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Determining the contribution of different yield components in broccoli (*Brassica oleracea* var. *italica* L.) through character association

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Abstract
A total of thirteen broccoli genotypes were evaluated for 14 quantitative traits to ascertain the traits involved in enhancing curd weight. Correlation and path coefficient analysis revealed the direct and indirect of fourteen quantitative characters studied. Estimates of phenotypic and genotypic correlation revealed that the curd yield per hectare to be highly positive and significantly correlated with curd weight / plant, curd length, curd width, leaf dry matter percentage, number of leaves, leaf length and leaf width. Path coefficient analysis of different characters contributing towards curd yield per hectare exhibited highest positive direct effect followed by curd weight/plant, days to curd initiation, leaf width, curd length, curd dry matter, leaf dry matter and Vitamin C. Therefore, these traits have to be considered, while practicing selection aimed at improvement of yield in broccoli.

Keywords: Vegetable improvement, broccoli, *Brassica oleracea* var. *italica*, correlation and path analysis

Introduction
Broccoli (*Brassica oleracea* L. var *italica*) is a member of the Brassicaceae (Cruciferae) family, originated from west Europe has considered as cool-season crops, now been distributed in both tropical and the sub tropical areas. Other members of the family include cauliflower, cabbage and kale (Guo *et al*., 2001) [3]. Its optimum growing temperature is in the range between 16 and 20 ^{0}C and is a biannual, herbaceous vegetable crop **(**Karistsapol *et al*., 2013) [5]. Compared to cabbage and cauliflower, broccoli is nutritionally very rich in protein (3.6%), fat (0.3%), carbohydrate (5.9%), vitamin A (9000 I.U.), calcium (2-16%) and iron (684 ppm). This nutritious vegetable also contains a chemical known as indole- 3-carbinol, which is supposed to possess anticancerous properties (Choudhury, 2005) [1]. United States of America is a leading producer of broccoli. In India, broccoli has become a commercial crop very recently and is grown in smaller area. The cultivation of sprouting broccoli is now gaining popularity among Indian growers for the last couple of years obviously due to increasing awareness of its high nutritive values and tourist influx.

Improvement in any crop depends on the magnitude of genetic variability and the extent of inheritance of characters from one generation to the next. The yield and its component characters are polygenic in nature, hence influenced by the environmental factors. The knowledge of inter relationships among the various yield components and their direct and indirect effect on yield are the important pre-requisites to bring genetic improvement in broccoli. Path coefficient will help plant breeders to decide suitable selection criteria to improve the yield. Path analysis facilitates partitioning of correlation coefficients into direct and indirect effects of various characters which to be prove useful in providing information, to improve yield or other related characters. The information on correlation and path coefficient analysis in broccoli is inadequate. Therefore, the present study was conceived with objective to examine the association between important yield traits and their direct and indirect effect in enhancing the yield of broccoli through selection.

Materials and methods
An experiment was carried out at ooty during the period of February to May 2018 and September to January 2019. The experiment was carried out in thirteen genotypes of broccoli (Punjab broccoli 1, Palam samridhi, Palam Kanchan, Palam vichithra, CITH 1 and CITH 2, Lucky, Fiesta, Dynasty, SSB06, A1, Green magic, Punjab hybrid. The seeds were sown in nursery on February 27th, 2018 in Horticultural Research Station, Ooty and seedlings were

transplanted to three locations (Ooty, Coonoor, Kothagiri) with a spacing of 45 x 45 cm Randomized Block Design (RBD) with three replications. Recommended crop production and protection practices were followed. The performance of different broccoli genotypes was studied and data recorded on plant height (cm), number of leaves (cm), leaf length (cm), leaf width (cm), curd length (cm), curd width (cm), curd weight g plant^{-1}, days to curd initiation, days to curd harvest, curd dry matter (%), leaf dry matter (%), total carotenoids (mg/100g^{-1}), vitamin C (mg/100g^{-1}) and curd yield (ton ha^{-1}). Path analysis were computed according to the method suggested by Dewey and Lew (1952). Correlation coefficients were computed according to the method suggested by Singh and Chaudhary (1985).

Result and discussion

In any crop improvement programme selection is very effective only when genetic variability exists. However,the knowledge on correlated traits help the crop breeders to identify elite genotypes with improved traits. The estimates of genotypic, phenotypic correlation and coefficient for various characters are given in Table 1.

Curd yield exhibited significant positive correlation with curd weight/plant, curd length, curd width, leaf dry matter%, leaf width, number of leaves, leaf length whereas yield had expressed significant negative correlation with days to curd harvest and days to curd initiation. It may be assumed that the selection based on these characters either in combination or alone would contribute for identifying the genotypes with high yielding potential. The present findings are in accordance with that of Prasad *et al.*, (1989) [9] and Jambal *et al.*, (1996) [4] and Rai and Asati (2005) [10] in cabbage. Most of the yield components exhibited positive and significant inter relationship among themselves which indicated the need of their simultaneous selection for improvement on yield.

Inter correlation among yield components

Plant height had positive significant correlation with Vitamin C meanwhile showed significant negative correlation with number of leaves and leaf width. A significant and positive correlation of number of leaves with leaf dry matter%, leaf width, curd weight/plant, curd length, curd dry matter%, curd width was noticed. However, it showed significant negative correlation with days to curd initiation. Leaf length exhibited positive significant correlation with Vitamin C, curd length, curd width, curd weight/plant and significant negative correlation with days to curd harvest. Leaf width was positively and significantly correlated with leaf dry matter%, curd weight/plant, curd length. Its association was negative and significant with days to curd harvest and days to curd initiation. Curd length exhibited highly significant positive correlation with curd width, curd weight/plant, leaf dry matter%, curd dry matter%, Vitamin C and it was significantly negative with days to curd harvest and days to curd initiation. Curd width was positively and significantly correlated with curd weight/plant, Vitamin C, curd dry matter%, leaf dry matter%. Its association was negative and significant with days to curd harvest and days to curd initiation. Curd weight/plant exhibited highly significant and positive correlation with leaf dry matter%, Vitamin C. Its association was negative and significant with days to curd initiation and days to curd harvest. A significant and positive correlation of days to curd initiation was recorded only with days to curd harvest and significant negative correlation with leaf dry matter%, curd dry matter%. Days to curd harvest showed significant negative correlation with leaf dry matter%, curd dry matter. Curd dry matter% showed significantly positive association with leaf dry matter%. The genotypic correlation coefficient is higher than the corresponding phenotypic correlation coefficient for all the parameters as reported by Meena *et al.* (2011) [8]. Thus, these traits may be effectively be used as a selection criterion for selecting potential genotypes in a breeding programme.

Path analysis of yield and its component traits

For clear and vivid understanding of the factors contributing towards curd yield per hectare the estimation of indirect and direct effects of traits to be ascertained. Path coefficient analysis is an efficient tool which helps in study of contributions of different independent characters on dependent characters i.e. curd yield per hectare. As this mutual relationship may vary both in magnitude as well as direction tends to deviate the association of curd yield with characters, it becomes necessary to partition both the genotypic and phenotypic correlation into indirect and direct effects of each other. The results are presented in Table 2 and Figure 1 & 2.

The data revealed that curd yield per hectare had highest positive direct effect with curd weight/plant, days to curd initiation, leaf width, curd length, curd dry matter, leaf dry matter and Vitamin C. Similar results were observed by Kumar *et al.*, (2017) [6] in cauliflower for days to curd initiation and curd weight/plant. The direct selections for these characters will directly contribute for improvement of curd yield per hectare.

In the present study, the characters *viz* days to curd harvest, curd width, number of leaves, leaf length, and total carotenoids were registered negative direct effect on yield. The results corroborated the findings of Manaware and Naidu (2017) [7] for curd width.

The data further revealed that curd weight/plant showed maximum positive indirect effects followed by curd length, curd width, leaf length, leaf dry matter, number of leaves, curd dry matter, total carotenoids and vitamin C respectively, on yield/ha.The results indicate that selection for these traits will indirectly contribute for yield improvement.

Table 1: Estimates of correlation at phenotypic (P) and genotypic (G) levels between different traits of broccoli

Traits		x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14
x1	G	1	-0.575*	0.385	-0.571*	-0.084	0.049	-0.164	0.328	0.281	-0.345	-0.384	-0.404	0.569*	-0.171
	P	1	-0.523	0.352	-0.512	-0.072	0.044	-0.150	0.298	0.261	-0.277	-0.320	-0.284	0.524	-0.159
x2	G		1	0.373	0.820**	0.616*	0.565*	0.724**	-0.555*	-0.539	0.577*	0.867**	0.684**	0.205	0.725**
	P		1	0.354	0.730**	0.582*	0.536	0.682*	-0.496	-0.468	0.466	0.762**	0.514	0.194	0.675*
x3	G			1	0.512	0.857**	0.879**	0.716**	-0.571*	-0.592*	0.586*	0.669*	0.275	0.962**	0.711**
	P			1	0.501	0.832**	0.862**	0.704**	-0.531	-0.551	0.479	0.605*	0.230	0.929**	0.678*
x4	G				1	0.807**	0.731**	0.731**	-0.776**	-0.799**	0.820**	0.878**	0.598*	0.303	0.748**
	P				1	0.733**	0.672**	0.668*	-0.662*	-0.674*	0.636*	0.730**	0.398	0.283	0.672*
x5	G					1	0.971**	0.894**	-0.733**	-0.733**	0.840**	0.858**	0.486	0.743**	0.893**

	P					1	0.952**	0.874**	-0.693**	-0.680**	0.655*	0.776**	0.365	0.712**	0.843**
x6	G						1	0.891**	-0.615*	-0.642*	0.769**	0.760**	0.522	0.775**	0.888**
	P						1	0.880**	-0.582*	-0.602*	0.626*	0.698**	0.379	0.754**	0.849**
x7	G							1	-0.646*	-0.635*	0.629*	0.854**	0.586*	0.625*	0.993**
	P							1	-0.611*	-0.600*	0.522	0.791**	0.431	0.610*	0.962**
x8	G								1	0.977**	-0.723**	-0.824**	-0.423	-0.470	-0.618**
	P								1	0.912**	-0.557*	-0.739**	-0.270	-0.437	-0.565*
x9	G									1	-0.765**	-0.797**	-0.473	-0.491	-0.622*
	P									1	-0.607*	-0.712**	-0.313	-0.453	-0.563*
x10	G										1	0.769**	0.567*	0.417	0.631*
	P										1	0.613*	0.317	0.335	0.547
x11	G											1	0.517	0.529	0.857**
	P											1	0.347	0.476	0.778**
x12	G												1	0.137	0.535
	P												1	0.103	0.395
x13	G													1	0.616*
	P													1	0.580*
x14	G														1
	P														1

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

X_1: Plant height (cm), X_2: Number of leaves, X_3: Leaf length (cm), X_4: Leaf width (cm), X_5: Curd length X_6: Curd width (cm), X_7: Curd weight/plant (g), X_8:Days to curd initiation, X_9:Days to curd harvest, X_{10}:Curd dry matter, X_{11}:Leaf dry matter, X_{12}: Total carotenoids , X_{13}:Vitamin C, X_{14}: Yield

Table 2: Estimate of direct (diagonal) and indirect (off diagonal) effects of various traits towards yield in broccoli genotypes

Traits		**x1**	**x2**	**x3**	**x4**	**x5**	**x6**	**x7**	**x8**	**x9**	**x10**	**x11**	**x12**	**x13**	**x14**
x1	G	0.118	-0.068	0.045	-0.067	-0.010	0.006	-0.019	0.039	0.033	-0.041	-0.045	-0.048	0.067	-0.172
	P	0.024	-0.013	0.009	-0.012	-0.002	0.001	-0.004	0.007	0.006	-0.007	-0.008	-0.007	0.013	-0.160
x2	G	0.075	-0.130	-0.049	-0.107	-0.080	-0.074	-0.094	0.072	0.070	-0.075	-0.113	-0.089	-0.027	0.725
	P	0.001	-0.002	-0.001	-0.002	-0.001	-0.001	-0.002	0.001	0.001	-0.001	-0.002	-0.001	0.000	0.675
x3	G	-0.035	-0.034	-0.092	-0.047	-0.079	-0.081	-0.066	0.053	0.054	-0.054	-0.062	-0.025	-0.088	0.712
	P	-0.007	-0.007	-0.019	-0.010	-0.016	-0.016	-0.013	0.010	0.010	-0.009	-0.011	-0.004	-0.018	0.678
x4	G	-0.154	0.221	0.139	0.270	0.218	0.197	0.198	-0.210	-0.216	0.222	0.237	0.162	0.082	0.749
	P	-0.048	0.069	0.047	0.094	0.069	0.063	0.063	-0.062	-0.063	0.060	0.069	0.038	0.027	0.673
x5	G	-0.004	0.030	0.041	0.039	0.048	0.047	0.043	-0.035	-0.035	0.040	0.041	0.023	0.036	0.893
	P	0.001	-0.006	-0.009	-0.008	-0.011	-0.010	-0.010	0.008	0.007	-0.007	-0.009	-0.004	-0.008	0.844
x6	G	-0.012	-0.140	-0.218	-0.181	-0.241	-0.248	-0.221	0.152	0.159	-0.191	-0.189	-0.129	-0.192	0.889
	P	-0.004	-0.049	-0.078	-0.061	-0.086	-0.090	-0.080	0.053	0.055	-0.057	-0.063	-0.034	-0.068	0.849
x7	G	-0.188	0.826	0.816	0.833	1.019	1.016	1.139	-0.736	-0.723	0.717	0.974	0.668	0.712	0.994
	P	-0.149	0.674	0.696	0.661	0.864	0.870	0.988	-0.604	-0.593	0.517	0.782	0.426	0.603	0.962
x8	G	0.174	-0.293	-0.302	-0.410	-0.387	-0.325	-0.341	0.528	0.516	-0.382	-0.436	-0.224	-0.249	-0.619
	P	0.029	-0.048	-0.051	-0.064	-0.067	-0.056	-0.059	0.096	0.088	-0.054	-0.071	-0.026	-0.042	-0.566
x9	G	-0.096	0.184	0.203	0.273	0.251	0.220	0.217	-0.334	-0.342	0.262	0.273	0.162	0.168	-0.623
	P	0.004	-0.006	-0.008	-0.009	-0.009	-0.008	-0.008	0.012	0.014	-0.008	-0.010	-0.004	-0.006	-0.564
x10	G	-0.010	0.016	0.017	0.023	0.024	0.022	0.018	-0.021	-0.022	0.028	0.022	0.016	0.012	0.631
	P	-0.024	0.040	0.041	0.055	0.057	0.054	0.045	-0.048	-0.052	0.086	0.053	0.027	0.029	0.548
x11	G	-0.074	0.168	0.129	0.170	0.166	0.147	0.165	-0.159	-0.154	0.149	0.193	0.100	0.102	0.857
	P	-0.014	0.033	0.026	0.032	0.034	0.031	0.035	-0.032	-0.031	0.027	0.044	0.015	0.021	0.778
x12	G	0.033	-0.056	-0.022	-0.049	-0.040	-0.042	-0.048	0.034	0.038	-0.046	-0.042	-0.081	-0.011	0.536
	P	0.010	-0.018	-0.008	-0.014	-0.012	-0.013	-0.015	0.009	0.011	-0.011	-0.012	-0.034	-0.004	0.395
x13	G	0.003	0.001	0.006	0.002	0.004	0.005	0.004	-0.003	-0.003	0.002	0.003	0.001	0.006	0.617
	P	0.018	0.007	0.031	0.010	0.024	0.025	0.021	-0.015	-0.015	0.011	0.016	0.004	0.034	0.580

X_1: Plant height (cm), X_2: Number of leaves, X_3: Leaf length (cm), X_4: Leaf width (cm), X_5: Curd length X_6: Curd width (cm), X_7: Curd weight/plant (g), X_8:Days to curd initiation , X_9:Days to curd harvest, X_{10}:Curd dry matter, X_{11}:Leaf dry matter, X_{12}: Total carotenoids , X_{13}:Vitamin C, X_{14}: Yield

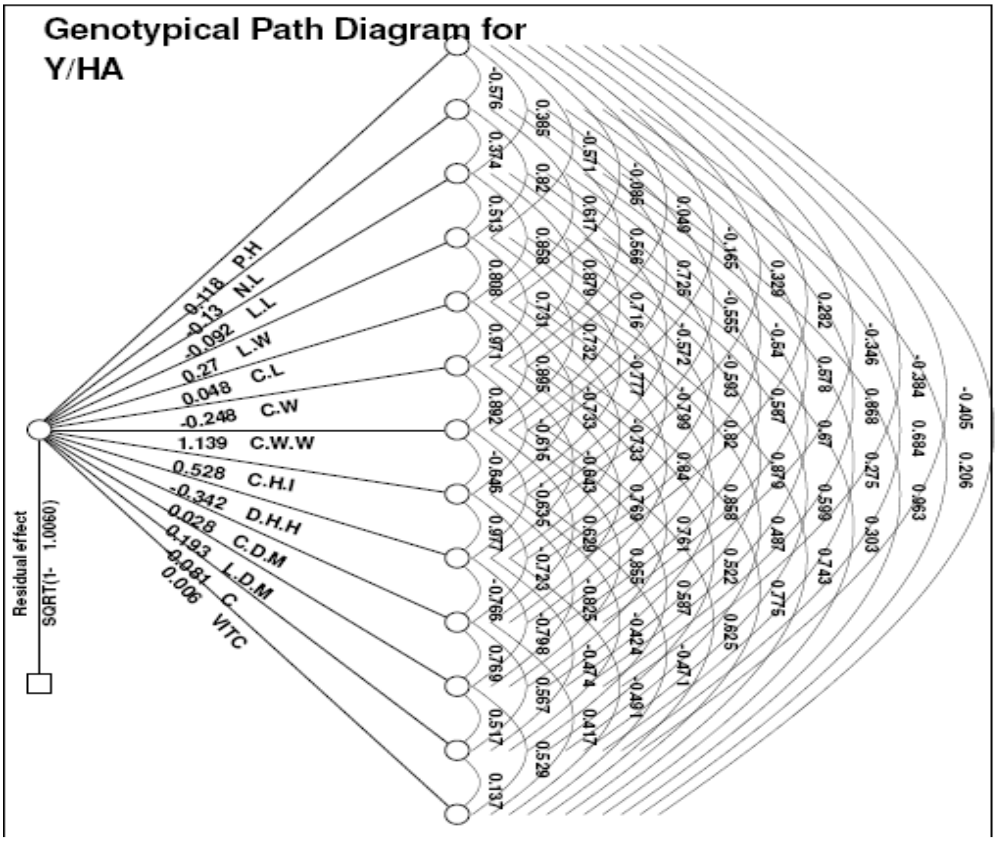

Fig 1: Genotypic path coefficient analysis for different traits

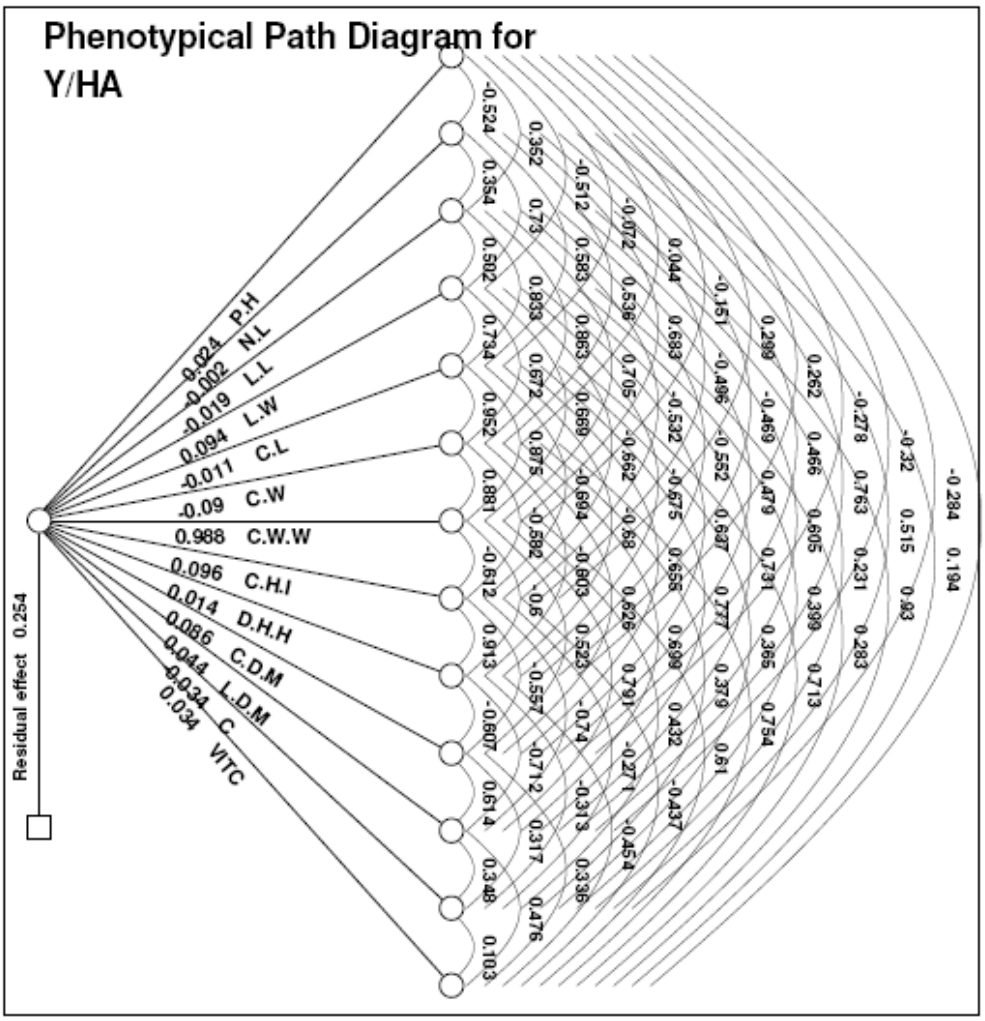

Fig 2: Phenotypic path coefficient analysis for different traits

Conclusion

Estimates of phenotypic and genotypic correlation for curd yield was found to be significantly and positive for curd weight/plant, curd width, curd length, leaf dry matter%, leaf length, number of leaves, leaf width. Path coefficient analysis revealed that curd yield per hectare revealed highest positive direct effect with curd weight/plant, days to curd initiation, leaf width, curd length, curd dry matter, leaf dry matter and Vitamin C. Hence it could be concluded that these parameters could be considered while selection for yield improvement in broccoli.

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