			
BI	0.003	0.03	0.05	0.20±0.44	63.04	11.84	22.19	9.33
BO[1]		0.01	0.04		6.01			
FL	0.008	0.012	0.07	0.48±0.28	8.07	2.42	6.82	1.50
OAQ	0.010	0.008	0.07	0.55±0.24	8.03	2.71	7.78	0.80

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
[1]Unable to calculate σ^2G, h^2_{bs} and associated genetic parameters due to negative variance components

4. Conclusion

The present study revealed the presence of low to moderate levels of variations for most of the studied cup quality characters among the eight hybrids along with two check varieties. Two of the bean physical characters (bean size, and shape and make) exhibited high and significant line mean based broad sense heritability estimates and should respond to phenotypic selection. The G x E effect of these characters was also not severing. This study indicated the presence of low levels of genetic variation among the genotype for most of evaluated cup quality characters.

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