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Assessment of the Growth and Yield Characters of Some Promising Arabica Coffee Hybrids under Highland Environments in Southwestern Ethiopia

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Abstract: The economic value of Arabica coffee (*Coffea arabica* L.) is determined mainly by its yielding potential. However, being yield is a character of low heritability, the identification of superior genotype merely depends on consideration of other related and influencing characters. The objectives of this study were to: (i) estimate the broad-sense heritability of yield related characters (ii) determine the genetic and phenotypic correlations between yield and other important agronomic characters. (iii) to determine the performance of the eight promising F_1 coffee hybrids under highland local environments based on growth and yield characters relative to that of the existing commercial cultivars in Southwestern Ethiopia. The mean difference among genotypes across environments for all thirteen out of fourteen studied variable were significant (*P* 0.01), except number of stem nodes per tree. On this basis, the heritability estimates of the seven growth characters were moderate to high (0.33 to 75), while the other six including berry yield, exhibited lower heritability (below 0.24). Berry yield had positive genetic and phenotypic correlation with most characters; however the magnitude of genetic correlation were higher than phenotypic correlation. The characters that combined high heritability value (0.55 to 0.75) and high genetic correlation (r_G=0.51 to 0.91) includes girth, canopy diameter and plant height followed by length of primary branches, internodes length of stem and internodes length of primary branches. These characters can be explored for indirect selection of higher yielding genotypes. Lack of genotype by environment interaction in present study permits direct selection of superior/comparable hybrids to best check-Ababuna in yield per se performance as well as that good for some of these particular character. The hybrid HC16 and HC18 had greater value for yield with resistance reaction to coffee berry disease(CBD), while HC8 had comparable yield and girth with moderately resistant reaction to CBD as compared to the best resistant check-74110.

Key words: Coffee hybrids · Yield · Growth characters · Heritability · Correlation · Indirect selection

INTRODUCTION

Coffee is undoubtedly the most valued of the stimulant crops. Coffee production is fundamental for over 50 developing countries [1] including Ethiopia, for which it is the main foreign currency earner. The main coffee growing areas in Ethiopia are in three altitude zones; the high altitude (over 1750 m above sea level), the medium altitude (between 1550 m and 1750m above sea level) and the low altitude (below1550 m above sea level) [2]. Southwestern Ethiopia is the probable origin of Arabica coffee (*Coffea arabica* L.) and also one of the major regions in coffee production and holds all the three major coffee growing agro- climates.

However, production across these climatic ranges is seriously constrained by diseases, especially coffee berry disease (CBD), coffee leaf rust (CLR) and coffee wilt disease (CWD). At highland CBD is the major one [3]. Control of CBD by growing of resistant varieties/hybrids is an economical and sustainable and thus advantageous

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over chemical control by use of fungicides [4, 2]. Moreover, the use of hybrid coffee is well known to contribute towards higher productivity and stability of performance under a wide range of environmental conditions [5]. In line with these, the hybrid variety development program in Ethiopia which started in 1978 so far has developed few hybrids (about three) including Ababuna which used in present study as check. These hybrids were also limited to low to medium altitude where CBD pressure is absent or low [6]. Superior hybrids that that combine high yielding potential with quality traits and/or CBD resistance are still lacking in highland production environments.

The current breeding 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 their Southwestern Ethiopian coffee parental origin. The selection of the superior one from these hybrids for economically important character of low heritability like yield can be maximized through increasing the efficiency of indirect selection of the secondary character or trait(s) that known to have high heritability and high genetic correlation with desired traits like yield [7]. Plant characters such as tree height, stem girth, width of canopy diameter, number of primary branches, percent of bearing nodes, flowers and berries are known to be related with and influence yield in Arabica coffee [8] as well as Robusta coffee [9, 10]. Plant height and stem girth also identified as positive selection criteria, where as canopy width identified as negative selection criteria in Arabica coffee [11].

The objectives of this study were to: (i) estimate the broad-sense heritability of yield related characters (ii) determine the genetic and phenotypic correlations between yield and other important agronomic characters. (iii) to determine the performance of the eight promising F_1 coffee hybrids under highland local environments based on growth and yield characters relative to that of the existing commercial cultivars in Southwestern Ethiopia. The information will be of importance to coffee breeders in future to follow Arabica coffee breeding programs under highland environments.

MATERIALS AND METHODS

Test Materials: Eight F_1 hybrids (Table 1) were evaluated in this study alongside two entries Ababuna and 74110 as checks. The hybrids were selected from different set of experimental hybrid trials based on their higher resistance to CBD, cup quality and yield during an initial screening carried out across different environments [12]. The check Ababuna is commercial F_1 hybrids selected for higher yield and moderately resistance to CBD. 74110 is a commercial cultivar developed by single tree selection as pure line selection for its resistance to CBD.

Experimental Sites and Design: The trials were conducted at two different sites around Gera district in South-western region of Ethiopia: Gera research station and Gera on-farm, representing highland coffee growing areas and the two sites are near each other. The Gera research site is situated at latitude 7°46'N, longitude 36°26’E and altitude 1974 m above sea level (asl) in the Southwestern region of Ethiopia. Gera station has a mean total annual rainfall of approximately 1880 mm. Mean average daily minimum and maximum temperatures are about 10.4 and 24.5, respectively. The soil around Gera station is dominantly Acrisols and Nitoso with P^H of 5-6 medium to high in exchangeable cation [13, 14]. The experimental plots in both sites were established in July, 2008 .The evaluations at both locations were carried out in two seasons 20013/14 and 20014/15, making a total of four environmental combinations. At each site planting was done using a Randomized Complete Block Design (RCBD) with three replications. Each plot comprised of sixteen coffee trees in two row of each genotype. The spacing between rows and trees within rows were 2 m by 2 m, respectively. Each experiment was surrounded by one row of border trees to provide competition to peripheral plots. Fertilizer was uniformly applied and crop management practices were similar for both sites throughout the trial periods. At each sites, *Susbania susban* shade tree was established to provide shade for every four coffee trees. All the coffee trees were maintained in single stem pruning system.

Data Collected: Measurements of growth and yield-related traits data were recorded for two consecutive years (20013/14 and 20014/15). Eight central trees across the two rows of each genotype in each plot were used. Variables measured included plant height(cm), taken from ground level to tip of the tree, girth (cm), taken at 5cm above the ground, total number of primary branches counted per plant, percent bearing primary branches per tree were estimated from total branches counted from four sample branches, Canopy diameter (cm), were estimated as an average value of the length of each tree in east-west

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

Entry No	Code- name	Germplasm Composition*	Cross categories†
1	HC¶8	SW X SW	CBD res +Q xCBD res +Q
2	HC16	SW X SW	CBD res +Q xCBD res +Q
3	HC17	SW X SW	CBD res +Q xCBD res +Q
4	HC18	SW X SW	CBD res +Q xCBD res +Q
5	HC19	SW X SW	CBD res +Q xCBD res +Q
6	HC20	SW X SW	CBD res +Q xCBD res +Q
7	HC21	SW X SW	CBD res +Q xCBD res +Q
8	HC22	SW X SW	CBD res +Q xCBD res +Q
9	Ababuna(hybrid check)	SW X SW	CBD res x high yielder
10	74110(variety check)	SW	CBD res

*SW=South-western Ethiopian coffee type † CBD res= CBD resistance, Q =quality, HY=high yielder, ¶HC =Hybrid coffee

and north-south direction, number of stem nodes per tree were counted for four sample trees, number of nodes per primary branch were estimated as an average value of the four sample branches at the middle of the stem per plant, internode length (cm) on the main stem, was estimated by dividing the total height of above the first primary to total numbers of nodes minus one per tree, length of primary branches length(cm) as mean length on four longest primaries selected from middle part of the tree, number of secondary branches counted from four selected primaries and taken as mean value per primary, internode length per branch (cm) was estimated from four branches per plant as an average of length of primary branch divided by the number of nodes of primary branch and the mean of these values obtained for the four primary branches. Percent bearing nodes, were estimated as the percent of the number of nodes with berries on four selected primaries per tree, number of berries were counted after six months of flowering and obtained as number of fruits from two heavily bearing nodes per branches and the mean of these values obtained for the four primary branches, Yield (fresh berries), taken as the weight of fresh fruits harvested per tree (Kg/tree) on plot basis. Data averaged across plots for each seasons across locations were used for statistical analysis.

Statistical Analysis: Analysis of variance was performed with the MIXED procedure of SAS version 9.2 [15]. For the purposes of estimating hybrid means and comparing check entries with experimental hybrids, entries were considered fixed effects. Environment and replications were considered random effects.

To estimate genetic components of variance, the genotypes (hybrids and checks) were considered random effects and variance components for genotypes and genotype x environment interaction were estimated with the SAS MIXED procedure. Genotypic and phenotypic correlations and their approximate standard errors were estimated for each pair of traits across environments using a multivariate extension of the mixed model after Holland [16]. 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*. [17].

The genetic correlation was estimated as:

$$\hat{}rg12 = \frac{\hat{}\sigma G12}{\hat{}\sigma G1\hat{}\sigma G2}$$

where $\hat{}\sigma G12$ is the estimated genotypic covariance between traits 1 and 2 and $\hat{}\sigma Gi$ is the estimated genotypic standard deviation for trait i (i = 1 or 2). The phenotypic correlation estimated as:

$$\hat{}rp12 = \frac{\hat{}\sigma P12}{\hat{}\sigma P1\hat{}\sigma P2} = \frac{\hat{}G12 + \hat{}\sigma GE12 + \hat{}\sigma e12}{\sqrt{\hat{}\sigma^2 G1 + \hat{}\sigma^2 GE1 + \hat{}\sigma^2 e1}\sqrt{\hat{}\sigma^2 G2 + \hat{}\sigma^2 GE2 + \hat{}\sigma^2 e2}}$$

where $\hat{}\sigma P12$ and $\hat{}\sigma GE12$ are the phenotypic covariance and genotype-by-environment covariance, respectively, between traits 1 and 2 and $\hat{}\sigma Pi$ and $\hat{}\sigma GEi$ are the phenotypic and genotype-by-environment standard deviations for character i.

Heritability (ˆH) on a plot-basis was estimated for all characters as:

$$\hat{}H = \frac{\hat{}\sigma^2 G}{\hat{}\sigma^2 G + \hat{}\sigma^2 GE + \hat{}\sigma^2 e}$$

where σ^2 genotypic variance, $\hat{}\sigma^2$ GE is the interaction variance and σ^2 e is the error variance.

RESULTS AND DISCUSSION

Analysis of Variance: Differences among genotypes were significant ($P < 0.01$) for all characters across environments, except number of stem nodes per tree.

Table 2: Means of all entries, hybrids and checks of arabica coffee evaluated at two locations for two years

Entry	YLD	PH	Girth	LPB	NPB	SNN	CD	ILS	%BP	BNN	ILB	%BN	SB	BeNo
All genotypes	4.82	268.2	5.77	83.44	80.89	42.61	183.07	5.83	82.6	21.67	3.88	43.17	6.36	21.63
Hybrids	5.01	267	5.8	82.51	81.73	42.86	182.21	5.58	22.35	21.60	3.85	43.38	5.25	21.6
Checks	4.08	273.2	5.67	87.12	77.54	41.64	186.48	6.04	83.53	22.01	3.99	42.34	5.82	21.75
Hybrids vs. Checks ‡	**	NS	NS	**	**	*	**	**	NS	NS	**	NS	**	NS

** = significant at P= 0.01. *= significant at P= 0.05.

Key: YLD = Berry yield in kg per tree, PH= Plant height in cm, Girth=Girth in cm, LPB = Length of primary branches in cm, NPB= Number of primary branches, SNN=Number stem node per tree, CD=Canopy diameter in cm, ILS = Internodes length of main stem in cm, %BP=Percent bearing primaries per plant, BNN=Number of nodes per primary branch, ILB= Internodes length of primary branches in cm, %BN = Percent bearing nodes, SB= Number of secondary branches, BeNo = Number of berries in two heavily bearing nodes

Table 3: Mean yield and growth characters of eight coffee hybrids and two commercial checks across four environments

Hybrids/checks	YLD	PH	Girth	LPB	NPB	SNN	CD	ILS	%BP	BNN	ILB	%BN	SB	BeNo
HC8	5.37	269.3	6.4	83.3	76.0	42.7	190.0	5.9	83.5	20.7	4.1	43.7	6.0	22.0
HC16	5.82	271.7	5.8	82.5	83.3	42.8	185.9	5.9	80	21.1	3.9	46.1	5.7	23.3
HC17	5.12	264.7	5.7	82.3	82.5	42.8	183.2	5.8	82	21.9	3.8	44.8	6.1	22.3
HC18	5.72	272.1	6.0	85.4	84.3	43.8	183.7	5.7	83.2	22.6	3.7	43.3	5.1	21.6
HC19	3.51	249.4	5.0	76	84.3	43.5	167.0	5.2	82.3	21.3	3.6	43.1	4.2	20.9
HC20	4.91	279.0	6.0	87.8	77.8	41.4	189.7	6.2	84	22.2	4.0	38.2	4.3	20.5
HC21	4.63	252.0	5.5	79.9	81.3	41.9	178.5	5.5	82.7	21.3	3.8	45.6	5.7	21.9
HC22	4.97	277.7	5.9	82.7	84.2	43.9	179.7	5.9	81.2	21.5	3.9	42.2	4.8	20.3
Hybrid check(Ababuna)	4.84	311.2	6.4	103	78.1	41.7	211.5	7.0	85.6	23.0	4.6	42.2	6.6	22.6
Variety check(74110)	3.31	235.1	4.9	71	77.0	41.6	161.5	5.1	81.5	21.1	3.4	42.5	5.0	20.8
Entries mean	4.82	268.2	5.8	83.4	80.9	42.61	183.1	5.82	82.6	21.67	3.9	43.2	5.4	21.6
Hybrid mean	5.01	267.0	5.8	82.51	81.7	42.86	182.2	5.58	82.35	21.6	3.9	43.4	5.3	21.6
Check mean	4.08	273.2	5.7	87.12	77.5	41.64	186.5	6.04	83.53	22.01	4.0	42.3	5.8	21.8
LSD(0.05) for comparisons between														
Entries	1.0	15.9	0.26	4.5	4.4	NS	6.40	0.34	2.70	1.2	0.23	3.20	0.85	1.6
Hybrids Vs checks	0.56	NS	NS	2.53	2.5	1.11	3.60	0.19	NS	NS	0.1	NS	0.47	NS

Key: YLD = Berry yield in kg per tree, PH= Plant height in cm, Girth=Girth in cm, LPB = Length of primary branches in cm, NPB= Number of primary branches, SNN=Number of stem node per tree, CD=Canopy diameter in cm, ILS = Internodes length of main stem in cm, %BP=Percent bearing primaries per plant, BNN=Number of nodes per primary branch, ILB= Internodes length of primary branches in cm, %BN = Percent bearing nodes, SB= Number Secondary branches, BeNo = Number of berries in two heavily bearing nodes

The hybrid and check means were significantly different for all characters, except plant height, girth, percent bearing node, percent bearing primaries, number of nodes per branch and number of berries per node (Table 2). The hybrids had higher mean berry yield, numberof primary branches, number of stem nodes per tree and lower length of primary branch, canopy diameter, internodes length of branch and stem and number of secondary branches than the checks. Hybrid check was superior to pure-line variety check for almost all observed characters (Table 3). The experimental hybrid that comparable or superior to this hybrid check, especially in yield and yield contributing traits, would have also been hypothesized to have special merit in production system. In this case, the hybrid that gave significantly ($P < 0.05$) higher mean yield than the best hybrid check (Ababuna) are HC16 and HC18, while HC8, HC17, HC22, HC20 and HC21 gave comparable yield to this hybrid. These hybrids also have shown resistance reaction to CBD, other than HC8, HC20 and HC22 which have shown moderately susceptible or moderately resistance reaction as compared to resistant check-74110 (data not shown).

Variance Components and Heritability of Characters: Estimation of variance components were carried out using pooled data across two locations in two years combination following REML Procedure. The REML procedure is a preferred one in combining all data sets to calculate variance components and thus and heritability that would give the greatest likelihood of getting the observed phenotypic values of all the individuals in the data [18]. Estimates of variance components of environment and genotype x environment interaction indicated significant and non-significance difference ($p < 0.05$) in all traits, respectively (tables not included).

Table 4: Percentage contribution of genotype, genotype x environment interaction and environment to the total components of their variances and estimates of broad sense heritability on a plot- basis (with standard error) for ten coffee genotypes

Variance components	YLD	PH	Girth	LPB	NPB	SNN	CD	ILS	%BP	BNN	ILB	%BN	SB	BeNo
σ^2G	45.5	46.8	50.0	52.9	15.9	5.4	65	16.7	0.85	5.9	47.4	1.4	50	0.6
σ^2GE	21.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.16	0.0	0.0	1.5	2.8	3.5
σ^2E	33	53.2	50. 0	47.1	84.1	94.6	35	83.3	99.0	94.1	52.6	97.1	47.2	95.8
h^2 plot –basis	0.23 (0.12)	0.55 (0.13)	0.71 (0.10)	0.70 (0.11)	0.24 (0.11)	0.06 (0.06)	0.75 (0.10)	0.61 (0.12)	0.12 (0.09)	0.15 (0.09)	0.57 (0.13)	0.13 (0.10)	0.33 (0.13)	0.05 (0.09)

Key: YLD = Berry yield in kg per tree, PH= Plant height in cm, Girth=Girth in cm, LPB = Length of primary branches in cm, NPB= Number of primary branches, SNN=Number of stem node per tree, CD=Canopy diameter in cm, ILS = Internodes length of main stem in cm, %BP=Percent bearing primaries per plant, BNN=Number of nodes per primary branch, ILB= Internodes length of primary branches in cm, %BN = Percent bearing nodes, SB= Number of secondary branches, BeNo = Number of berries in two heavily bearing nodes

Table 5: Genotypic and phenotypic correlations between berry yield and agronomic traits based on the mean of eight hybrid coffee and two commercial checks across four environments

	Genotypic correlations	Phenotypic correlations
Traits	Berry yield	Berry yield
Plant height(cm)	0.64±0.26	0.34±0.12
Girth (cm)	0.91±0.14	0.46±0.12
Length of primary branches (cm)	0.54±0.27	0.32±0.14
Number of primary branches /plant	NS	0.19±0.09
Number of stem nodes	NS	0.14±0.10
Canopy diameter(cm)	0.69±0.23	0.34±0.14
Percent bearing primaries/plant	NS	0.16±0.11
Internodes length of stem(cm)	0.57±0.29	0.24±0.12
Number of nodes /primary branch	NS	0.19±0.10
Internodes length of primary branches(cm)	0.51±0.25	0.32±0.13
Percent bearing nodes/ primary branch	NS	0.20 ±0.09
Number of secondary branches / primary branch	0.62±0.31	0.16±0.07
Number of berries in two heavily bearing nodes /branch	0.97±0.68	0.23±0.10

The percentage contribution of genotype and genotype x environment interaction variances towards total phenotypic variance is presented in Table 4. In all 14 characters, the genotype x environment interaction variances is low or negligible (0 to 21.4%) and there was no interaction variance in nine of fourteen characters. Conversely, in six of these traits the genotypic variance relatively predominate (equal or more than from 47%). The broad-sense heritability of each trait on plot mean-basis was ranged from 0.05 to 0.75 (Table 4). The heritability value derived from a genotypes evaluated over number of environment would increase the accuracy of the estimates of each traits [7]. Yield and its related characters (percent bearing nodes, percent bearing primaries and no of berry in two heavily bearing nodes had lower heritability than vegetative traits (plant height, girth, length of primary branches, canopy diameter, internodes length of branch and stem and no of secondary branches).

Correlations among Characters: Genotypic and phenotypic correlation coefficients between yield and vegetative traits across four environments are shown in Table 5. Among coffee genotypes, berry yield had significantly positive genetic correlations (rG = 0.51- 0.97) with all traits except with number of primary branches, number of main stem node per tree, number of nodes per branches, percent of bearing primary branches per tree and percent bearing nodes per primary branch. The significant positive genetic associations between yields and girth, canopy diameter agrees with previous findings in Arabica coffee [18], 19] and Robusta coffee [10]. However, Wardiana and Pranowo [11], identified differently from present result, the negative relationship of canopy diameter with yield in Arabica coffee. Seven of fourteen characters had plot-basis heritability estimates of moderate to high (0.33 to 0.75), other than yield related characters which had low heritability (0.05 to 0.24). Number of berry per node which had lowest heritability (0.05), despite its highest genetic correlation (r_G = 0.97) with berry yield, this might be attributed to higher σ^2GE variance and σ^2e in relative to σ^2G contributed higher value to denominator factor. Lynch, [20], on other way explained the genetic correlation may biased upwardly, when the fraction of shared relatives in the sample is high but the heritabilities of the trait are low.

The six traits that combine high heritability with high genetic correlations were girth, canopy diameter, plant height, length of primary branches, internodes length of stem and internodes length of primary branches

(Tables 4 and 5). Walyaro [8], working on Arabica coffee observed similar high heritability estimates for these characters. Thus, these six traits can be explored for indirect selection for yield in the future coffee breeding program after determining their relative efficiency (RE), according to the formula of Falconer and Mackay [7].

Berry yield had significantly positive phenotypic correlations with all traits but its magnitude is lower than genetic correlations, other than those shown non-significant genotypic associations. This revealed that association between berry yield and these characters was under genetic control, while the apparent association with number of primary branches, number of main stem node per tree, number of nodes per branches, percent of bearing primary branches per tree and percent bearing nodes per primary branch were under favorable influence of environment, this was further illustrated in Table 4 with greater contribution of environmental variance components of the two traits to the total phenotypic variance. High environmental variance was also observed for other growth characters mainly due to the existing normal morphological and developmental increment of coffee trees in the two years. Moreover, in perennial crop like coffee at adult plant stage, the number of bearing primaries is more related to yield than the total number of primary branches which contain more of unproductive primaries in favoring of vegetative growth than reproductive growth, especially at lower level of tree canopy, mainly due to mutual shading of interlocked primary branches; though it lacked significant genotypic association with yield in the present study which could mainly be attributed to over bearing die back of some of unprotected trees with shades, consequently these highly productive branches lose their green berries before converting into matured berry yields.

CONCLUSION

Lack of genotype by environment interaction in present study permits direct selection of superior hybrids or comparable to the best check in yield per se performance as well as that good for some of particular characters based on environmental mean. In this case, the hybrid HC16 and HC18 had greater value for yield with resistance reaction to CBD, while HC8 had comparable yield and girth with moderately resistant reaction to CBD as compared to the best check (Ababuna in yield and 74110 in CBD resistance reaction). However, to confirm the yield stability of these best performing hybrids evaluation of the material for two additional years is suggested.

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