Research Article

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Correlation and path coefficient analysis of yield components in cocoa (*Theobroma cacao* L.)

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Abstract

Phenotypic correlations and their direct and indirect effects were estimated with twenty traits of 151 cocoa trees using path analysis. A high coefficient of phenotypic correlation was found between, tree girth, pod length, pod weight, pod volume, number of beans per pod, wet bean weight per pod before and after fermentation, dry bean weight per pod, single wet bean weight, single dry bean weight, number of pods per tree and polyphenol content exhibited highly significant positive correlation with the dry bean yield per tree. However, path analysis revealed that jorquetting height, tree girth, number of fan branches, pod girth, pod volume, pod wall thickness at furrows, wet bean per pod weight after fermentation, dry bean weight per pod, number of pods per tree, shelling percentage, fat content and polyphenol exhibited significance at high level in positive direction.

Keywords: Cocoa, correlation coefficient, dry bean, path analysis, yield

Introduction

The cocoa tree (*Theobroma cacao* L.) is the main source of raw materials used in the multi-billion dollar chocolate and confectioneries industry. In the crop improvement studies carried out around the world in cocoa, special emphasis has been given on the maximization of yield in the new plantation. Most traits of economic importance is of complex inheritance and may involve several characters. This means that selection for a given trait can provoke a simultaneous change in one or more other traits (Robinson *et al*., 1951) with the consequent need to learn about the degree of association between such traits. However, correlation estimates do not provide an exact view of the direct and indirect effects of each primary component on productivity (Bhatt, 1973). For a more appropriate understanding of the causes of association between traits, Wright (1934) proposed path-coefficient analysis which permits the partition of correlation coefficients in to direct and indirect effects since the correlation between two variables is the result of the sum of the values for all effects associated with the two variables (Li, 1977).

The path coefficient method has proved to be a valuable tool for revealing the true nature of cause-effect interrelations between yield and its primary components. Many studies have been published on the use of path-coefficient analysis for various plant species of economic importance such as cocoa (Almeida *et al*., 1994), pomegranate (Meena *et al*., 2009) and mango (Majumder *et al*., 2012). The objective of the present study was to evaluate the phenotypic correlations and their partitions into direct and indirect effects by path analysis of some yield components of cocoa.

Materials and methods

Pollachi region of Tamil Nadu state in India contributes more than 90 per cent of the total cocoa production. Hence, surveys were undertaken in these regions from June to October 2008 to identify candidate plus trees of cocoa. About 151 trees were selected based on yield, pod and bean characters.

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All the selected trees were seedling progenies with uniform age of 10 years. The trees were marked and observations were made for morphological, yield and quality parameters. The traits such as jorquetting height, tree girth, number of fan branches, pod length, pod girth, pod weight, pod volume, pod wall thickness at ridges, pod wall thickness at furrows, number of beans per pod, wet bean weight per pod before fermentation, wet bean weight per pod after fermentation, dry bean weight per pod, single wet bean weight, single dry bean weight, number of pods per tree, dry bean yield per tree, pod value, shelling percentage, fat content and polyphenol content were analysed.

The correlation coefficients were calculated to determine the degree of association of characters with yield. Phenotypic correlation coefficient was estimated according to the formula given by Al-Jibouri *et al.* (1958).

$$\text{Phenotypic correlation} = r_{xy}\,(g) = \frac{COV_{xy}\,(p)}{\sqrt{V_x(p) \times V_y(p)}}$$

Where,

Cov_{xy} (p) = Phenotypic covariance between x and y

V_x (p) = Phenotypic variance of characters x

V_y (p) = Phenotypic variance of characters y

The significance of correlation coefficients was tested against 'r' values given by Fisher and Yates (1963).

Path coefficient analysis as applied by Dewey and Lu (1959) was used to partition the phenotypic correlation into components of direct and indirect effects. By keeping the yield as dependant variable and the other traits as independent variable, simultaneous equations which express the basic relationship between path coefficients were shown to estimate the direct and indirect effects.

The dry bean yield per tree was considered as dependant variable and other traits were considered as explicative variable.

Results and discussion

The quantitative and qualitative characters which influenced final yield were inter correlated and also correlated with dry bean yield per tree. The direction of correlation among the traits and their test of significance were estimated by Pearson analysis (Table 1).

Jorquetting height expressed a highly significant and positive correlation with number of fan branches (0.290). Tree girth showed a strong and positive correlation with number of pods per tree (0.425) and dry bean yield per tree (0.385) and positive correlation with pod length (0.208).

Pod length recorded a highly positive correlation with pod girth (0.367), pod weight (0.693), pod volume (0.695), pod wall thickness at ridges (0.483), pod wall thickness at furrows (0.392), number of beans per pod (0.468), wet bean weight before fermentation (0.513), wet bean weight after fermentation (0.578), dry bean weight per pod (0.568), single wet bean weight (0.444), single dry bean weight (0.432), dry bean yield per tree (0.397) and positive relation with fat content (0.195). Pod length showed a highly negative correlation with pod value (-0.556) and negative relation with shelling percentage (-0.190).

Pod girth showed highly significant and positive correlation with pod weight (0.790), pod volume (0.800), pod wall thickness at ridges (0.476), pod wall thickness at furrows (0.528), number of beans per pod (0.293), wet bean weight before fermentation (0.522), wet bean weight after fermentation (0.444), dry bean weight per pod (0.447), single wet bean weight (0.384), single dry bean weight (0.384) and positive correlation with dry bean yield per tree (0.207). It expressed highly negative correlation with pod value (-0.394) and negative correlation with number of pods per tree (-0.174).

Pod weight expressed highly positive correlation with pod volume (0.978), pod wall thickness at ridges (0.569), pod wall thickness at furrows (0.540), number of beans per pod (0.527), wet bean weight before fermentation (0.682), wet bean weight after fermentation (0.647), dry bean weight per pod (0.644), single wet bean weight (0.496), single dry bean weight (0.490), dry bean yield per tree (0.398) and the pod weight also showed positive correlation with fat content (0.209) and negatively correlated with pod value (-0.582).

Pod volume registered a highly significant correlation with pod wall thickness at ridges (0.598), pod wall thickness at furrows (0.572), number of

Table 1. Phenotypic correlation coefficient between 21 traits of cocoa trees

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1.000																				
2	-0.157	1.000																			
3	0.290 **	-0.089	1.000																		
4	-0.064	0.208 *	-0.100	1.000																	
5	-0.039	0.034	0.002	0.367 **	1.000																
6	0.013	0.119	-0.030	0.693 **	0.790 **	1.000															
7	-0.004	0.129	0.006	0.695 **	0.800 **	0.978 **	1.000														
8	-0.063	0.038	0.100	0.483 **	0.476 **	0.569 **	0.598 **	1.000													
9	-0.138	0.152	-0.030	0.392 **	0.528 **	0.540 **	0.572 **	0.738 **	1.000												
10	0.122	0.034	0.018	0.468 **	0.293 **	0.527 **	0.520 **	0.220 **	0.146	1.000											
11	0.063	0.004	-0.071	0.513 **	0.522 **	0.682 **	0.671 **	0.234 **	0.199 *	0.597 **	1.000										
12	0.054	0.086	-0.101	0.578 **	0.444 **	0.647 **	0.631 **	0.221 **	0.203 *	0.676 **	0.869**	1.000									
13	0.042	0.094	-0.097	0.568 **	0.447 **	0.644 **	0.630 **	0.207 *	0.193 *	0.652 **	0.866**	0.995 **	1.000								
14	-0.023	0.096	-0.164 *	0.444 **	0.384 **	0.496 **	0.481 **	0.155	0.201 *	0.203 *	0.727 **	0.853 **	0.865 **	1.000							
15	-0.032	0.098	-0.154	0.432 **	0.384 **	0.490 **	0.476 **	0.132	0.175	0.195 *	0.720 **	0.840 **	0.865 **	0.991 **	1.000						
16	0.007	0.425 **	-0.116	-0.048	-0.174 *	-0.119	-0.114	-0.120	-0.119	0.023	-0.163 *	-0.102	-0.104	-0.138 *	-0.139	1.000					
17	0.051	0.385 **	-0.141	0.397 **	0.207 *	0.398 **	0.391 **	0.062	0.053	0.513 **	0.529**	0.691 **	0.696 **	0.570 **	0.571 **	0.630 **	1.000				
18	0.031	-0.100	0.077	-0.556 **	-0.394 **	-0.582 **	-0.578	-0.200 *	-0.213 **	-0.645 **	-0.761**	-0.931**	-0.942 **	-0.810**	-0.820**	0.081	-0.677 **	1.000			
19	-0.030	-0.116	-0.008	-0.190 *	-0.063	-0.105	-0.098	-0.014	-0.080	-0.129	-0.192 *	-0.173 *	-0.173 *	-0.140	-0.141	-0.036	-0.157	0.172 *	1.000		
20	0.187 *	-0.102	-0.070	0.195 *	0.076	0.209 *	0.208 *	0.348 **	0.149	0.026	0.132	0.170 *	0.161 *	0.203 *	0.179 *	0.081	0.179 *	-0.060	-0.048	1.000	
21	-0.038	0.131	0.061	-0.008	0.015	-0.044	-0.018	-0.010	-0.07 6	-0.082	-0.119	-0.068	-0.055	-0.033	-0.018	0.311 **	0.200 *	0.018	0.011	-0.007	1.000

** Correlation is significant at 0.01 level
* Correlation is significant at 0.05 level

1. Jorquetting height
2. Tree girth
3. Number of fan branches
4. Pod length
5. Pod girth
6. Pod weight
7. Pod volume
8. Pod wall thickness at ridges
9. Pod wall thickness at furrows
10. Number of beans per pod
11. Wet bean weight per pod before fermentation
12. Wet bean weight after fermentation
13. Dry bean weight per pod
14. Single wet bean weight
15 Single dry bean weight
16. Number of pods per tree
17. Dry bean yield per tree
18. Pod value
19. Shelling percentage
20. Fat content
21. Polyphenol content

Table 2. Path co-efficient analysis in cocoa trees for yield

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	**0.0804**	-0.0107	-0.0013	0.0068	-0.0064	0.0018	-0.0059	0.0139	-0.0011	0.0897	0.0226	-0.0791	-0.2357	0.0759	0.0043	-0.2331	0.0384	-0.0003	-0.0060	-0.0098
2	-0.0377	**0.0227**	0.0004	-0.0051	0.0031	-0.0015	0.0049	-0.0096	0.0007	-0.0489	-0.0112	0.0569	0.1757	-0.0485	-0.0028	0.3499	-0.0066	0.0001	0.0020	0.0064
3	-0.0225	0.0020	**0.0046**	-0.0012	0.0022	-0.0004	0.0020	-0.0033	0.0003	-0.0327	-0.0040	0.0057	0.0162	-0.0016	-0.0001	0.0186	-0.0228	0.0001	0.0013	0.0041
4	-0.0463	0.0098	0.0005	**-0.0118**	0.0056	-0.0043	0.0135	-0.0180	0.0013	-0.1012	-0.0384	0.1515	0.4563	-0.1017	-0.0058	0.1282	0.0300	0.0001	0.0056	0.0054
5	-0.0573	0.0079	0.0011	-0.0074	**0.0089**	-0.0045	0.0141	-0.0213	0.0015	-0.0941	-0.0383	0.1280	0.3892	-0.0971	-0.0056	0.0928	0.0030	0.0002	0.0054	0.0073
6	-0.0240	0.0057	0.0003	-0.0084	0.0066	**-0.0061**	0.0183	-0.0200	0.0015	-0.0914	-0.0453	0.1607	0.4921	-0.0977	-0.0057	0.0083	0.0522	0.0001	0.0044	0.0022
7	-0.0254	0.0060	0.0005	-0.0085	0.0067	-0.0060	**0.0186**	-0.0208	0.0016	-0.0920	-0.0448	0.1582	0.4851	-0.0962	-0.0056	0.0118	0.0510	0.0001	0.0045	0.0028
8	-0.0369	0.0071	0.0005	-0.0070	0.0062	-0.0040	0.0128	**-0.0304**	0.0020	-0.0570	-0.0243	0.0846	0.2510	-0.0691	-0.0038	0.0771	0.0058	0.0001	0.0059	0.0055
9	-0.0348	0.0065	0.0006	-0.0064	0.0056	-0.0038	0.0120	-0.0253	**0.0024**	-0.0628	-0.0211	0.0817	0.2443	-0.0609	-0.0034	0.0371	0.0083	0.0001	0.0049	0.0027
10	-0.0458	0.0071	0.0010	-0.0076	0.0053	-0.0035	0.0109	-0.0110	0.0010	**-0.1574**	-0.0423	0.1687	0.5018	-0.0715	-0.0040	0.1705	0.0362	0.0002	0.0041	0.0047
11	-0.0288	0.0040	0.0003	-0.0072	0.0054	-0.0044	0.0132	-0.0117	0.0008	-0.1055	**-0.0632**	0.2090	0.6401	-0.1347	-0.0079	-0.0071	0.0673	0.0000	0.0040	0.0020
12	-0.0270	0.0055	0.0001	-0.0076	0.0048	-0.0042	0.0125	-0.0109	0.0008	-0.1126	-0.0560	**0.2358**	0.7216	-0.1527	-0.0090	0.0293	0.0877	0.0000	0.0042	0.0024
13	-0.0261	0.0055	0.0001	-0.0074	0.0048	-0.0041	0.0125	-0.0105	0.0008	-0.1089	-0.0557	0.2346	**0.7252**	-0.1542	-0.0092	0.0248	0.0900	0.0000	0.0040	0.0024
14	-0.0349	0.0063	0.0000	-0.0068	0.0049	-0.0034	0.0102	-0.0120	0.0008	-0.0643	-0.0486	0.2059	0.6393	**-0.1749**	-0.0103	0.0244	0.0676	0.0001	0.0051	0.0038
15	-0.0331	0.0061	0.0000	-0.0066	0.0048	-0.0034	0.0101	-0.0112	0.0008	-0.0613	-0.0482	0.2034	0.6399	-0.1735	**-0.0104**	0.0172	0.0708	0.0001	0.0047	0.0038
16	-0.0267	0.0113	0.0001	-0.0021	0.0012	-0.0001	0.0003	-0.0033	0.0001	-0.0383	0.0006	0.0098	0.0256	-0.0061	-0.0003	**0.7015**	-0.0216	0.0001	0.0034	0.0081
17	-0.0250	0.0012	0.0009	0.0029	-0.0002	0.0026	-0.0077	0.0014	-0.0002	0.0461	0.0344	-0.1674	-0.5280	0.0957	0.0059	0.1226	**-0.1236**	0.0002	0.0015	0.0035
18	-0.0417	0.0030	0.0008	-0.0021	0.0030	-0.0005	0.0018	-0.0049	0.0004	-0.0377	-0.0031	0.0128	0.0338	-0.0217	-0.0011	0.0928	-0.0376	**0.0007**	0.0031	0.0055
19	-0.0342	0.0032	0.0004	-0.0047	0.0034	-0.0019	0.0060	-0.0128	0.0008	-0.0456	-0.0179	0.0707	0.2080	-0.0639	-0.0035	0.1703	-0.0131	0.0001	**0.0141**	0.0044
20	-0.0433	0.0080	0.0010	-0.0035	0.0036	-0.0008	0.0029	-0.0091	0.0004	-0.0411	-0.0069	0.0309	0.0973	-0.0370	-0.0022	0.3155	-0.0240	0.0002	0.0034	**0.0181**

Residual effect - 0.1134

Diagonal values are in bold – direct effect

1. Jorquetting height
2. Tree girth
3. Number of fan branches
4. Pod length
5. Pod girth
6. Pod weight
7. Pod volume
8. Pod wall thickness at ridges
9. Pod wall thickness at furrows
10. Number of beans per pod
11. Wet bean weight per pod before fermentation
12. Wet bean weight after fermentation
13. Dry bean weight per pod
14. Single wet bean weight
15 Single dry bean weight
16. Number of pods per tree
17. Pod value
18. Shelling percentage
19. Fat content
20. Polyphenol content

beans per pod (0.520), wet bean weight before fermentation (0.671), wet bean weight after fermentation (0.631), dry bean weight per pod (0.630), single wet bean weight (0.481), single dry bean weight (0.476), dry bean yield per tree (0.391) and positive correlation with fat content (0.208).

Pod wall thickness at ridges recorded highly positive correlation with pod wall thickness at furrows (0.738), number of beans per pod (0.220), wet bean weight before fermentation (0.234), wet bean weight after fermentation (0.221), fat content (0.348) and positive correlation with dry bean weight per pod (0.207). The pod wall thickness registered negative correlation with pod value (-0.200). Pod wall thickness at furrows expressed positive correlation with number of beans per pod (0.199), wet bean weight before fermentation (0.203), wet bean weight after fermentation (0.193), dry bean weight per pod (0.201) and significant negative correlation with pod value (-0.213).

The number of beans per pod expressed highly positive correlation with wet bean weight before fermentation (0.597), wet bean weight after fermentation (0.676), dry bean weight per pod (0.652), dry bean yield per tree (0.513) and positive correlation with single wet bean weight (0.203) and single dry bean weight (0.195). The number of beans per pod was found to be negatively correlated with pod value (-0.645).

The wet bean weight before fermentation recorded a strong positive correlation with wet bean weight per pod after fermentation (0.869), dry bean weight per pod (0.866), single wet bean weight (0.727), single dry bean weight (0.720) and dry bean yield per tree (0.529). It registered highly negative correlation with pod value (-0.761) and negatively correlated with number of pods per tree (-0.163) and shelling percentage (-0.192).

The wet bean weight after fermentation also showed highly positive correlation with dry bean weight per pod (0.995), single wet bean weight (0.853) and single dry bean weight (0.840) and dry bean yield per tree (0.691). It registered strong negative correlation with pod value (-0.931) and negative correlation with shelling percentage (-0.173). The dry bean weight also showed similar trend in correlation analysis as that of wet bean weight.

Single wet bean weight expressed highly significant positive correlation with dry bean weight (0.991), dry bean yield per tree (0.570) and positive correlation with fat content (0.203). It showed strong negative correlation with pod value (-0.810) and negative correlation with number of pods per tree (-0.138) and shelling percentage (-0.140).

The single dry bean weight showed strong positive correlation with dry bean yield per tree (0.571) and positively correlated with fat content (0.179). It registered highly negative correlation with pod value (-0.820). The number of pods per tree recorded highly significant correlation with dry bean yield per tree (0.630) and polyphenol content (0.311). The dry bean yield per tree expressed positive correlation with fat content (0.179) and polyphenol content (0.200) and highly negative correlated with pod value (-0.677). The pod value recorded positive correlation with shelling percentage (0.172).

In this present investigation, correlation studies made among the characters revealed both positive and negative association with varying levels of significance. Tree girth, pod length, pod weight, pod volume, number of beans per pod, wet bean weight per pod before fermentation and after fermentation, dry bean weight per pod, single wet bean weight and dry bean weight, number of pods per tree and polyphenol content showed highly significant positive correlation with the dry bean yield per tree. Pod girth, shelling percentage and fat content showed significant positive correlation with dry bean yield per tree. The jorquetting height, pod wall thickness at ridges and pod wall thickness at furrow showed positive correlation with the dry bean yield per tree.

Number of fan branches and shelling percentage recorded significant negative correlation with the dry bean yield per tree and the pod value had showed highly negative correlation with the dry bean yield per tree. These correlation studies were earlier reported in cocoa (Glendinning, 1963; Gregory, 1983; Khan *et al.*, 2008; Soria, 1975)

Path analysis

The estimation of correlation coefficient indicates only the event and nature of association between yield and its attributes, but does not show the direct and indirect effects of different yield attributes which are mutually associated. These will in turn impair the true association existing between a component and yield and a change in any one of these component is likely to disturb the whole network of cause and effect. Thus each component has two paths of action *viz.,* direct influence on yield and indirect effects through components which are not revealed from the correlation studies. In this context, the path analysis was analyzed to provide an effective measure of direct and indirect causes of association and depicts the relative importance of each factor involved in contributing to the final product *i.e.*, yield.

Out of twenty characters studied, twelve traits showed positive, direct effects on cocoa dry bean yield per tree. They were jorquetting height (0.0804), tree girth (0.0227), number of fan branches (0.0046), pod girth (0.0089), pod volume (0.0186), pod wall thickness at furrows (0.0024), wet bean per pod weight after fermentation (0.2358), dry bean weight per pod (0.7252), number of pods per tree (0.7015), shelling percentage (0.0007), fat content (0.0141) and polyphenol (0.0181). The direct effects of pod length (-0.0118), pod weight (-0.0061), pod wall thickness at ridges (-0.0304), number of beans per pod (-0.1574), wet bean weight per pod before fermentation (-0.0632), single wet bean weight (-0.1749), single dry bean weight (-0.0104) and pod value (-0.1236) were in negative direction (Table 2).

The earlier studies by Almeida *et al*. (1994) in cocoa also confirmed that number of pods per tree and dry bean weight per pod should be considered as main yield components because these traits showed direct effects of high value on dry bean weight per tree. They also reported that the number of beans per pod and bean dry weight constituted the main components of dry bean weight per pod. In the present study, the results of path analysis among cocoa accessions revealed that greater emphasis should be given to jorquetting height, tree girth, number of fan branches, pod girth, pod volume, pod wall thickness at furrows, wet bean weight per pod after fermentation, dry bean weight per pod, number of pods per tree, shelling percentage, fat content and polyphenol content for crop improvement through selection. Pod weight, pod wall thickness at ridges, number of beans per pod, wet bean weight per pod before fermentation, single wet bean and dry bean weight and pod value should be considered as secondary yield components.

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