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Genotypic Association Between Yield and Yield Related Traits of Some Coffee (*Coffea arabica* L.) Genotypes

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ABSTRACT

Background and Objective: Variability among genotypes and the association between yield and yield-related traits are among the prominent criteria for crop improvement. The current study was carried out to determine the genotypic correlation between yield and yield-related traits and to study the genotypic association among yield-related traits. **Materials and Methods:** A total of 26 coffee genotypes were involved in the study. The experiment was conducted at Haru and Mugi using RCBD with three replications. Around 23 quantitative traits were recorded and analyzed using R-software. **Results:** A significant different performance was revealed among genotypes in most traits at an individual location. Because of the discrepancy in performance, the focus needs to be given to generating technology separately for an individual location. Number of bearing primary branch (NPB) (gr = 0.99**), average length of primary branch (gr = 0.99**) and number of nodes per primary branch (gr = 0.99**) exhibited strong positive genotypic correlation with yield at Haru. Plant height, NPB, total node number and diameter of the main stem had shown positive genotypic correlation with the yield at both locations. Also, most of these traits showed a positive association with each other. Some bean and fruit traits showed a positive correlation with yield. **Conclusion:** Generally, one has to be cognizant to select genotypes with thick girth and tall possessing high node number from which a high number of primary branches emanate and wider canopy diameter having a high number of bearing primary branches during yield improvement via selection.

KEYWORDS

Arabica coffee, association, bean, correlation, fruit, genotypic, yield

INTRODUCTION

Coffee is a perennial crop which belongs Rubiaceae family and genus *coffea*[1]. Among 141 coffee species, both *Coffea arabica* L. and *Coffea canephora* P. are the principal species in the world coffee production and market[2,3]. Arabica coffee is tetraploid and predominantly autogamous but Canephora is diploid and allogamous species[4,5]. In addition to the corolla, the nature of the pistil and stamen position of the coffee Arabica flower contribute a great role in its autogamous. Also, *Coffea arabica* is shade lover species and has a high biennial characteristic in bearing yield relative to *Coffea canephora* species.

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Coffee is a cash crop and the second dominant trade commodity in the world. Of all coffee species, *Coffea arabica* contributes more than 60% of the world's coffee production[3]. It is highly preferred by consumers around the world due to its superiority in flavour and low caffeine constituents. Coffee is the main source of income for coffee-producing countries and it serves as an income source for 25 million livelihoods in the world. Ethiopia which is the homeland of Arabica coffee earns up to 31% of foreign exchange income from Arabica coffee alone[6]. Hence, around 15 million livelihoods in Ethiopia depend directly and indirectly on Arabica coffee production[7].

Arabica coffee production increment is prominent to increase the income of coffee producers and realize food security, especially in developing countries. Also, in response to exponentially increasing demands of consumers, boosting yield with required quality is a priority issue. Thus, to solve yield, disease, insect pest and quality problems, for the last five and half decades different breeding methods have been followed and powerful technologies were developed. In Ethiopia, 35 pure lines and 7 hybrids, a totally of 42 high yieldings, disease resistance and acceptable quality coffee varieties had been released for low, mid and high land coffee-producing ecologies[8]. To realize food security and response to the current world demand for Arabica coffee, yield potential improvement remains an alarming issue.

Yield is a quantitative trait contributed by huge yield components and agronomic traits. These traits have direct and/or indirect positive associated with yield[9]. This enables breeders and other experts who work on coffee genetic improvement to use as indices for yield improvement via selection and/or hybridization. For instance, *Coffea arabica* has open, mid-open, compact and mid-compact growth habits which are among the indicative traits in heterosis achievement during hybridization depending upon the combining ability of the parents[10]. Also, yield-related traits such as plant height, number of primary branches, number of secondary branches, node number per the main stem, stem girth, canopy diameter, leaf traits, bean traits and fruit traits are traits that are used as indices during coffee yield potential improvement. Different scholars indicated the association of some of these traits with clean coffee yield and each other[9,11,12]. However, there is less information on the association of leaf, fruit and bean traits with yield, with other growth traits and each other which may affect the selection of high-yielding coffee genotype. Thus, the present study is implemented to estimate the association between clean coffee yield and yield-related traits indices for selection, to study the existing association among yield-related traits at the genotypic level.

MATERIALS AND METHODS

Description of the study areas: The experiment was conducted at Haru and Mugi’s Agricultural Research Sub-Centres (Table 1) which was established in June, 2015. Both Haru and Mugi's Agricultural Research Sub-Centres are under Jimma Agricultural Research Center (JARC).

Materials, agronomic practices and experimental design: The experiment was implemented on 22 coffee accessions which were consolidated from three baths of collections (1998, 1999 and 2001 years of collection) with four checks and established using RCBD with three replication, a total of 26 coffee genotypes were involved in this study (Table 2). The accession was collected from different coffee-growing agro-ecologies of Wollega Western Ethiopia. Six coffee trees were planted per plot with the spacing of 2×2 m between plant and row and 3 m between replications. All agronomic practices such as temporal shade and permanent, fertilizer application and weed control had been applied as per recommendation.

Methods and data recorded: The data of growth parameters were recorded following the IPGRI descriptor. For yield and disease data, all plants per plot were used to record the necessary data.

Growth traits: Plan height (PH) (cm): Height from the ground level to the tip of the main stem, Height up to first primary branch (HFPB) (cm): Measurement of height above the ground up to the first primary

Table 1: Description of the study areas

Location	Altitude (m.a.s.l)	Temperature (°C)		Rainfall (mm)	Latitude	Longitude	Soil types	Distance from JARC
		Minimum	Maximum					
Mugi	1570	17	29	1655	8°4'00"	34°4'00"	Nitosol	610 km
Haru	1752	16	27	1727	8°59'21"	35°47'56"	Sandy clay loam	360 km

Dubale[13] and Merga *et al.*[14]

Table 2: Background description of the coffee accessions

Accessions	Woreda	Peasants association	Specific location	Collection altitude (m.a.s.l)
W02/98	Haru	Wora Baro	Kori	1740
W34/98	Haru	Wora Baro	Kori	1790
W98/98	Haru	Chageli	Gincho Gamo	1800
W141/98	Gimbi	H. Giorgis	Kiti Negede	1620
W163/98	Gimbi	Homa Arsama	Homa Arsama	1600-1670
W167/98	Gimbi	Homa Arsama	Homa Arsama	1600-1670
W175/98	Gimbi	Homa Arsama	Homa Arsama	1600-1670
W188/98	Gimbi	Homa Biribir	Homa Biribir	1550-1600
W191/98	Gimbi	Homa Biribir	Homa Biribir	1500-1570
W203/98	Gimbi	Siba Yesus	Nayesoo Kiti	1560
W212/98	Gimbi	Sibo Charo	Abaku qaba	1560
W01/99	Haru	Guracha Holata	Jilcha Nacha	1660
W40/99	Haru	Dogi Adere	Tilli Kalo	1720
W109/99	Ayira Guliso	-	Meso	1600
W03/00	Ayira Guliso	Waro Seyo	Meso	1500
W09/00	Ayira Guliso	Boke Keda	Roge	1600
W50/00	Ayira Guliso	Kurfessa birbir	Layo	1580
W52/00	Ayira Guliso	Kurfessa birbir	Kurfe	1520
W06/01	Ayira Guliso	Lalo Asella	Warrago Arsema	1600
W08/01	Ayira Guliso	Tosiyo mole	Abetu Gole	1620
W15/01	Ayira Guliso	Buro Hasabar	Abetu Gole	1700
W38/01	Ayira Guliso	Nebo Daleti	Basha Amench	1600
Checks				
Mana sibu (W78/84)	Haru	Haru	-	1550
Sinde (W92/98)	Haru	Haru	Weyesa Hirpha	1590
Chala (W76/98)	Haru	Haru	Adan Tarara	1740
Haru-I (66/98)	Haru	Haru	Bmura Kuso	1800

branch, Total node number of main stem (TNN): Counts of number of nodes on the main stem, Internodes length of the main stem (IL) (cm): Obtained by computing per tree as (PH-HFPB)/TNN-1, Diameter of the main stem (DM) (mm): Measured the diameter of the main stem at 5 cm above the ground, Number of primary branches (NPB): Counted number of primary branches per main stem, Number of secondary branches (NSB): Counted number of secondary branches per tree, Average length of primary branches (ALPB) (cm): It was measured from the point of attachment to the main stem to the apex, Number of nodes per primary branch (NNPB): Average value of the four longest branches at the middle of the stem per plant, Number of bearing primary branches (NBPB): Number of bearing primary branch counted per tree, Percentage of bearing primary branches (PBPB) (%): It was computed per tree as (NBPB/NPB)×100, Canopy diameter (CD) (cm): Average length of coffee tree canopy measured twice (East-West and North-South), Leaf traits (cm): Leaf length (LL), Leaf width (LW): Average length and width of five matured leaves and Leaf area (LA) (cm^2): Calculated as:

$$LA = K \times LL \times LW$$

where, K is constant specific to cultivars and canopy classes (0.67), Bean traits (mm): Bean length (BL) (mm), Bean width (BW) and Bean thickness (BT): Average length of ten normal matured seeds, measured at the longest, widest and thickness part, respectively, Fruit traits (mm): Fruit length (FL), Fruit width (FW) and Fruit thickness (FT) (mm): Average of five normal matured green fruits, measured at the longest, widest and thickness part, respectively, clean bean yield (YLD) (kg ha^{-1}): The weight of fresh cherries per plot was recorded in gm and converted into kg ha^{-1}, coffee leaf rust (CLR): Estimated by using the following method developed by Zadoks and Schein[15].

Data analysis: Analysis of Variance (ANOVA) was computed for quantitative characters analysis random model had been used to test the variability among genotypes for combined over locations (Table 4). This was performed using R-software version 4.1 software package and a significant difference was tested at a 5% ($p<0.05$) level. The statistical model followed:

$$Y_{ijk}=\mu+G_i+L_j+B_k\ (L_j)+GL_{ij}+\varepsilon_{ijk}$$

where, Y_{ijk} was the observation for genotype 'i' at location 'j' in replication 'k'. In the model 'μ' was the overall mean 'G_i' the effect of the genotype 'i', 'L_j' was the effect of environment 'j', 'B_k' block effect, 'GL_{ij}' the interaction between genotype and location or environment and 'ε_{ijk}' was the random error associated with the kth observation on genotype 'i' in environment.

Analysis of association: Genotypic (rg) correlations between two traits were estimated using the following formula[16]:

$$\text{Gcov}\ (x, y) = \frac{\text{MSPg} - \text{MSPe}}{r}$$

where, r and g are numbers of replications and genotypes, respectively, Gcov (x, y) = Genotypic covariance between traits x and y.

The correlation was estimated using the following formula:

$$rg = \frac{\text{Gcov}\ (x, y)}{\sqrt{\sigma^2 gx \times \sigma^2 gy}}$$

where, σ^2gx = Genotypic variance for character x, σ^2gy = Genotypic variance for character y
Note: In this paper only genotypic correlation was included and discussed.

RESULTS AND DISCUSSION

Most bean, fruit, leaf and growth traits showed highly significant to a significant differences in genotype by environmental interaction (G×E) including yield (Table 3). However, G×E was non-significant in coffee leaf rust (CLR), the number of nodes per primary branch (NNPB), leaf length (LL) and fruit width (FW). There was a non-significant difference among coffee genotypes for all agronomic traits except in NNPB in which genotype contribution is 51.8%, conversely, a highly significant difference was observed between locations in these traits. Variability was observed among Arabica coffee accessions using these quantitative traits[17-19]. The contribution of genotype for yield was 43.2%, whereas, 19.1 and 37.4% were contributed by location/environment and G×E, respectively. Additionally, except in fruit traits, all leaf and bean traits indicated non-significant among genotypes from the pooled analysis. This is due to the high G×E mean square (MSG×E) against which the mean square of genotypes (MSG) had tested. The highest genotype contribution 83.2% recorded for CLR flowed by 70.1, 69 and 61.5 which were recorded for fruit length (FL), fruit thickness (FT) and bean width (BW), respectively. The G×E contribution range from 22.4-45.6% for growth traits except for plant height (PH) and number of bearing primary branch (NBPB) which showed 17.9 and 11.7%, respectively. For most of these traits, environmental (Econt.) contribution was higher than both genotype and G×E. Significant differences were observed between locations in all growth traits,

Table 3: Combined analysis of variance for quantitative traits

	MSB	MSG Gcont.		MSL Econt.		MSG*LG×Econt.		MSE	
Traits	(df = 4)	(df = 25)	(%)	(df = 1)	(%)	(df = 25)	(%)	(df = 100)	CV (%)
Growth traits									
PH	4.15**	0.95^{ns}		147.36**		1.48***		0.46	5.12
	(4887.75**)	(700.46^{ns})	11.7	(105798.44**)	70.5	(1072.39***)	17.9	(326.76)	(10.23)
HFPB	2.11^{ns}	39.95^{ns}	40.2	730.64***	29.4	30.26***	30.4	9.5	11.95
TNN	0.26**	0.11^{ns}		13.19***		0.18***		0.05	4.38
	(35.84**)	(11.55^{ns})	13.6	(1357.89***)	64	(19.04***)	22.4	(5.22)	(8.91)
DM	0.35*	0.16^{ns}		19.25**		0.33***		0.11	5.61
	(47.59*)	(24.21^{ns})	13	(2853.14**)	61.2	(48.25***)	25.9	(18.05)	(11.69)
IL	2.03*	0.75^{ns}	36.8	9.04**	17.6	0.93***	45.6	0.33	9.36
CD	798.47**	460.09^{ns}	25	22637.13**	49	473.22**	25.7	224.84	17.17
NPB	64.66**	49.39^{ns}	28.9	2045.8**	47.9	39.68***	23.2	15.7	11.08
NSB	41.41^{ns}	187.28^{ns}	28	7770.10***	46.5	170.68**	25.5	74.77	20.58
NBPB	9.00^{ns}	17.68^{ns}	17.1	1841.92**	71.2	12.12**	11.7	7.4	15.88
PBPB	4.05^{ns}	75.90^{ns}	22.2	4150.60**	48.5	100.71**	29.4	50.39	14.9
ALPB	0.59**	0.30^{ns}		4.59*		0.26**		0.13	3.92
	(198.08**)	(105.23^{ns})	39.8	(1640.02*)	24.8	(93.80**)	35.4	(44.63)	(7.8)
NNPB	4.46^{ns}	7.21*	51.8	84.10**	24.2	3.33^{ns}	23.9	2.33	7.96
Leaf traits									
LL	2.81**	0.91^{ns}	51.1	8.76^{ns}	19.7	0.52^{ns}	29.2	0.44	4.41
LW	0.27*	0.24^{ns}	51.2	0.03^{ns}	0.3	0.22**	48.5	0.11	5.24
LA	112**	53.93^{ns}	51.6	120.58^{ns}	4.6	45.83*	43.8	27.94	8.02
Fruit traits									
FL	1.57*	1.95*	70.1	0.07^{ns}	0.1	0.83*	29.8	0.56	5.5
FW	0.34^{ns}	0.74**	25.6	47.83***	65.9	0.25^{ns}	8.6	0.19	4.13
FT	0.36*	0.83*	69	1.13^{ns}	3.8	0.33***	27.2	0.14	4.02
Bean traits									
BL	1.71***	0.46^{ns}	51.8	2.57^{ns}	11.6	0.33***	36.6	0.05	3.11
BW	0.34***	0.14^{ns}	61.5	0.06^{ns}	1.1	0.08***	37.4	0.02	3.26
BT	0.02^{ns}	0.10^{ns}	43	1.67**	27.9	0.07***	29.1	0.02	5.79
YLD	129557.52**	69243.67^{ns}	43.2	766228.09^{ns}	19.2	59593.41*	37.4	34089.15	44.38
CLR	2.33^{ns}	7.66***		0.08^{ns}		1.83^{ns}		1.67	53.66
	(117.75^{ns})	(387.34***)	83.2	(1.73^{ns})	0	(78.17^{ns})	16.8	(96.13)	(116.03)

Gcont.: Genotype contribution, Econt.: Environmental contribution and G×Econt.: G×E contribution, PH: Plant height (cm), HFPB: Height up to the first primary branch (cm), TNN: Total node number of the main stem, DM: Diameter of the main stem (mm), IL: Internodes' length of the main stem (cm), CD: Canopy diameter (cm), NPB: Number of the primary branch, NSB: Number of secondary branch, NBPB: Number of bearing primary branch, PBPB: Percent of bearing primary branch, ALPB: Average length of primary branch (cm), NNPB: Number of nodes per primary branch, LL: Leaf length (cm), LW: Leaf width (cm), LA: Leaf area (cm^2), FL: Fruit length (mm), FW: Fruit width (mm), FT: Fruit thickness (mm), BL: Bean length (mm), BW: Bean width (mm), BT: Bean thickness (mm), YLD: Yield (kg ha^{-1}), CLR: Coffee leaf rust (%) and *,**,***ns: Represent significant different at a probability level of 0.05, 0.01, 0.001 and non-significant different, respectively

however, the non-significant difference had been recorded in leaf, fruit and bean traits except in fruit width (FW) and bean thickness (BT). High G×E and high contribution to the environment resulted in the discrepancy performance of coffee genotypes across locations.

This indicates that it is very difficult to obtain genetic progress in selecting genotypes with high performance at both locations, i.e., the identification of genotypes with high performance over a wide coffee-producing area is very difficult. Thus, it seems better to divide coffee-growing areas into similar ecologies, some similar to Haru and others similar to Mugi and focuses on developing coffee varieties with specific adaptations to these ecologies. This is confirmed by Merga *et al.*[20,21], who found the inconsistent performance of Arabica coffee genotypes across locations.

When the top five genotypes with the highest bean yield were selected at two locations, no common genotype was selected at both locations (Table 4). Also, for the girth/diameter of the main stem (DM) at

Table 4: Five highest-yielding genotypes at Haru, Mugi and over locations

	Haru	Mugi	Reduction (%)	Combined	Reduction
	W203/98	W09/00		W09/00	
	W167/98	W02/98		W212/98	
	Haru-I	W08/01		W167/98	
	W03/00	Sinde		W02/98	
	W212/98	W188/98		W203/98	
Mean at Haru	467.4	329.0	29.6	437.64	6.4
Mean at Mugi	500.4	745.3	32.9	581.25	22.01
Mean combined	483.9	537.2		509.45	

Table 5: Five genotypes with the highest DM at Haru, Mugi and over locations

	Haru	Mugi	Reduction (%)	Combined	Reduction
	Mena Sibu	W08/01		W08/01	
	W06/01	W188/98		W15/01	
	W203/98	W15/01		W06/01	
	Chala	W167/98		W212/98	
	Haru-I	W175/98		Sinde	
Mean at Haru	35.5	29.4	17.2	33.9	4.5
Mean at Mugi	38.2	46.9	18.6	44.5	5.1
Mean combined	36.8	38.1		39.2	

Table 6: Genotypes with the highest FW at Haru, Mugi and over locations

	Haru	Mugi	Reduction (%)	Combined	Reduction
	W141/98	W50/00		W141/98	
	W08/01	W141/98		W08/01	
	Sinde	W163/98		W50/00	
	W06/01	W188/98		W109/99	
	W109/99	W08/01		Sinde	
Mean at Haru	10.6	10.3	2.8	10.5	0.9
Mean at Mugi	11.2	11.5	2.6	11.4	0.9
Mean combined	10.9	10.9		10.9	

Table 7: Five most tolerant genotypes for CLR at Haru, Mugi and over locations

	Haru	Mugi	Reduction (%)	Combined	Reduction
	W52/00	W191/98		W109/99	
	Chala	W38/01		W175/98	
	W09/00	Chala		Chala	
	W175/98	W02/98		W52/00	
	W191/98	W52/00		W191/98	
Mean at Haru	0.88	1.44	-63.6	0.94	-6.8
Mean at Mugi	1.33	1.12	-18.8	1.27	-13.4
Mean combined	1.11	1.28		1.11	

each location (about 5% selection intensity), no genotype was common for both locations (Table 5). The five genotypes with the highest DM over both locations give lower DM at both Haru and Mugi, (reduction of 4.5 and 5.1%, respectively). Due to high discrepancy performance across locations, selection based on mean performance is inferior to selection at specific locations.

As a result of, stability in fruit width (FW), two of the five genotypes having wider fruit were selected at both locations (Table 6). Also, for CLR, from selecting the top five genotypes tolerant to the disease, common tolerant genotypes were observed at two locations, thus, three of the five genotypes with the lowest CLR infection were selected at both locations (Table 7). This may be due to high contribution of genotype than G×E contribution for the traits. For CLR genotypic contributions were 83.2 and 25.6% for fruit width (FW), whereas the G×E contribution was 8.6 and 16.8% for FW and CLR, respectively (Table 3).

Association among traits

Genotypic correlation at Haru: Traits with positive correlation with bean yield merge first with it to form the cluster of bean yield, first merges NNPB, then PBPB, NBPB and cluster consisting of PH, TNN, NPB and

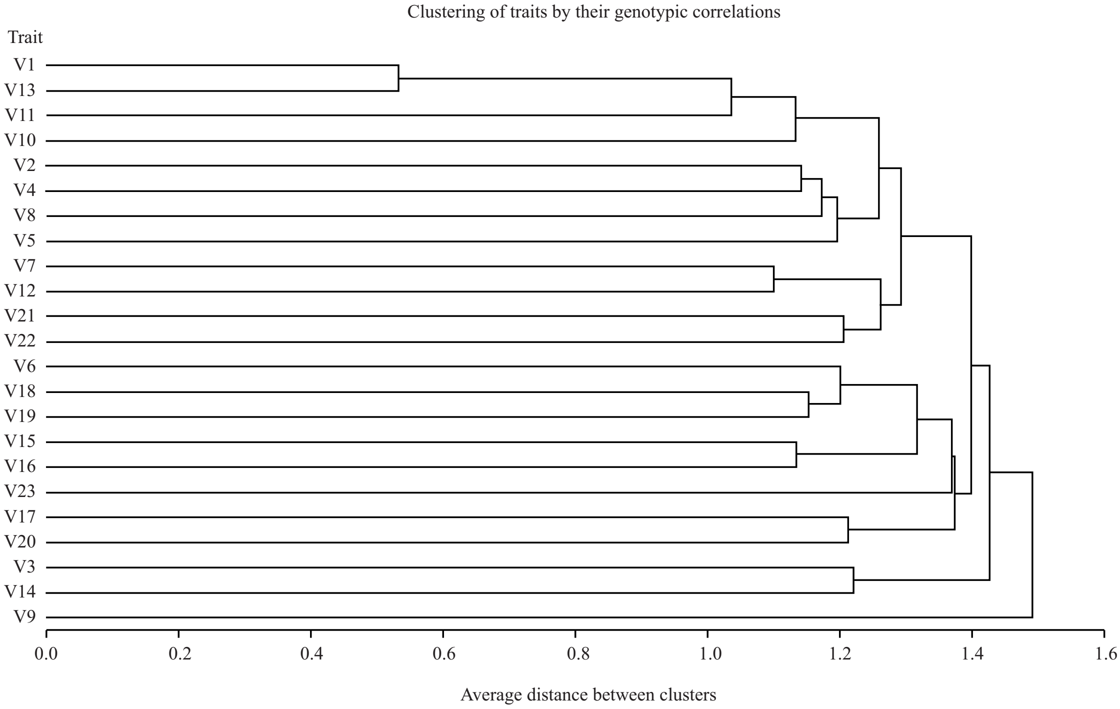

Fig. 1: Clustering of traits by their genotypipc correlation at Haru

YLD: V1, PH: V2, PFPB: V3, TNN: V4, DM: V5, IL: V6, CD: V7, NPB:V8, NSB: V9, NBPB: V10, PBPB: V11, ALPB: V12, NNPB: V13, LL: V14, LW: V15, LA: V16, FL: V17, FW: V18, FT: V19, BL: V20, BW: V21, BT: V22 and CLR: V23

DM joins the cluster of bean yield until finally BT and BW merge with the cluster of bean yield (Fig. 1). The finding of Dubale[13] confirmed the positive association of PH, NPB and CD with clean coffee yield. The number of secondary branches which had the strongest negative genotypic correlation (r_g = -0.990**) (Table 8) lies on the opposite side of bean yield. On contrary, from the previous experimental result, a positive correlation between yield and NSB was reported by Yirga *et al.*[22]. All traits with negative genotypic correlation with bean yield such as HFPB (gr = -0.154), IL (gr = -0.76), LW (gr = -0.322), LA (gr = -0.161), BL (gr = -0.435) and CLR (gr = -0.107) (Table 8) first merge with the cluster of NSB (gr = -0.990) which was strong negatively correlated and finally merge with cluster of bean yield (Fig. 1). Of the traits that had positive genotypic correlation with bean yield, FL (r_g = 0.61) and LL (r_g = 0.46) are in the cluster of NSB because FL had strong positive correlation with BL (r_g = 0.68) while LL had strong correlation with HFPB (r_g = 0.66) (Table 8). Additionally, almost all these traits are positively correlated with each other at the genotypic level at this location (Appendix Table 1). Plant height (PH) had a strong and significant positive genotypic correlation with TNN (0.904**), DM (0.830**) and NPB (0.771*), also, it showed a positive correlation with CD, HFPB, with some leaf, fruit and bean traits. TNN had positive correlation with NBPB (0.766*), NNPB (0.764*) and NPB (0.852**). Internode length (IL) positively correlated with fruit width (FW) (0.816*) and FT (0.633), CD had positive correlation with ALPB (0.990**), NPB showed positive correlation with NBPB (0.897**) (Appendix Table 1).

Genotypes with high bean yield are expected to have stronger (vigour) plants with wider stem diameter (DM rg = 0.40) and possess more nodes on the main stem (TNN) (rg = 0.990**) and hence, more number of primary branches (NPB) (rg = 0.78). Such genotypes also are expected to have taller plants (PH) (rg = 0.79). Primary branches are expected to possess many nodes and longer (NNPB and ALPB) (rg = 0.990** for both). Many of the primary branches should bear berries (NBPB and PBPB with rg = 0.990** for both). Such genotypes logically have wider canopy (CD) (rg = 0.3). They are expected to have longer leaves (LL) (rg = 0.46) and longer fruits (FL) (rg = 0.61). In line with this result, Marandu *et al.*[23], reported that PH, DM and TNN had a positive genotypic correlation with yield. Similar results were reported by Weldemichael *et al.*[18] on the association among these quantitative traits.

Appendix Table 1: Genotypic correlation coefficient (above diagonal at Haru and below at Mugi)

Trait	YLD	PH	HFPB	TNN	DM	IL	CD	NPB	NSB	NBPB	PBPB	ALPB	NNPB	LL	LW	LA	FL	FW	FT	BL	BW	BT	CLR
YLD		0.787	-0.154	0.990**	0.417	-0.76	0.262	0.778	-0.990**	0.990**	0.990**	0.990**	0.990**	0.46	-0.322	-0.191	0.612	0.017	0.052	-0.435	0.371	0.990**	-0.107
PH	0.651		0.353	0.904**	0.830**	0.194	0.685	0.771*	-0.236	0.587	-0.053	0.541	0.502	-0.539	0.197	-0.021	-0.238	0.103	0.211	-0.091	0.294	0.587	0.099
HFPB	0.277	0.118		0.259	0.372	-0.399	0.069	-0.128	-0.272	-0.149	-0.055	-0.057	0.04	0.659	0.342	0.536	-0.502	-0.271	0.136	-0.221	-0.045	-0.039	-0.091
TNN	0.481	0.389	-0.627		0.752*	-0.153	0.426	0.852**	-0.177	0.766*	0.14	0.389	0.764*	-0.225	-0.11	-0.192	-0.22	-0.172	-0.11	-0.13	0.019	0.465	0.197
DM	0.127	0.547	-0.335	0.216		0.101	0.523	0.633	-0.143	0.485	-0.114	0.441	0.258	0.058	0.245	0.235	0.011	0.023	-0.034	0.531	0.287	0.549	-0.196
IL	0.251	0.783*	0.537	-0.277	0.514		0.67	0.117	0.01	-0.139	-0.426	0.463	-0.471	-0.99**	0.414	-0.066	0.192	0.816*	0.633	0.203	0.712	0.435	-0.101
CD	0.034	0.501	0.043	-0.236	0.758	0.775		0.405	-0.524	0.351	0.051	0.990**	0.458	0.263	0.259	0.342	-0.002	0.366	0.292	0.023	0.516	0.661	-0.627
NPB	0.43	0.418	-0.571	0.863*	0.462	-0.151	-0.103		0.077	0.897**	0.166	0.46	0.698	-0.373	0.025	-0.118	-0.18	-0.094	-0.189	-0.182	0.206	0.532	0.268
NSB	-0.001	0.463	0.432	0.572	0.413	-0.043	0.094	0.467		-0.044	-0.245	-0.515	-0.453	-0.514	-0.276	-0.422	-0.425	-0.47	-0.209	0.209	-0.065	0.137	0.102
NBPB	0.554	0.512	0.128	0.404	0.823*	0.217	0.293	0.309	-0.042		0.585	0.499	0.684	0.121	0.209	0.215	0.018	-0.012	-0.184	-0.181	0.249	0.482	0.194
PBPB	0.179	0.169	0.599	-0.17	0.463	0.229	0.379	-0.443	-0.343	0.718		0.242	0.274	0.815	0.357	0.589	0.272	0.123	-0.063	-0.115	0.123	0.089	-0.064
ALPB	-0.167	-0.009	-0.421	-0.307	0.369	0.334	0.824	-0.253	0.17	-0.082	0.143		0.541	-0.057	0.288	0.257	0.082	0.356	0.176	0.071	0.381	0.545	-0.384
NNPB	-0.205	-0.245	-0.585	-0.196	-0.125	0.015	0.16	0.002	0.27	0.16	0.109	0.441		0.054	-0.239	-0.195	-0.154	-0.069	-0.308	-0.205	-0.021	0.32	-0.049
LL	-0.458	-0.151	0.039	-0.296	0.061	0.06	0.479	-0.163	0.023	-0.462	-0.355	0.614	-0.06		0.031	0.416	-0.733	0.241	-0.067	-0.797	0.084	-0.629	-0.318
LW	-0.39	0.837*	-0.064	-0.094	-0.694	-0.808*	-0.307	-0.09	-0.507	-0.301	-0.18	-0.333	-1.047**	0.429		0.922	0.226	0.412	0.448	0.118	0.27	0.12	0.189
LA	-0.504	-0.607	-0.003	-0.203	-0.411	-0.479	0.071	-0.147	-0.301	-0.457	-0.323	0.133	-0.677	0.818	0.871*		-0.064	0.453	0.38	-0.178	0.267	-0.109	0.054
FL	-0.218	-0.074	0.081	-0.073	0.31	0.011	-0.044	-0.252	-0.607	-0.116	0.104	-0.206	-0.993**	0.508	0.598	0.641		0.53	0.427	0.684	0.296	-0.079	0.151
FW	-0.418	-0.186	-0.164	0.365	0.214	-0.427	-0.516	0.117	-0.615	0.376	0.275	-0.455	-0.531	-0.003	0.142	0.086	0.637		0.865	-0.014	0.485	0.161	0.388
FT	-1.047*	-0.256	-0.059	-0.004	0.367	-0.236	-0.154	-0.347	0.148	-0.027	0.288	-0.095	-0.653	0.33	0.25	0.339	0.566	0.418		0.062	0.484	0.22	0.358
BL	-0.31	0.18	0.119	-0.036	0.141	0.229	0.138	-0.016	-0.6	-0.234	-0.294	-0.073	-0.651	0.307	0.475	0.451	0.958**	0.519	0.393		0.264	0.368	-0.065
BW	-0.025	0.253	0.141	0.134	0.268	0.154	0.042	0.197	-0.355	-0.33	-0.496	-0.203	-1.05*	0.261	1.270**	0.922**	0.646	0.024	0.201	0.623		0.71	-0.026
BT	-0.452	0.334	0.221	0.203	0.177	0.17	0.158	0.078	-0.313	-0.459	-0.577	0.095	-0.46	0.41	0.527	0.555	0.966**	0.566	0.518	0.746*	0.766**		0.03
CLR	0.358	0.648	0.028	0.844*	0.632	-0.068	0.334	0.692	0.021	0.394	-0.185	0.218	0.006	-0.484	0.984**	0.321	0.618	0.552	0.323	0.308	0.156	-0.496	

YLD: Yield (kg ha^{-1}), PH: Plant height (cm), HFPB: Height up to the first primary branch (cm), TNN: Total node number of the main stem, DM: Diameter of the main stem(mm), IL: Internodes' length of the main stem (cm), CD: Canopy diameter (cm), NPB: Number of the primary branch, NSB: Number of Secondary branch, NBPB: Number of bearing primary branch, PBPB: Percent of bearing primary branch, ALPB: Average length of primary branch (cm), NNPB: Number of nodes per primary branch, LL: Leaf length (cm), LW: Leaf width (cm), LA: Leaf area (cm^2), FL: Fruit length (mm), FW: Fruit width (mm), FT: Fruit thickness (mm), BL: Bean length (mm), BW: Bean width (mm), BT: Bean thickness (mm) and CLR: Coffee leaf rust (%), *Significant and **Highly significant

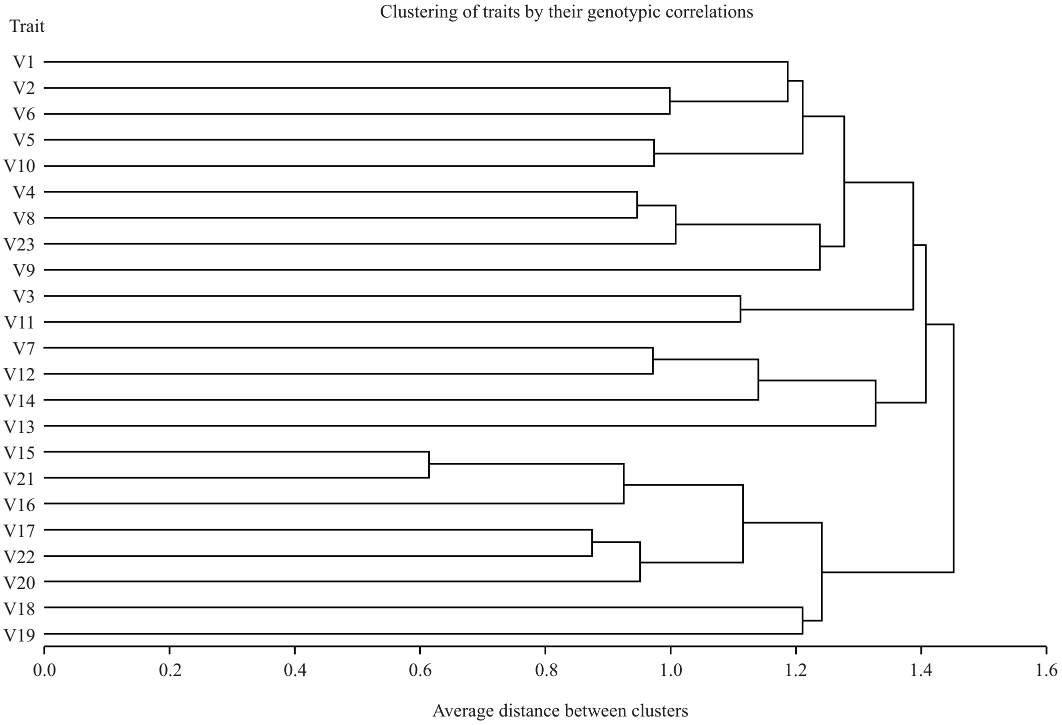

Fig. 2: Clustering of traits by their genotypic correlation at Mugi

YLD: V1, PH: V2, PFPB: V3, TNN: V4, DM: V5, IL: V6, CD: V7, NPB: V8, NSB: V9, NBPB: V10, PBPB: V11, ALPB: V12, NNPB: V13, LL: V14, LW: V15, LA: V16, FL: V17, FW: V18, FT: V19, BL: V20, BW: V21, BT: V22 and CLR: V23

On contrary, the highest yielding genotypes are expected to have low placement of the first primary branch (HFPB), shorter internodes, narrower leaves and smaller leaf area (LA), shorter beans (BL) and non or lower infestation by coffee leaf rust (CLR) due to negative correlation of these traits with bean yield (Table 8). This may be due to the pleiotropic gene effect that resulted from the previous selection[24].

Association of traits and expected mean performance of genotypes at Haru: The means of various traits of the five highest-yielding and the five lowest-yielding genotypes were compared at Haru (Table 9). The two groups had average bean yields of 383.7 and 307.6 kg ha^{-1}, respectively, an advantage of 76.1 kg ha^{-1} or an increase of 24.7% in the highest yielding group. The direction of change was as expected from the genotypic correlations except in HFPB, IL, LW, LA and CLR, where the means of the highest yielding genotypes increased by 8.1, 0.0, 1.6, 2.2 and 16.7% instead of decreasing as expected from the negative genotypic correlation between bean yield and these traits (Table 9). This may be due to a weak negative correlation (weak negative effect on yield) with bean yield and a strong correlation with other traits which had a strong positive correlation with yield. The higher infestation by CLR of the highest yielding genotypes is due to the genotype's moderate resistance and resistance to infection of CLR and weak correlation of CLR with yield (r_g = -0.1) at Haru. For NSB and BL these means were lower by 26.6 and 2.6%, respectively as expected from the negative correlation with bean yield.

For traits having a positive genotypic correlation with bean yield, the means of the five highest-yielding genotypes were increased by more than 10% in PH (12.4%), TNN (12.7%) and NPB (13.0%) and NBPB (19.7%). Also, the highest yielder genotypes increased in NNPB by 9.4%. At Haru, high-yielding genotypes had taller plants with many nodes on the main stem and bearing many primary branches with many nodes. Many of these nodes produced berries (fruits), i.e., such plants had more bearing nodes on each primary branch.

Table 8: List of genotypic correlation coefficients at both locations

Traits	Haru (Gr)	Mugi (Gr)
PH	0.787	0.651
HFPB	-0.154	0.277
TNN	0.990**	0.481
DM	0.417	0.127
IL	-0.76	0.251
CD	0.262	0.034
NPB	0.778	0.43
NSB	-0.990**	-0.001
NBPB	0.990**	0.554
PBPB	0.990**	0.179
ALPB	0.990**	-0.167
NNPB	0.990**	-0.205
LL	0.46	-0.458
LW	-0.322	-0.39
LA	-0.161	-0.504
FL	0.612	-0.218
FW	0.017	-0.418
FT	0.052	-1.047*
BL	-0.435	-0.31
BW	0.371	-0.025
BT	0.990**	-0.452
CLR	-0.107	0.358

PH: Plant height (cm), gr: Genotypic correlation coefficient, HFPB: Height up to the first primary branch (cm), TNN: Total node number of the main stem, DM: Diameter of the main stem (mm), IL: Internodes' length of the main stem (cm), CD: Canopy diameter (cm), NPB: Number of the primary branch, NSB: Number of secondary branch, NBPB: Number of bearing primary branch, PBPB: Percent of bearing primary branch, ALPB: Average length of primary branch (cm), NNPB: Number of nodes per primary branch, LL: Leaf length (cm), LW: Leaf width (cm), LA: Leaf area (cm^2), FL: Fruit length (mm), FW: Fruit width (mm), FT: Fruit thickness (mm), BL: Bean length (mm), BW: Bean width (mm), BT: Bean thickness (mm), CLR: Coffee leaf rust (%), *Significant and **Highly significant correlation

Genotypic correlations at Mugi: Agronomic traits such as PH, HFPB, TNN, DM, IL, CD, NPB, NBPB and PBPB had a positive correlation with clean coffee bean yield at the genotypic level, CLR showed a positive correlation with a yield which is expected due to high cherry bearer coffee genotypes exposed to CLR infection (Table 8). However, bean yield had a negative correlation with NSB (near zero), with all leaf, fruit and bean traits. However, Kifle *et al.*[25], reported a positive correlation between NSB and clean coffee yield. The correlation of bean yields with FT-1.0 was strong.

Therefore, PH, IL, DM, NBPB, TNN, NPB and CLR were the first to form a cluster with bean yield (Fig. 2). These traits had a genotypic positive association with each other, PH was positively correlated with IL (0.783*), DM (0.501), NBPB (0.512), TNN (0.389) and NPB (0.418) (Appendix Table 1). Also, IL had a positive genotypic correlation with coffee tree girth (0.775) and NBPB (0.217), additionally, coffee main stem girth (CD) showed a positive correlation with NBPB (0.825*), TNN (0.216) and NPB (0.462). Likewise, the past finding confirmed the positive association between clean bean yield and PH, IL, DM, NBPB, TNN and NPB and the positive association among yield-related traits themselves[12,22,25]. Although NSB had a negative genotypic correlation near zero with bean yield, its association with PH, TNN, DM and NPB were relatively strong (Appendix Table 1) and it combined with a cluster of bean yield. HFPB was relatively closely correlated with percentage bearing primary branch which later joined the cluster of clean bean yield. Also, the CD was relatively closely correlated with ALPB, LL and NNPB, these four traits form a cluster which later joined with the yield cluster. Fruit thickness which showed a strong genotypic correlation (-1.0) with yield was found at the last opposite side of the clean yield cluster. Traits like LW, BW, LA, FL, BT, BL and FW which showed negative genotypic correlation to bean yield first merge or form a cluster with fruit thickness which later joined with the cluster of bean yield. This result agreed with the finding of Tefera *et al.*[26] and Atinafu and Mohammed[11], who reported that the positive genotypic correlation of bean yield with PH, NPB and CD and positive association among each other.

Table 9: Five highest and lowest yielding genotypes based on genotypes correlations at Haru

	YLD	PH	HFPB	TNN	DM	IL	CD	NPB	NSB	NBPB	PBPB	ALPB	NNPB	LL	LW	LA	FL	FW	FT	BL	BW	BT	CLR
High	383.7	156.8	24	23.9	32.4	5.8	155.3	33.8	30.7	14.6	43.1	81.1	18.6	15.7	6.3	66.5	13.6	10	9.1	7.5	4.8	2.1	3.5
Low	307.6	139.5	22.2	21.2	30.4	5.8	150.5	29.9	41.8	12.2	41	76.9	17	15.6	6.2	65.1	13.4	9.9	9	7.7	4.7	2	3
Increment	76.1	17.3	1.8	2.7	2	0	4.8	3.9	-11.1	2.4	2.1	4.2	1.6	0.1	0.1	1.4	0.2	0.1	0.1	-0.2	0.1	0.1	0.5
Percentage	24.7	12.4	8.1	12.7	6.6	0	3.2	13	-26.6	19.7	5.1	5.5	9.4	0.6	1.6	2.2	1.5	1	1.1	-2.6	2.1	5	16.7

YLD: Yield (kg ha^{-1}), PH: Plant height (cm), HFPB: Height up to the first primary branch (cm), TNN: Total node number of the main stem, DM: Diameter of the main stem (mm), IL: Internodes' length of the main stem (cm), CD: Canopy diameter (cm), NPB: Number of the primary branch, NSB: Number of secondary branch, NBPB: Number of bearing primary branch, PBPB: Percent of bearing primary branch, ALPB: Average length of primary branch (cm), NNPB: Number of nodes per primary branch, LL: Leaf length (cm), LW: Leaf width (cm), LA: Leaf area (cm^2), FL: Fruit length (mm), FW: Fruit width (mm), FT: Fruit thickness (mm), BL: Bean length (mm), BW: Bean width (mm), BT: Bean thickness (mm) and CLR: Coffee leaf rust (%)

Table 10: Five highest and lowest yielding genotypes based on genotypic correlations at Mugi

	YLD	PH	HFPB	TNN	DM	IL	CD	NPB	NSB	NBPB	PBPB	ALPB	NNPB	LL	LW	LA	FL	FW	FT	BL	BW	BT	CLR
High	678.3	222	28.3	30.4	43	6.7	190.6	41.4	51.9	22	54.1	91.3	19.4	15.1	6.3	63.6	13.8	11	9.2	7.3	4.7	2.2	2.5
Low	340.5	194	28	27.8	38	6.2	175.4	37.5	45.9	18.4	49.3	86.6	19	15.3	6.4	65.5	13.6	11	9.3	7.5	4.7	2.4	1.8
Increment	337.8	29.4	0.3	2.6	5	0.5	15.2	3.9	6	3.6	4.8	4.7	0.4	-0.2	-0.1	-1.9	0.2	0	-0.1	-0.2	0	-0.2	0.7
Percentage	99.2	15.2	1.1	9.4	13.2	8.1	8.7	10.4	13.1	19.6	9.7	5.4	2.1	-1.3	-1.6	-2.9	1.5	0	-1.1	-2.7	0	-8.3	38.9

YLD: Yield (kg ha^{-1}), PH: Plant height (cm), HFPB: Height up to the first primary branch (cm), TNN: Total node number of the main stem, DM: Diameter of the main stem (mm), IL: Internodes' length of the main stem (cm), CD: Canopy diameter (cm), NPB: Number of the primary branch, NSB: Number of secondary branch, NBPB: Number of bearing primary branch, PBPB: Percent of bearing primary branch, ALPB: Average length of primary branch (cm), NNPB: Number of nodes per primary branch, LL: Leaf length (cm), LW: Leaf width (cm), LA: Leaf area (cm^2), FL: Fruit length (mm), FW: Fruit width (mm), FT: Fruit thickness (mm), BL: Bean length (mm), BW: Bean width (mm), BT: Bean thickness (mm) and CLR: Coffee leaf rust (%)

Correlation and expected mean performance at Mugi: On the genotypic level yield of the highest yielding genotypes was increased by 99.2%, PH by 15.2%, TNN by 9.4%, DM by 13.2%, NPB by 10.4%, NBPB by 19.6% and PBPB by 9.7% which was expected from their positive correlation with yield (Table 10). Although NSB had a small negative genotypic correlation with bean yield it was increased by 13.1% in the elite selections. ALPB and NNPB were also increased by 5.4 and 2.1% although they were expected to decrease. This may be due to their weak correlation effect on bean yield. The reductions in leaf, fruit and bean traits were all lower than 5.0%, the highest being that of BT (8.3%) which is expected from their negative effect on bean yield at this location. The highest yielding lines had 38.4% more infestation by coffee leaf rust as compared to the five lowest yielding lines. Hence, the high yielding genotypes should possess many numbers of primary branches, many bearing numbers of the primary branch, many numbers of nodes per the main stem, wider (vigour) main stem, distant internodes length, taller plant (height), few numbers of the secondary branch, small leaf length, narrow leaf area, small fruit and bean size at this location. At the Mugi location, CLR showed a negative correlation with IL, LL and BT. Thus, during selection for CLR resistance, a genotype having distant internode length is suggested to be selected at this location.

CONCLUSION

Variability was revealed among genotypes at the individual location for most traits. High discrepancy performance was observed across the location and it is ideal to group locations as areas similar to Mugi and Haru for further performance analysis. Plant height, total node number, the diameter of main stem/girth, number of primary branches and number of bearing primary branches, showed positive genotypic correlation with a yield at both locations. Most of these traits had a strong positive genotypic correlation with each other. All fruit traits and bean thickness showed a positive genotypic correlation with the yield at Haru but the reverse at Mugi.

SIGNIFICANCE STATEMENT

The high yielding and low yielding genotypes selected at 5% indicate the superiority of high yielder over low yielding for traits that showed a positive association with yield. Thus, this study realized that one has to be conscious to select genotypes with tall height, many number nodes on the stem and possess huge long primary branches with many nodes and high berry-bearing capacity and thick girth during high-yielding coffee variety development via selection.

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