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Correlation and Path Coefficient Analysis in Coffee (*Coffea arabica* L.) Germplasm Accessions in Ethiopia

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Abstract: Sufficient information on the nature and magnitude of traits association will facilitate effective selection and hybridization to develop high yielding coffee progenies. The study was conducted at Metu Agricultural Research Sub Center to determine the extent of association among yield and yield related traits of coffee. Sixty four Coffee (Coffea arabica L.) germplasm including two standard check varieties (74110 and 74112) were used for this study. The field experiment was superimposed during 2018 cropping seasons on six years old coffee trees, which was laid down in 8x8 simple lattice design. The orchard was managed as per the coffee agronomic production practices. Data on 19 quantitative traits were recorded from four representative trees per row for each accession. Yield per tree exhibited significant ($P<0.05$) and positive phenotypic and genotypic association with fruit width (r_{ph}=0.19; r_g=0.19) and fruit thickness (r_{ph}=0.18; r_g=0.15). On the other hand, number of primary branches showed positive and significant ($P<0.05$) phenotypic and genotypic correlations with fruit width (r_{ph}=0.23; r_g=0.12) and fruit thickness (r_{ph}=0.21; r_g=0.07). Hence, indirect selection in favor of this trait can improve yield in coffee. Coffee berry disease mainly attacks fruits and beans, however, the disease showed negative phenotypic and genotypic correlation with fruit and bean quantitative traits. Average inter-node length of main stem, number of nodes on primary branches, Number of primary branches, fruit width and thickness, bean width and thickness and hundred beans weight exerted positive direct effect and also had positive genotypic association with yield per tree, while the other traits affected yield indirectly, mainly through average inter-node length of primary branches production. Therefore, these traits could be used as a reliable indicator in indirect selection for higher tree yield.

Keywords: *Coffea arabica* L., Correlation, Path Coefficient

1. Introduction

Coffee is one of the most widely drunk beverages in the world, and is a very important source of foreign exchange income for many countries. It is grown in about 80 countries spanning over 10.2 million hectares of land in the tropical and subtropical regions of the world, especially in Africa, Asia and Latin America. More than 125 million people in the coffee growing areas worldwide derive their income directly or indirectly from its products [20, 22]. It ranks second after oil in international trade and has created several million jobs in the producer and consumer countries where more than nine million tons of green beans are produced annually [15]. Ethiopia is not only the major producer and exporter of Arabica coffee, but also origin and center of genetic diversity for this valuable crop species. The entire genetic diversity of indigenous (wild) Arabica is confined mainly in the Afromontane rain forest located in the West and East of Great Rift Valley [19, 31].

The nature and extent of genetic variation governing the inheritance of characters and association will facilitate effective selection and hybridization aimed at producing high yielding progenies [17]. The selection of parents becomes more difficult if the important is made for a polygenically controlled complex character like yield. Therefore understanding the magnitude of variation, correlation and inheritance of important agronomic traits in the base population is imperative to select genetically superior individuals. Correlation coefficient quantifies the relationship between two variables. It simply measures mutual association without cause and effect relationship [11].

The existing relationships between traits are, generally determined by the genotypic, phenotypic and environmental correlations. Correlation coefficients, although very useful in quantifying the size and direction of trait associations, can be ambiguous if the high correlation between two traits is a consequence of the indirect effect of other traits [8]. Hence, path coefficient analysis is a very important statistical tool that indicate which variables (causes) exert influence on other variables (responses), while recognizing the impacts of multi co linearity [1]. Path coefficient analysis partitions the genetic correlation between yield and its component traits into direct and indirect effects and has effectively been used in identifying useful traits as selection criteria to improve yield [2, 27].

In coffee, the outcome of yield depends on various growth characters and their combinations, such as stem girth, canopy width, number of primary branches and number of secondary branches [10, 30]. In addition, a number of other agronomic characters; such as plant height, leaf area, number of nodes on primary branches, number of fruits, etc can directly or indirectly influence yield [21]. Accordingly, it is important to have a clear understanding about the magnitudes of the relationships between yield and other agronomic traits, because yield is influenced by all factors that determine productivity [6].

Several correlation studies indicated that the quantitative characters like number of stem nodes, primary branches, plant height, canopy diameter, length of the longest primary branch and stem diameter etc. have positive correlation with yield and such traits could be used as a selection criterion for improving the productivity of the crop since they represent the lion's share in the variability of the coffee population in the specified area [13]. Similarly, the current study was conducted to understand the nature and magnitude of correlation among quantitative trait and to estimate the direct and indirect contributions other traits to yield of coffee germplasm.

2. Materials and Methods

2.1. Description of the Experimental Site

The experiment was conducted at Metu Agricultural Research Sub Center during 2018 cropping season. Metu is located 600 km away from Addis Ababa in Illubabor zone of the Oromia Regional State. The sub center is situated at a distance of 3 km from Metu town. The geographical location of the sub center is 8°19' 0" N latitude 35°35' 0"E longitude and 1558 meters above sea level of altitude. The mean annual temperature ranges from 12.7 and 28.9°C with annual rainfall of 1829 mm/annum. The major soil type is Nitosols with pH of 5.24 [24].

2.2. Experimental Materials, Design and Field Management

Sixty-two *Coffea arabica* L. germplasm which have been collected in the year, 2012 from Yayu woreda of Illubabor zone and two commercially grown standard check varieties were used for this study (Table 1). The study was superimposed during the 2018 cropping seasons on six years old coffee trees. Experiment was laid down in an 8X8 simple lattice design with eight accessions per each incomplete block. Each accession was planted in a single row of six trees using spacing of 2m by 2m. Accessions were established under uniform *Sesbania sesban* temporary shade trees and all other management practices were also uniformly applied for the orchard as per the coffee agronomic production practices.

2.3. Data Collection

According to the International Plant Genetic Resources Institute [16] coffee descriptor, data of quantitative traits were recorded from each accessions as described below.

Table 1. *Description of Coffea Arabica L. germplasm used in the study.*

Accessions	District	peasant association	Specific collection site	Accessions	District	Specific collection site
Y63	Yayu	Gechi	Dogi	Y95	Yayu	Geri geba
Y64	Yayu	Gechi	Dogi	Y96	Yayu	Geri geba
Y65	Yayu	Gechi	Dogi	Y97	Yayu	Geri geba
Y66	Yayu	Gechi	Dogi	Y98	Yayu	Geri geba
Y67	Yayu	Gechi	Dogi	Y99	Yayu	Geri geba
Y68	Yayu	Achebo	Sembo	Y100	Yayu	Geri geba
Y69	Yayu	Achebo	Sembo	Y101	Yayu	Geri geba
Y70	Yayu	Achebo	Sembo	Y102	Yayu	Geri geba
Y71	Yayu	Achebo	Sembo	Y103	Yayu	Geri geba
Y72	Yayu	Achebo	Sembo	Y104	Yayu	Geri geba
Y73	Yayu	Achebo	Sembo	Y105	Yayu	Gordeya
Y74	Yayu	Achebo	Sembo	Y106	Yayu	Gordeya
Y75	Yayu	Achebo	Sembo	Y107	Yayu	Gordeya
Y76	Yayu	Achebo	Sembo	Y108	Yayu	Gordeya
Y77	Yayu	Achebo	Sembo	Y109	Yayu	Gordeya
Y78	Yayu	Achebo	Sembo	Y110	Yayu	Gordeya
Y79	Yayu	Achebo	Sembo	Y111	Yayu	Gordeya
Y80	Yayu	Achebo	Sembo	Y112	Yayu	Gordeya

Accessions	District	peasant association	Specific collection site	Accessions	District	Specific collection site
Y81	Yayu	Achebo	Geba	Y113	Yayu	Degitu
Y82	Yayu	Achebo	Geba	Y114	Yayu	Degitu
Y83	Yayu	Achebo	Geba	Y115	Yayu	Degitu
Y84	Yayu	Achebo	Geba	Y116	Yayu	Degitu
Y85	Yayu	Achebo	Geba	Y117	Yayu	Degitu
Y86	Yayu	Achebo	Geba	Y118	Yayu	Degitu
Y87	Yayu	Yayu	Achebo	Y119	Yayu	Degitu
Y88	Yayu	Yayu	Achebo	Y120	Yayu	Degitu
Y89	Yayu	Yayu	Achebo	Y121	Yayu	Degitu
Y90	Yayu	Yayu	Achebo	Y122	Yayu	Degitu
Y91	Yayu	Yayu	Achebo	Y123	Yayu	Degitu
Y92	Yayu	Yayu	Achebo	Y124	Yayu	Degitu
Y93	Yayu	Yayu	Achebo	74110	Metu	Bishari
Y94	Yayu	Yayu	Achebo	74112	Metu	Bishari

1. Total tree height (cm): height from the ground level to the tip of the tree was measured using tape meter per tree
2. Average Inter-node length on orthotropic branch (cm): was computed per tree as (TH–HFPB)/TNN-1, where TH = total plant height, HFPB =height up to first primary branch, TNN = total number of main stem nodes.
3. Main stem diameter (mm): was measured as a diameter of the main stem at five cm above the ground using caliper.
4. Canopy Diameter (cm): average length of tree canopy was measured twice, east-west and north- south direction.
5. Number of primary branches: total number of primary branches was counted per tree
6. Number of secondary branches: total number of secondary branches was counted per tree
7. Number of nodes on primary branches: numbers of nodes of six selected primary branches (from bottom, middle and top of the tree) were counted.
8. Length of primary branches (cm): the average lengths of six selected primary branches (from bottom, middle and top of the tree) were measured using tape meter.
9. Average Inter-node length on primary branches (cm): the average internodes length of primary branches was calculated by dividing the average length of primary branch to the average number of nodes on primary branch.
10. Leaf length (cm): average of five normal (> node 3 from the terminal bud) leaves measured from petiole end to apex per tree.
11. Fruit width (mm): average of 10 normal and mature green fruits of each tree measured at the widest part using digital caliper
12. Fruit thickness (mm): average of 10 normal and mature green fruits of each tree measured at the thickest part using digital caliper
13. Bean length (mm): average of 10 normal beans of each tree measured at the longest part
14. Bean width (mm): average of 10 normal beans of each tree measured at the widest part
15. Bean thickness (mm): average of 10 normal beans of each tree measured at the thickest part
16. Hundred Bean weight: hundred beans per accession were dried with oven and calculated at 11% moisture content as follows: ("bean weight at 0% moisture content" x 100) / ("bean number" x 0.89)
17. Green bean yield per tree (kg): weight of fresh cherries per tree recorded and converted in to clean coffee per tree
18. Coffee berry disease severity: severity was directly estimated as the percentage of diseased berries (damaged berries over on all barriers of bearing branch) from each of the trees assessed. It was rated using standard disease scales (0-6) adopted from Phiri *et al*. [25].; where, 0= no disease, 1= trace to 5%, 2= 6-10% showing infected berries, 3= 11-30% of infection, 4=31-50% of infection, 5=51-75% of infection and 6=maximum black lesion girdling the stem top killed and Highest yield lose.
19. Coffee leaf rust severity:- severity percentage of leaves per tree were also directly estimated as the percentage of diseased leaves (damaged leaves over on all the top, middle and bottom part of the tree) and it was estimated by using a rating scale 0 to 6 points [7], as follows: 0 = no chlorosis; 1 = trace up to 5% showing infected leaves; 2 = 6–10% of infection, 3 = 11–30% infection; 4 = 31 – 50% of infection; 5 =51-75% of infection and 6=intense lesions associated with leaf shedding. The percentage of severity index (PSI) for each disease was calculated using the formula suggested by [28], and the result was transformed using arc sin transformation method for statistical analysis.

$$\mathrm{PSI} = \frac{\text{Sum of all numerical rating}}{\text{Total plants rated x maximum score}} \text{x100}$$

Based on the disease severity level for each respective diseases, 0–10% of infection were considered as resistant, 11–20% infection as moderately resistant, 21–30% of infection as moderately susceptible, and 31–50% infection as susceptible and >51% infection as higly susceptible response.

2.4. Data Analysis

2.4.1. Correlation Analysis

The phenotypic correlation and genotypic correlation coefficients (r) between paired traits were estimated from variance and covariance components based on the method suggested by Singh and Chaudhury [29]. Data analysis was subjected to SAS statistical package.

Correlation coefficients at genotypic level (rg_{xy}) were calculated as;

$$rg_{(xy)} = \frac{\sigma g_{(X.Y)}}{\left(\sqrt{\sigma^2 g_x * \sigma^2 g_y}\right)}$$

Where: $rg_{(xy)}$= genotypic correlation coefficient between traits x and y; $\sigma g_{(X.Y)}$ = genotypic covariance between traits x and y; $\sigma^2 g_x$ = genotypic variance of trait x; $\sigma^2 g_y$ = genotypic variance of trait y.

Correlation coefficients at phenotypic level rp (xy) were calculated as;

$$rp_{(XY)} = \frac{\sigma p_{(X.Y)}}{\left(\sqrt{\sigma^2 p_x * \sigma^2 p_y}\right)}$$

Where: $rp_{(xy)}$= phenotypic correlation coefficient between traits x and y; $\sigma p_{(X.Y)}$ = phenotypic covariance between traits x and y; $\sigma^2 px$ = phenotypic variance of trait x; $\sigma^2 py$ = phenotypic variance of trait y.

2.4.2. Path Coefficient Analysis

Path coefficient analysis was calculated using the formula suggested by [11]. to determine direct and indirect effect of different variables on yield as:

$$r_{ij} = P_{ij} + \Sigma r_{ik} P_{kj}$$

Where; r_{ij} = is the mutual association between the independent trait (i) and dependent trait (j) as measured by the correlation coefficients

P_{ij} = is the component of direct effects of the independent trait (i) on the dependent trait (j)

$\Sigma r_{ik} P_{kj}$ = is summation of components of indirect effect of a given independent trait via all other independent traits.

The residual effect (U) was computed using the following formula:

$$U = \sqrt{1 - R^2}$$

Where: - $R^2 = \Sigma p_{ij}\, r_{ij}$

p_{ij} = component of direct effects of the independent character (i) on the dependent character (j) as measured by the path coefficient, r_{ij} = mutual association between the independent character (i) and dependent character (j) as measured by the correlation coefficient.

3. Results and Discussion

3.1. Association Among Quantitative Traits

3.1.1. Phenotypic (r_{ph}) and genotypic (r_g) Correlation of Yield and Component Traits

Genotypic (above diagonal) and Phenotypic (below diagonal) correlation coefficients of 19 quantitative traits were computed and presented (Table 2). Thus, yield per tree exhibited significant (P<0.05) and positive phenotypic and genotypic association with fruit width (r_{ph}=0.19; r_g=0.19) and fruit thickness (r_{ph}=0.18; r_g=0.15), indicating accessions producing wider and thick fruits were high yielder. On the other hand, number of primary branches showed positive and significant (P<0.05) phenotypic and genotypic correlations with fruit width (r_{ph}=0.23; r_g=0.12) and fruit thickness (r_{ph}=0.21; r_g=0.07). Hence, indirect selection in favor of this trait can improve yield per tree in coffee.

Tree yield also showed positive and negative phenotypic and genotypic correlation with the remaining morphological traits and disease reactions. Yield found negative phenotypic and genotypic correlation with coffee berry disease (r_{ph}=0.10; r_g=0.18) and coffee leaf rust severity (r_{ph}=0.07; r_g=0.06), which has important implication in the improvement of this trait during disease resistant coffee variety development. However, yield exhibited a weak uphill (positive) and downhill (negative) phenotypic as well as genotypic linear relationship with most of other studied traits, the reason behind will be, since Arabica coffee as perennial crop, its yield is influenced by a variety of factors. For instance, high temperature and dry conditions during flowering and grain filling phase are critical for the optimum coffee yield production [9]. Timely arrival of pre-monsoon showers of rain fall from January to April is crucial for the blossoming of the Arabica coffee floral buds. If this shower is delayed, then the fruit setting drops significantly [4].

Apart from the rainfall timing, the coffee floral buds are also very sensitive to the quantity of water. A good blossom requires one and a half inches of artificial rain or one inch of natural rain. If the moisture status is excessive in the soil required for the plant, it results imbalance between growth regulators and promoters, in this case a particular hormone responsible for vegetative phase comes into play. Therefore, the bud movement ceases while the photosynthates are diverted towards vegetative development. Under such conditions the bush appears healthy, but drastically reduces the number of flowers and at the end productivity suffers. On the other hand if it rains during the flower opening period, then water gets inside the bud and it starts to balloon up, thus the flower in such a situation will not set fruit [5, 4]. Crop load is also the other factor which reduces yield in the next cropping season.

3.1.2. Phenotypic (r_{ph}) and Genotypic (r_g) Correlation Among Other Component traits

Other orthotropic and Plagiotropic shoot characteristics had also showed either positive or negative Phenotypic (r_{ph}) and genotypic (r_g) correlation with each other or other characteristics (Table 2). Moreover disease reaction traits also revealed positive and negative significant associations with each other and the other yield component traits, for instance, coffee berry disease severity showed negative and significant correlation with fruit width (r_{ph}=0.16; r_g=0.24) and bean thickness (r_{ph}=0.0.11; r_g=0.11), while it had negative and non significant association with the rest of fruit and bean quantitative traits. Even though, CBD mainly attacks fruits and berries, interestingly the disease showed negative association with fruit and bean quantitative traits, which has important implication in the improvement of these traits during disease resistant coffee cultivar development.

The association of coffee leaf rust reaction was also negative with most of the traits. Coffee leaf rust severity exhibited positive and significant associations with coffee berry disease severity (r_{ph}=0.25; r_g=0.26) which means the presence of one disease will aggravate the other, suggesting simultaneous evaluations of coffee accessions for these closely associated important traits during future disease resistant cultivar development. The positive and significant association was observed between coffee leaf rust severity with bean length and bean width, which pose a challenge for coffee breeders to improve these traits simultaneously. Most of the traits associations in the current study were also in conformity with the report of earlier researchers [12, 23, 14].

Generally, the association could be either genetic or environment or else the contribution of both factors. Therefore, positive correlation among paired traits might allow improving both traits simultaneously, whereas for a negative correlation, selection for improving one trait will likely cause decreases the other trait [26]. Kearsey and Pooni1 [18] also suggested that the positive and significant association of traits due to the effect of genes can be the existence of strong coupling linkage between genes or the traits might be the result of pleiotropic genes that could control the traits in the same direction, while the negative correlation might be because of different genes or pleiotropic genes that have dominance on the traits which would control in different direction.

3.2. Path Coefficient Analysis

Correlation coefficient among paired traits may not give a complete picture for a parameter like yield which is either directly or indirectly controlled by several other traits. In such situations, path analysis partitions the correlation coefficients into the measures of direct and indirect effects of a set of independent variables on the dependent variable. As said by Ali and Shakor [3], path analysis not only measures the direct influence of one variable upon the other, but also furnishes a means of partitioning both direct and indirect effects and effectively measuring the relative importance of causal factors, which helps to build an effective selection program. In the current research, path-coefficient analysis was carried out at genotypic level using coffee yield per tree as dependent variable and other traits as independent variables which is presented in Table 3.

The genotypic path coefficient analysis revealed that average inter-node length of primary branches (0.295) observed the maximum positive direct effect on yield per tree followed by number of nodes on primary branches (0.247). Moderate positive direct effects were recorded from bean thickness (0.121) and coffee leaf rust severity (0.140). Moreover, average inter-node length of main stem (0.073); stem diameter (0.093), number of primary branches (0.027), fruit width (0.070), fruit thickness (0.028), bean width (0.034) and hundred bean weight (0.052) also had low degree of positive direct effects toward yield per tree. Conversely, bean length (-0.311), coffee berry disease severity (-0.158), number of secondary branches (-0.141), average length of primary branches (-0.116), total plant height (-0.083), canopy diameter (-0.059) and leaf length (-0.005) exhibited negative direct effects on yield per tree.

Similarly, Ermiyas [12]. reported that average length of primary branches and canopy diameter showed negative direct effect on yield. The current finding was also consistent with Getachew *et al.* [14]. who found out number of nodes of primary branches, average inter-node length of primary branches, number of primary branches, fruit length and thickness, height up to first primary branches and stem diameter showed positive direct effect on yield per plant; while the remaining had negative direct effects.

The positive direct effect of average inter-node length of primary branches, number of nodes on primary branches, bean thickness and hundred beans weight on yield had path coefficient values larger than their correlation values, indicating more indirect influence of these traits via other component traits. Number of primary branches, fruit width, fruit thickness and bean width were positively correlated with yield while the magnitude of the direct effect is by far less than that of the correlation coefficient, implying the importance of other traits via which these traits contributed to yield per tree. The high magnitude of its effect through average inter node length of primary branches confirms this finding. The correlation coefficient of stem diameter and coffee leaf rust severity with yield was negative, but the direct effect was positive, indicating the importance of indirect effect of these traits via other traits. Observation about average inter-node length of main stem showed that its correlation coefficient and its direct effect on yield were almost equal, indicating that there is true relationship among the two traits [29], and hence, selection through average inter node length of main stem would be effective.

The direct effect of total plant height and average length of primary branches on yield was negative, while these traits showed positive and almost negligible genotypic correlation coefficients with yield per tree, in which their indirect effects was via other traits. This in turn, implies that the other traits through which it influenced the indirect effect need to be considered for selection. On the other hand, canopy diameter, number of secondary branches, leaf length, bean length and CBD severity showed negative direct effect and negative correlation coefficients with yield per tree, which implies consideration of these traits like narrow canopy diameter, minimum number of secondary branch, short leaf length and bean length and low level CBD severity would be effective in breeding work. Comparable with this result, length of primary branches and coffee berry disease had negative direct effect and negative correlation coefficients with yield per tree [14].

Table 2. *Genotypic (above diagonal) and Phenotypic (below diagonal) correlation coefficients among 19 traits of 64 C. arabica L. germplasm tested at Metu (2016/2017)*

Traits	TPH	AILM	SD	CD	NPB	NSB	NNPB	ALPB	AILPB	LL	FW	FT	BL	BW	BT	HBW	CBD	CLR	YLD
TPH		0.70**	0.17	0.36**	0.59**	0.18	0.21	0.29*	0.14	-0.05	0.14	0.14	0.00	0.14	0.17	0.22	-0.05	0.07	0.08
AILM	0.60**		0.15	0.23	0.11	0.03	0.12	0.25*	0.14	0.09	0.00	0.08	0.00	0.03	0.02	0.21	0.003	0.00	0.07
SD	0.20*	-0.12		0.44**	0.11	0.47**	0.07	-0.05	-0.14	0.10	-0.03	0.02	-0.11	0.05	-0.07	-0.16	-0.06	-0.20	-0.02
CD	0.28**	0.10	0.27**		0.15	0.34**	-0.04	0.26*	0.27*	0.27*	0.06	0.11	0.10	0.18	0.18	0.15	0.01	0.00	-0.03
NPB	0.48**	-0.10	0.31**	0.14		0.24*	0.02	0.13	0.12	-0.04	0.12	0.07	0.01	0.02	0.05	0.11	-0.12	0.13	0.03
NSB	0.16	0.11	0.31**	0.18*	0.15		0.004	0.14	0.13	0.06	0.002	0.06	-0.01	0.10	-0.01	0.01	0.05	-0.02	-0.10
NNPB	0.19*	0.07	0.15	-0.04	0.12	0.04		0.33**	-0.40**	-0.19	-0.04	-0.07	-0.01	0.05	0.07	-0.06	0.00	0.04	0.10
ALPB	0.20*	0.34**	-0.17	0.12	-0.08	0.15	0.30**		0.72**	0.25*	0.13	0.14	0.29*	0.09	-0.04	0.13	0.03	0.19	0.08
AILPB	0.04	0.26**	-0.32**	0.14	-0.16	0.09	-0.43**	0.71**		0.36**	0.18	0.19	0.30*	0.06	-0.08	0.20	-0.01	0.16	0.02
LL	-0.05	0.06	-0.05	0.27**	-0.04	0.06	-0.19*	0.13	0.26**		-0.02	-0.07	0.30*	-0.03	-0.12	0.18	-0.20	0.20	-0.02
FW	0.07	-0.24**	0.21*	0.08	0.23**	-0.09	0.04	-0.12	-0.14	-0.05		0.88**	0.08	0.48**	0.38**	0.37**	-0.24*	-0.11	0.19
FT	0.07	-0.21*	0.28**	0.09	0.21*	-0.03	0.03	-0.09	-0.11	-0.09	0.89**		0.08	0.42**	0.30*	0.33**	-0.17	-0.13	0.15
BL	0.05	-0.08	0.05	0.11	0.13	-0.01	0.06	0.07	0.02	0.20*	0.16	0.18*		0.20	0.31*	0.65**	-0.09	0.41**	-0.12
BW	0.11	-0.11	0.18*	0.18*	0.14	-0.01	0.16	-0.04	-0.15	-0.09	0.40**	0.38**	0.32**		0.62**	0.49**	-0.20	-0.18	0.11
BT	0.18*	-0.06	0.08	0.16	0.17	-0.02	0.11	-0.13	-0.20*	-0.10	0.37**	0.32**	0.37**	0.58**		0.55**	-0.28*	0.25**	0.09
HBW	0.25**	0.08	0.07	0.11	0.23*	0.03	0.06	0.01	-0.04	0.08	0.32**	0.29**	0.60**	0.52**	0.54**		-0.23	0.14	0.03
CBD	-0.05	0.001	0.001	-0.08	-0.07	0.004	0.10	0.08	-0.02	-0.12	-0.16	-0.11	-0.01	-0.09	-0.15	-0.15		0.26*	-0.18
CLR	0.04	0.0003	-0.03	-0.04	0.10	-0.06	0.17	0.16	0.03	0.07	-0.02	-0.04	0.31**	-0.06	-0.18*	0.15	0.25**		-0.06
YLD	0.06	0.03	0.02	0.003	0.07	-0.06	0.09	0.08	0.01	-0.03	0.19*	0.18*	-0.07	0.09	0.10	0.04	-0.10	-0.07	

**, *= significant at probability level of ($p<0.01$) and ($p< 0.05$), respectively. TPH= total plant height, AILMS= average inter node length of main stem, SD= stem diameter, CD= canopy diameter, NPB= number of primary branches, NSB=number of secondary branches, NNPB= number of nodes of primary branches, ALPB= average length of primary branches, AILPB= average inter node length of primary branches, LL= leaf length, FW= fruit width, FT= fruit thickness, BL= bean length, BW= bean width, BT=bean thickness, HBW=hundred bean weight, CBD=coffee berry disease, CLR=coffee leaf rust, YLD= yield per tree

Table 3. *Estimate of direct (bold diagonal) and indirect effects (off diagonal) at genotypic level of 19 traits on yield in 64 coffee germplasm.*

traits	TPH	AILMS	SD	CD	NPB	NSB	NNPB	ALPB	AILPB	LL	FW	FT	BL	BW	BT	HWT	CBD	CLR	rg$_{(xy}$
TPH	-0.083	0.051	0.016	-0.021	0.016	-0.025	0.051	-0.034	0.041	0.000	0.010	0.004	0.001	0.005	0.021	0.011	0.009	0.011	0.081
AILMS	-0.058	0.073	0.013	-0.014	0.003	-0.004	0.028	-0.028	0.043	0.000	0.000	0.002	0.000	0.001	0.003	0.011	0.000	0.000	0.071
SD	-0.014	0.011	0.093	-0.026	0.003	-0.066	0.017	0.006	-0.040	0.000	-0.002	0.001	0.034	0.002	-0.008	-0.008	0.010	-0.028	-0.018
CD	-0.030	0.017	0.041	-0.059	0.004	-0.047	-0.009	-0.030	0.079	-0.001	0.004	0.003	-0.032	0.006	0.022	0.008	-0.002	0.000	-0.026
NPB	-0.049	0.008	0.010	-0.009	0.027	-0.034	0.006	-0.015	0.035	0.000	0.009	0.002	-0.004	0.001	0.006	0.006	0.019	0.018	0.034
NSB	-0.015	0.002	0.043	-0.020	0.006	-0.141	0.001	-0.016	0.038	0.000	0.000	0.002	0.005	0.003	-0.002	0.001	-0.008	-0.002	-0.103
NNPB	-0.017	0.008	0.006	0.002	0.001	-0.001	0.247	-0.038	-0.119	0.001	-0.003	-0.002	0.004	0.002	0.009	-0.003	0.000	0.006	0.102
ALPB	-0.024	0.018	-0.005	-0.015	0.003	-0.020	0.080	-0.116	0.213	-0.001	0.009	0.004	-0.092	0.003	-0.005	0.007	-0.005	0.026	0.080
AILPB	-0.011	0.011	-0.013	-0.016	0.003	-0.018	-0.099	-0.084	0.295	-0.002	0.012	0.005	-0.093	0.002	-0.009	0.010	0.001	0.023	0.017
LL	0.004	0.006	0.009	-0.016	-0.001	-0.009	-0.047	-0.029	0.107	-0.005	-0.002	-0.002	-0.092	-0.001	-0.015	0.009	0.031	0.028	-0.023
FW	-0.012	0.000	-0.003	-0.004	0.003	0.000	-0.010	-0.015	0.052	0.000	0.070	0.024	-0.024	0.016	0.046	0.019	0.038	-0.016	0.187
FT	-0.011	0.006	0.002	-0.007	0.002	-0.008	-0.017	-0.016	0.057	0.000	0.061	0.028	-0.026	0.014	0.036	0.017	0.026	-0.019	0.146
BL	0.000	0.000	-0.010	-0.006	0.000	0.002	-0.003	-0.034	0.089	-0.001	0.005	0.002	-0.311	0.007	0.037	0.034	0.013	0.058	-0.118
BW	-0.012	0.002	0.005	-0.011	0.000	-0.014	0.013	-0.010	0.017	0.000	0.034	0.012	-0.063	0.034	0.075	0.025	0.032	-0.026	0.113
BT	-0.014	0.002	-0.006	-0.011	0.001	0.002	0.018	0.005	-0.023	0.001	0.027	0.008	-0.095	0.021	0.121	0.029	0.045	-0.036	0.094
HWT	-0.018	0.015	-0.014	-0.009	0.003	-0.001	-0.016	-0.016	0.058	-0.001	0.026	0.009	-0.201	0.017	0.067	0.052	0.036	0.019	0.026
CBD	0.005	0.000	-0.006	-0.001	-0.003	-0.007	0.001	-0.004	-0.002	0.001	-0.017	-0.005	0.027	-0.007	-0.034	-0.012	-0.158	0.037	-0.185
CLR	-0.006	0.000	-0.018	0.000	0.003	0.002	0.010	-0.022	0.048	-0.001	-0.008	-0.004	-0.129	-0.006	-0.031	0.007	-0.041	0.140	-0.056

Residual effects (*U*) =0.934

TPH= total plant height, AILMS= average inter node length of main stem, SD= stem diameter, CD= canopy diameter, NPB= number of primary branches, NSB=number of secondary branches, NNPB= number of nodes of primary branches, ALPB= average length of primary branches, AILPB= average inter-node length of primary branches, LL= leaf length, FW= fruit width, FT= fruit thickness, BL= bean length, BW= bean width, BT= bean thickness, HBW= hundred bean weight, CBD =coffee berry disease, CLR =coffee leaf rust, rg(xy)= genotypic correlation coefficient between yield per tree and other trait.

Generally, except average inter-node length of main stem, number of nodes on primary branches, bean thickness, average inter node length of main stem, stem diameter, number primary branches, fruit width, fruit thickness, bean width, hundred bean weight and coffee leaf rust severity, all the other traits i.e., total plant height, canopy diameter, number of secondary branches, average length of primary branches, leaf length, bean length, and coffee berry disease affected yield indirectly mainly through average inter node length of primary branches production. Therefore, selection for average inters-node length of primary branches will possibly improve other component traits, thereby, improving yield per tree. The residual effect in path analysis determines how best the component (independent) variables account for the variability of the dependent variable, yield per plant [28]. To this end, the residual effect in the present study was (0.934), elucidated that the variability explained by the component factors toward yield per tree were low. Therefore the remaining unexplained variability will either due to non-studied traits or the influence of environment on the traits was high.

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