Genotypic Correlations and Paths of Influence among Components of Yield in Selected Robusta Coffee (*Coffea canephora* L.) Clones

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Abstract

On-farm trial comprising five selected robusta coffee clones and one seedling used as control were tested for component associations in farmers' fields at four different agro-ecological zones in the coffee growing areas of Kagera Region, Tanzania during the 2001/2002 growing season. In each zone, one site was selected for the trial. Each farmer's field represented a replicate and had two replicates. Data were collected for the vegetative and reproductive variables and subjected to standard statistical analyses. Simple correlation and path coefficient analyses revealed that in selection for yield of robusta coffee, greater emphasis should be given to plant height and number of berries per node as they had significant positive correlations and relatively high direct effects on yield of clean coffee. Plant girth, canopy radius and primary branches interacted positively with plant height in influencing yield of clean coffee. Number of primary branches with plant height had similar phenotypic and genotypic correlations indicating that both of these variables can simultaneously be selected in robusta coffee. On the other hand, selection for genes promoting percentage bearing primary branches will select against branching and flowering as shown by their opposite signs for genotypic and phenotypic correlations. The importance of the inter-relationships among the components of yield for high yielding clones of robusta coffee is discussed.

Introduction

The importance of using component selection criteria for high yielding clones of coffee was noted by Leroy *et al.* (1997) and Montagnon *et al.* (2001) while working on robusta coffee. Thus, knowledge of the interrelationships between yield and its components is important for selecting or improving two or more variables contributing to yield. Plant characters such as stem girth, width of canopy, percentage bearing nodes, number of flowers and berries are known to be related with and influence yield of clean coffee according to the findings of Dancer (1964), Srinivasan (1980) and Walyaro (1983). The environment may influence the relationships of variables in different ways, thus, making selection and improvement programmes unreliable. This calls for an analysis of relationships attributed to genetic causes in addition to the phenotypic relationships. However, simple correlation coefficient analysis does not provide detailed information on the paths of influence contributing to the total correlation. Path coefficient, on the other hand, enables partitioning of correlation coefficients to their components of direct effects of variables upon others and indirect effects giving a clear picture of individual contributions of variables to a dependent variable. The method is important in the assessment of compensation mechanisms operating among plant components which make improvement of one variable less rewarding because increment in yield will reach a certain level after which it declines because of sacrificial effects of other components. Strategies can be designed to circumvent the problem by using a path coefficient analytical method that was devised by Wright (1921) and revised by Dewey & Lu (1959).

Some studies on phenotypic, genetic associations and path coefficient analysis have been conducted on arabica coffee (e.g. Cannell, 1971; Srinivasan, 1980; Cilas *et al.*, 1998; Khoktong, 1998), but very limited in robusta coffee (see Leory *et al.*, 1994, 1997). The present study sets out to investigate the interrelationships among components of selected clones of robusta in the coffee growing zones of Kagera Region, Tanzania, for a more efficient planning of the improvement programmes.

Materials and methods

Five robusta clones and one seedling were used in the study. The clones and the seedling are MS1/95 formerly known as BK21, MS2/95 formerly known as BK22, and MS3/95 formerly known as BK 47, which are robusta trees selected in 1957 in the then Bukoba district but now known as Karagwe, Bukoba and Muleba districts. Also, clones MS5/95 formerly known as U.218/32 and MS6/95 formerly known as U.224/37 are Uganda selected robusta trees introduced to Tanzania in the early 1960's, and FS robusta coffee plants raised by using seeds selected from farmers' fields. In 1998, trials were established in farmers' fields at villages of Chanika and Bisheshe in Karagwe district and Kabirizi A and Kabirizi B in Bukoba district. Eleven farmers were involved in these trials, and each selected farmer's site represented a replicate. Five plants per clone or seedling were planted in one row in each site/replicate and this constituted a plot.

The randomization of treatments was done within sites, and planting of the clones done at a spacing of 3 m between rows and 2 m between plants within a row. The planting hole was made at 60 cm × 60 cm × 60 cm, and 20 kg of well-rotten farm yard manure per planting hole incorporated with the top soil was applied to fill the hole. After planting, the fields were mulched and, when the plants were one year old, 45 kg of N/ha were applied per year. In addition, when the trees were 2 years old and above, 85 kg of N/ha were applied in a split during the beginning of the short rains of September/October, beginning of long rains of February/March, and toward the end of the long rains of May/June. Training of the trees to give two to three stems was done when the trees were 1 year old. During 2000/2001, when the second crop was permissible, vegetative and reproductive characters namely plant height, plant girth, canopy diameter, internode length, number of primary branches, bearing primary branches, number of flowers and fruit set were measured on selected three uniform plants of each plot. Cumulative yield data were recorded as fresh cherries per hectare per year that was converted to clean coffee yield per hectare per year using a conventional figure of 0.22 for robusta coffee (Wellman, 1961).

Correlation coefficient analysis was carried out using MSTAT-C software. Relationship between yield and some vegetative as well as reproductive variables were computed across locations as a combined analysis.

Covariance analysis was done to estimate genotypic ($\sigma_{g1.2}$) and phenotypic ($\sigma_{ph.1.2}$) covariance components between two selected variables for comparison. M-STAC-C software was used to obtain the covariance components as it was used to obtain the variance components using the random effect model as shown in Table 1. The covariance components were used to compute genotypic and phenotypic correlation coefficients between chosen characters by using the formula given by Robinson *et al.* (1951) as shown below:

Genotypic correlation, $r_{g1.2} = \sigma_{g1.2} / \sqrt{(\sigma_{g1}^2)(\sigma_{g2}^2)}$; where $\sigma^2_{g1.2}$ = genetic covariance between the two variables; σ_{g1} = genotypic variance of the first variable; σ^2_{g2} = genotypic variance of the second variable.

Phenotypic correlation, $r_{ph\,1.2} = \sigma_{ph1.2} / \sqrt{(\sigma^2_{ph1})(\sigma^2_{ph2})}$; where $\sigma_{ph1.2}$ = phenotypic covariance of the two variables; σ^2_{ph1} = phenotypic variance of the first variable; σ^2_{ph2} = phenotypic variance of the second variable.

The phenotypic variance (σ^2_{ph}) among genotype means tested in *r* replications and *l* locations was computed by using the following formula after Robinson *et al.* (1949):

$$\sigma^2 ph = \sigma^2 g + \sigma^2 lg/l + \sigma^2_e/lr$$

Where $\sigma^2 ph$ = phenotypic variance

$\sigma^2 g$ = genetic variance

$\sigma^2 lg$ = variance due to genotypes × locations

σ^2_e = error variance

l = number of locations

r = number of replications

Path-coefficient analysis as designed by Wright (1921) and revised by Dewey & Lu (1959) to describe the relationship between correlation coefficient and path coefficients were used to discern the paths of influence among the variables. The relationships between correlation coefficients and path coefficients were established using the following statistical model arranged in matrix notation:

$$r_{16} = P_{16} + r_{12}P_{26} + r_{13}P_{36} + r_{14}P_{46} + r_{15}P_{56}$$
$$r_{26} = r_{12}P_{16} + P_{26} + r_{23}P_{36} + r_{24}P_{46} + r_{25}P_{56}$$
$$r_{36} = r_{13}P_{16} + r_{23}P_{26} + P_{36} + r_{34}P_{46} + r_{35}P_{56}$$
$$r_{46} = r_{14}P_{16} + r_{24}P_{26} + r_{34}P_{36} + P_{46} + r_{45}P_{56}$$
$$r_{56} = r_{15}P_{16} + r_{25}P_{26} + r_{35}P_{36} + r_{45}P_{46} + P_{56}$$
$$1 = P^2X_6 + P^2_{16} + P^2_{26} + P^2_{36} + P^2_{46} + P^2_{56} + 2P_{16}r_{12}P_{26} + 2P_{16}r_{13}P_{36} + 2P_{16}r_{14}P_{46} +$$

TABLE 1

Combined analysis of variance model for evaluating components of variance in different locations and clones of robusta coffee

Source of variance	*df*	*Mean square*	*Expected mean square*
Environments (L)	l-1	M_1	$\sigma^2e + r\sigma^2_{G\times L} + g\sigma^2_{R/L} + rg\sigma^2_L$
Replications (R/L)	l(r-1)	M_2	$\sigma^2e + g\sigma^2_{R/L}$
Clones (G)	g-1	M_3	$\sigma^2e + r\sigma^2_{G\times L} + rl\sigma^2_G$
G×E	(g-1)l-1)	M_4	$\sigma^2e + r\sigma^2_{G\times L}$
Error ((R/E) × G)	l(r-1)(g-1)	M_5	σ^2e

σ^2e = Plot error variance

σ^2G = Genotypic variance among clones/genotypes

$\sigma^2_{G\times L}$ = Genotypic × Location variance

r = Number of replications

l = Number of locations

g = Number of genotypes

$2P_{16}r_{15}P_{56}$ + $2P_{26}r_{23}P_{36}$ + $2P_{26}r_{24}P_{46}$ + $2P_{26}r_{25}P_{56}$ + $2P_{36}r_{34}P_{46}$ + $2P_{36}r_{35}P_{56}$ + $2P_{46}r_{45}P_{56}$;

where r's are the correlation coefficients; P's are the direct effects, rp's are the indirect effects and Px_6 is the residual.

Results

Phenotypic and genotypic correlations

Interrelationships between yield and yield attributes combined over four locations are presented in Table 2. Plant height, girth, canopy radius and internode's length were significantly and positively correlated to each other. A similar relationship was displayed among number of primary branches, berries per node and yield of clean coffee. Berries produced per node and yield showed significantly positive relationships with all the components studied except internode's length.

Genotypic and phenotypic correlations for some vegetative and reproductive variables on data combined over the locations are presented in Table 3. Plant height and number of primary branches had high positive genotypic and phenotypic correlations with higher value for phenotypic correlation. Number of primary branches and flowers per node had significant negative genetic correlations but positive phenotypic correlations with percentage bearing primary branches.

Path coefficient analysis

Results indicating direct and indirect effects of some vegetative and reproductive characters using phenotypic correlations combined over four locations for the six clones are shown in Fig. 1 and Table 4, with detailed illustration on how the indirect effects were obtained. The correlation between plant height and yield ($r = 0.642^{**}$) was predominantly attributed to the direct

TABLE 2

Simple correlation coefficients among yield, vegetative and reproductive variables of six robusta coffee clones (n = 48)

Variables	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1. Plant height	1.000									
2. Plant girth	0.911**	1.000								
3. Canopy radius	0.769**	0.741**	1.000							
4. Inter-node length	0.412**	0.400**	0.342*	1.000						
5. Number of primary branches	0.817**	0.868**	0.733**	0.282	1.000					
6. Number of flowers per node	0.530**	0.467**	0.520**	0.290*	0.358*	1.000				
7. Percentage bearing primary branches	0.658**	0.734**	0.580**	0.354*	0.817**	0.408**	1.000			
8. Number of berries per node	0.472**	0.458**	0.494**	0.248	0.294*	0.790**	0.288*	1.000		
9. Fruit set percentage	0.443**	0.411**	0.445**	0.252	0.273	0.659**	0.251	0.946**	1.000	
10. Yield of clean coffee	0.642**	0.590**	0.575**	0.211	0.510**	0.480**	0.402**	0.549**	0.507**	1.000

* Significant at 5% level
** Significant at 1% level

TABLE 3

Genotypic and phenotypic correlation coefficients of some growth and yield variables of six robusta coffee clones combined over four locations

Variables	Plant height	Percentage bearing primary branches
Number of primary branches	0.700** (0.764**)	0.718** (0.670**)
Number of flowers /node	- -	-0.348* (0.452**)

Phenotypic correlations in parentheses
n = 48

Similarly, the correlation between number of primary branches and yield ($r = 0.510^{xx}$) was mainly due to the indirect effect of number of primary branches through plant height (0.328). The latter was in turn attributed to the positive relationship between number of primary branches with plant height ($r = 0.817^{xx}$) and positive direct effect of plant height on yield (0.401). The relationship between number of berries per node and yield ($r = 0.549^{xx}$) was largely attributed to the direct influence (0.315) of number of berries per node on the yield of coffee.

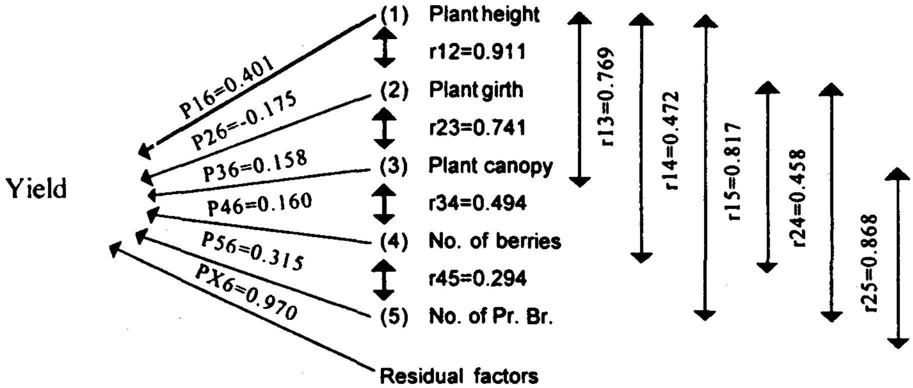

Fig. 1. Path diagram indicating paths of influence for yield and growth components of robusta coffee

influence (0.401) of plant height on the yield of coffee. On the other hand, the relationship between plant girth and yield ($r = 0.590^{xx}$) was largely due to the indirect effect (0.365) of plant girth through plant height. The latter was due to the relatively high direct effect of plant height on yield (0.401) and a significant and positive correlation between plant height and plant girth ($r = 0.911^{xx}$). As for the relationship between plant canopy and yield ($r = 0.575^{xx}$), it was largely due to indirect effect of canopy radius through plant height (0.308) as plant height had high direct effect on yield (0.401) and significantly positive correlation between canopy radius with plant height ($r = 0.769^{xx}$).

Discussion

In the present investigation, simple correlations were studied to find the associations of growth and yield attributes to the final yield. From simple correlation coefficients combined over four locations, yield was highly significant and positively correlated with all the tested variables except internode length (Table 2). This indicates that selection for high yielding clones is possible by indirectly selecting for taller plants, thicker stems, wider canopies, more primary branches and flowers per node, higher percentage of bearing primary

Table 4

Path coefficient analysis for some growth and yield character effects on yield of robusta coffee

1. *Effect of plant height*	r_{16}	0.642**
Direct effect	P_{16}	0.401
Indirect effect *via* plant girth	$r_{12}P_{26}$	-0.159
Indirect effect *via* canopy radius	$r_{13}P_{36}$	0.121
Indirect effect *via* number of primary branches	$r_{14}P_{46}$	0.131
Indirect effect *via* number of berries per node	$r_{15}P_{56}$	0.148
Total r		0.642
2. *Effect of plant girth*	r_{26}	0.590**
Direct effect	P_{26}	-0.175
Indirect effect *via* plant height	$r_{12}P_{16}$	0.365
Indirect effect *via* canopy radius	$r_{23}P_{36}$	0.116
Indirect effect *via* number of primary branches	$r_{24}P_{46}$	0.140
Indirect effect *via* number of berries per node	$r_{25}P_{56}$	0.144
Total r		0.590
3. *Effect of plant canopy*	r_{36}	0.575**
Direct effect	P_{36}	0.158
Indirect effect *via* plant height	$r_{13}P_{16}$	0.308
Indirect effect *via* plant girth	$r_{23}P_{26}$	-0.130
Indirect effect *via* number of primary branches	$r_{34}P_{46}$	0.083
Indirect effect *via* number of berries per node	$r_{35}P_{56}$	0.156
Total r		0.575
4. *Effect of number of primary branches*	r_{46}	0.510**
Direct effect	P_{46}	0.160
Indirect effect *via* plant height	$r_{14}P_{16}$	0.328
Indirect effect *via* plant girth	$r_{24}P_{26}$	-0.152
Indirect effect *via* plant canopy	$r_{34}P_{36}$	0.082
Indirect effect *via* number of berries per node	$r_{45}P_{56}$	0.092
Total r		0.510
5. *Effect of number of berries per node*	r_{56}	0.549**
Direct effect	P_{56}	0.315
Indirect effect *via* plant height	$r_{15}P_{16}$	0.189
Indirect effect *via* plant girth	$r_{25}P_{26}$	-0.080
Indirect effect *via* plant canopy	$r_{35}P_{36}$	0.078
Indirect effect *via* number of primary branches	$r_{45}P_{46}$	0.047
Total r		0.549

Residual effect Px_6 = 0.970

branches, more berries per node and higher fruit set percentage. However, for variables tested to be meaningfully important as selection criteria for yield, the variables should be positively and significantly correlated among themselves.

In the present investigation, selecting clones for plant height, plant girth, canopy radius, number of flowers per node, percentage bearing primary branches and number of berries per node was at the same time selected for yield of clean coffee. These variables can be selected simultaneously in a selection breeding programme since they are positively correlated among themselves hence selection for any of these components will select for yield without the risk of component compensatory effects (Adams, 1967). It can, therefore, be observed that a number of growth and important yield variables, in particular plant height, plant girth, canopy radius, number of flowers per node, percentage bearing primary branches and number of berries per node are worth improving in robusta coffee breeding programmes for improvement of yield. Cilas *et al.* (1998), while studying prediction of genetic value in arabica coffee, found that stem diameter, plant height and number of primaries were genetically correlated with yield.

The present study on robusta coffee indicates that plant height, girth and number of primary branches had significant phenotypic correlations with yield of clean coffee. Thus, the variables seem to be important in coffee production for both arabica and robusta coffee. Leroy *et al.* (1994) in studies on robusta coffee reported that canopy diameter of 4 year old trees was closely correlated with cumulated productivity in the absence of developmental competition between trees. The present investigation also indicates a significant positive correlation between canopy radius and yield of clean coffee. However, Leroy *et al.* (1997) recommended selection for high yield, good vigour and moderate canopy diameter in robusta coffee.

Montagnon *et al.* (2001) noted that for young trees of robusta coffee vigour, as estimated by stem diameter, was best correlated to competition effects; i.e. vigorous clones were more aggressive than others. Similarly, their study showed that when trees became adult, the length of the orthotropic internodes (L_{ort}) was the trait that most effectively explained the competition effects of clones. Aggressiveness of clones is reflected either on competition for their neighbours and or stimulating or promoting yield (Montagnon *et al.* 2001). The authors suggest that in future, L_{ort} may be used in a selection index to prevent selecting aggressive coffee clones that would undergo their own aggressiveness when grown alone in plantations. Their idea may be true for robust trees that grow under minimal biotic and abiotic stresses resulting to excessively robust trees in the field. However, if there are environmental stresses, less robust types in production, clones with longer orthotropic nodes and, hence, more competitive, may be desirable to stand the test of the environments.

Leroy *et al.* (1997) reported that more vigorous young plants reflected high yields of robusta coffee. In the present study, however, yield of clean coffee was not related to inter node length. Further studies are recommended on the consistence and relationships among stem diameter, inter node length, vigour/aggressiveness and yield under varying environments and clone types. Fruit set percentage and number of berries per node had a consistent positive and significant correlation in each location (data not shown), indicating that the relationship is not easily influenced by changes of environments. Khoktong (1998) reported that in arabica coffee, the number of branches and fruit set percentage were highest with highest yield per tree as the results of the present study indicate for robusta coffee. Therefore, selection for number of berries after flowering will also select for higher fruit set percentage, and finally improving yield of clean coffee since these variables were also positively correlated with yield.

Covariance components were estimated from covariance analyses in an analogous manner to the variance components computed from the analyses of variance to calculate the phenotypic and genotypic correlation coefficients. The phenotypic correlation is the outcome of the genetic and environmental effects. Environmental correlation is of little importance to the breeder when simultaneous selection for more than one quantitative character is attempted. The current study indicates that primary branches with plant height were significantly and positively correlated with respect to phenotypic and genotypic correlations on a combined analysis (Table 3). In addition, both phenotypic and genotypic correlations were similar indicating that little environmental effects were involved in the association of the two variables and that genetic causes were more responsible for the correlation between primary branches with plant height. Both of these variables can all be selected together in coffee improvement programmes. However, the phenotypic correlations were not consistent in every location, suggesting that the relationship between primary branches and plant height depends on the environment. Number of primary branches and percentage bearing primary branches had highly positive phenotypic correlation, however, there was a correspondingly negative genotypic correlation between the two variables. The opposite signs for genotypic and phenotypic correlations exhibited by the number of primary branches with percentage bearing primary branches implied complexity in response to selection and that it might impair or enhance the achievement of breeding objectives (Chandraratna, 1964).

Significant and negative genetic correlations but positive and significant phenotypic correlations were obtained between percentage bearing primary branches with number of flowers per node and number of primary branches. The findings suggest that there are negative genetic influences involved in the relationships of these variables. Thus, selection for higher percentage of bearing primary branches will directly select against number of primary branches and the number of flowers per node. However, the positive phenotypic correlations between percentage bearing primary branches with the number of flowers per node and the number of primary branches suggest that environmental effects play important roles in the components associations. Investigations should be done to ascertain the environmental conditions that favour the positive relationships among the components of yield.

Reasons for negative relationships among components of yield, and among other factors, may be due to pleiotropy, or genetic linkage. Thus, selection for genes promoting percentage bearing primary branches will select against branching and flowering. The differential relationships between phenotypic and genetic correlations indicate that the environment has a differential effect from genetic causes on the relationships. These variables should have a positive relationship from genetic causes and ways should be sought to break these negative associations. Also, genetic studies should be conducted to discern the cause of such adverse associations and, if it is from genetic linkage, then such associations could be broken by inter crossing and selection of recombinants. However, if the cause is pleiotropy, then mutation breeding could be done to circumvent the problem.

Results of path analysis of components of yield indicate that only plant height and number of berries per node produced had significant and positive correlations with yield, and their independent effects on yield were relatively high and positive as compared to the other indirect effects. Plant growth variables have been reported to influence yield of coffee (Dancer, 1964; Srinivasan, 1980; Walyaro, 1983). On the other hand, associated reproductive components such as number of flowers per node, percentage bearing primary branches, fruit set and number of berries per node have been reported to influence yield according to studies by Cannell (1971). The findings, therefore, suggest that for the variables used in the study, taller genotypes which produce more berries per node favour production of higher yields of robusta coffee. With the vegetative variables *viz*. plant girth, plant canopy, number of primaries; their positive and significant relationships with yield were predominantly due to their positive interactions with plant height (Table 4 and Fig. 1). Thus, in robusta coffee, height interacts favourably with wider stems and canopies and more primaries in the production of higher yields. Breeders should, therefore, produce taller robusta genotypes that are also bending, as farmers prefer bending type of robusta coffee for picking and easiness in spraying.

Srinivasan (1980) working with arabica coffee in India by using path coefficient and genotypic correlations found that greater weight should be given for longer primaries and shorter inter-nodes in selection for yield, as they had high direct effects. Differential findings could be attributed to differences in species, environments and variables included in the analysis. Since farmers prefer coffee clones with optimum height for easiness in working, breeding programmes should exploit the possibility of obtaining rare recombinants of shorter genotypes that produce more berries per node. This combination should, however, result in increased yield while maintaining optimum berry quality of robusta coffee.

Conclusion

Stem girth, canopy radius and primary branches interact well with height in influencing yield of robusta coffee in Kagera region, Tanzania. Robusta coffee improvement in the coffee growing zones of Kagera region should focus on taller clones that produce more berries per node. However, care should be taken to develop clones with optimum height that bend easily to facilitate spraying and picking of berries.

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