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Correlation and path coefficient analysis studies in mid-season cauliflower (*Brassica oleracea* var. *botrytis* L.)

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Abstract
The present study was undertaken at Vegetable Research Center, G.B. Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar (U.K.) during September- December, 2015. Fifty seven genotypes of cauliflower were grown in Augmented Block Design II including five checks which were arranged in four blocks with eighteen genotypes in each block inclusive of five checks. The study was primarily focused on assessing correlation coefficient and path coefficient analysis. The genotypic correlation coefficient was higher than the corresponding phenotypic correlation coefficient for all the parameters. Estimates of phenotypic and genotypic correlation revealed curd yield per hectare to be highly positive and significantly correlated with marketable curd weight, net curd weight, curd diameter, number of leaves per plant and gross plant weight. Path coefficient analysis revealed net curd weight having a high positive direct effect towards the total yield while harvest index exerting a negative direct effect on curd yield per hectare.

Keywords: Genotypic correlation, phenotypic correlation, path coefficient analysis, curd yield, cauliflower

Introduction
Cauliflower (*Brassica oleracea* var. *botrytis* L., 2n = 2x = 18) is an important vegetable crop cultivated throughout India (Singh *et al*., 2005) [17]. The highly suppressed pre-floral apical meristem commonly known as 'curd' is the edible part (Sidki, 1962) [16]. For a good cauliflower crop, high yield, compact, white colour and medium-sized curds free from any diseases or disorders, are desired (Varalaxmi, 2009) [20]. Cauliflower is thought to have been domesticated in the Mediterranean region, since the greatest range of variability is found in cauliflower (Horne, 1954) [5]. It was originated from *Brassica oleracea* var. *sylvestris*, a wild ancestor found in Mediterranean areas. The *Brassica oleracea* cytodeme is a polymorphic aggregate species with chromosome number, 2n=18. Cauliflower is a monogenomic species having genomic constitution C and chromosome number, n=9. It belongs to the Order Cruciferae, Tribe Brassicae, Sub-Tribe Brassica under the family Brassicaceae (Hazra *et al*., 2011) [4]. Cauliflower contains vitamins to the tune of 70 IU vitamin A, 56 mg/100 g vitamin B and 75mg/100g vitamin C. Among the minerals, it constitutes of 0.35 per cent Ca, 0.76 per cent P, 3.58 per cent K, 117mg Fe and 36 mg Cu. Besides vitamins and minerals cauliflower also contains 2.4 per cent protein, 4.9 per cent total carbohydrate, 0.2 per cent fat and 91.7 per cent water (Brown and Hutchison, 1949) [1]. In addition, cauliflower is fairly a high source of glucosinolates (40-80 mg/100g) predominantly sinigrin and glucobrassicin which have predominantly anti-carcinogenic property. The temperate or Snowball types behave like biennial crop which require 6-8 weeks of vernalization at mean temperature range of 4º to 8º C after they have passed the initial curding phase for the production of seed stalks (Hazra *et al*., 2011) [4]. The present study was undertaken to study correlation and path analysis of economically important traits in mid-season cauliflower which are helpful in ascertaining the real components of yield which is a complex character. The correlation coefficients indicate the degree of relationship between characters but it alone does not give clear picture of association between the characters. Furthermore, the success in selection is also directly proportional to the amount of genetic advance obtained in a generation.

Materials and methods
The present investigation was conducted at Vegetable Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar (Uttarakhand) during 2015-2016. The experimental material comprised of fifty two genotypes and five checks. The experiment was laid out in Augmented Block Design with four blocks at Vegetable Research Centre, G.B. Pant

University of Agriculture and Technology. Observations were recorded for sixteen quantitative characters *viz*., leaf length (cm), leaf width (cm), Petiole length (cm), plant height (cm), plant spread (cm), number of leaves per plant, stalk length (cm), days to curd maturity, gross plant weight (g), marketable curd weight (g), net curd weight (g), curd length (cm), curd breadth (cm), harvest index (%), curd sixe index (cm^2) and curd yield per hectare (q/ha).). Searle's (1961) [14] formula was used to estimate the correlation coefficients. The path coefficient analysis of component traits with fruit yield was done by method of Dewey and Lu (1959) [3].

Results and Discussion

Correlation among different traits is of vital importance to know their association, as yield is an important outcome of many correlated characters. Thus it becomes necessary to study the association for effective selection. The estimates of both phenotypic and genotypic correlation coefficient for various characters are given in Table 1 and Figure 1 & 2.

In the present investigation leaf length was significantly and positively correlated with leaf width, gross plant weight, marketable curd weigh, plant spread, curd yield, plant height, petiole length, net curd weight, curd breadth, number of leaves and curd size index, while leaf length had a significant negative correlation with harvest index. Plant height shows a positive and significant correlation with gross plant weight, curd yield, marketable curd weight, plant spread, number of leaves, net curd weight and curd breadth, while negative and significantly correlated with harvest index. Plant spread had significant and positive correlation with gross plant weight, marketable curd weight, curd yield, net curd weight, curd breadth, curd size index and number of leaves, whereas negative but significant correlation with harvest index. Number of leaves per plant varies positively and significantly with gross plant weight, marketable curd weight, curd yield and net curd weight and negatively but significantly correlated with curd length. Stalk length was positively and significantly correlated with curd size index and curd length.

Gross plant weight had a positive and significant correlation with marketable curd weight, curd yield, net curd weight, curd breadth and curd size index, while a significant but negative correlation with harvest index. Marketable curd weight is correlated positively and significantly with curd yield, net curd weight and curd breadth. Also, marketable curd weight is correlated negatively and significantly with harvest index. Net curd weight is significantly and positively correlated with curd yield and curd breadth. Curd length is significantly and positively correlated with curd size index while non-significantly with curd breadth. It is significantly and negatively correlated with harvest index. Curd breadth establishes a positive and significant correlation with curd yield and curd size index. Harvest index is negative and significantly correlated with curd size index with curd yield.

The genotypic correlation coefficient is higher than the corresponding phenotypic correlation coefficient for all the parameters as reported by Meena *et al*. (2011) [10]. Thus, these traits may be effectively be used as a selection criterion for screening potential genotypes in a breeding programme.

Santhosha *et al*. (2015) [13] also reported high significant positive association of marketable curd weight with plant weight, leaf number, leaf length, leaf breadth, leaf weight, curd diameter, curd size, net curd weight, net plot yield and yield per hectare at both genotypic and phenotypic levels. Curd yield per hectare was highly positive and significantly correlated with marketable curd weight, net curd weight, curd diameter, number of leaves per plant and gross plant weight as reported by Chittora and Singh (2014) [2]. Highly significantly and positively correlation of curd yield with the ancillary characters *viz*., curd diameter, weight of curd, plant height was also reported by Singh *et al*. (2014) [18]. Significant and positive correlation of net curd weight with gross curd weight was also reported by Kanwar and Korla (2002) [6], Nimkar and Korla (2008) [12], Kumar *et al*. (2005) [7], Sheemar *et al*. (2012) [15] and Nimkar (2013) [11]. Kumar *et al*. (2010) [8] and Kumar *et al*. (2011) [9] observed yield to be positive and significantly correlated with net curd weight.

For clear and vivid understanding of the factors contributing towards curd yield per hectare the estimation of indirect and direct effects were calculated using path coefficient analysis. Path coefficient analysis 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 therefore, 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 3 & 4.

A critical examination of path-coefficient analysis, at genotypic and phenotypic level revealed maximum direct effect on curd yield per hectare mediated through marketable curd weight followed by leaf length, curd size index. Positive direct effect on curd yield per hectare was also observed with net curd weight, curd breadth, days to maturity and plant spread. While maximum negative direct effect was exerted by leaf width followed by curd length. Negative direct effect on curd yield per hectare was also contributed through gross plant weight, petiole length, plant height, harvest index, number of leaves per plant and stalk length.

Plant height had a positive indirect effect on curd yield per hectare through harvest index, stalk length and curd length, whereas maximum negative indirect effect on curd yield per hectare was imposed via gross plant weight, marketable curd weight, plant spread, leaf length, petiole length, number of leaves, net curd weight, leaf width, curd breadth, curd size index, days to maturity. Number of leaves per plant imposes a positive indirect effect on curd yield per hectare via curd length, harvest index, stalk length, days to maturity and curd size index, while maximum negative indirect effect on curd yield per hectare was imposed through gross plant weight, plant height, marketable curd weight, leaf length, plant spread, net curd weight, leaf width, curd breadth and petiole length. Days to maturity was observed to have a positive indirect effect on curd yield per hectare through petiole length, leaf width, plant height, harvest index and leaf length, whereas stalk length, curd size index, curd length, gross plant weight, net curd weight, number of leaves, marketable curd weight, plant spread and curd breadth had a maximum negative indirect effect on curd yield per hectare. The character gross plant weight imposes a positive indirect effect on curd yield per hectare via harvest index and days to maturity, whereas marketable curd weight, plant height, net curd weight, plant spread, leaf length, curd breadth, leaf width, number of leaves, petiole length, curd size index, stalk length and curd length had a maximum negative indirect effect on curd yield per hectare.

Net curd weight had a positive indirect effect on curd yield per hectare mediated through marketable curd weight, gross plant weight, curd breadth, plant spread, leaf length, plant height, leaf width, petiole length, number of leaves, harvest index, curd size index and stalk length, whereas days to

maturity and curd length laid a maximum negative indirect effect on curd yield per hectare. Curd length imposes a positive indirect effect on curd yield per hectare via harvest index, stalk length, plant spread, leaf width, curd breadth, leaf length, gross plant weight and petiole length while maximum negative indirect effect on curd yield per hectare was imposed through curd size index, number of leaves, days to maturity, net curd weight, marketable curd weight and plant height. Positive indirect of Curd breadth on curd yield per hectare was noticed via marketable curd weight, gross plant weight, net curd weight, curd size index, plant spread, leaf length, leaf width, plant height, petiole length, number of leaves, curd length and stalk length, while maximum negative indirect effect on curd yield per hectare was imposed via harvest index and days to maturity. There exists a positive indirect effect of harvest index on curd yield per hectare mediated through gross plant weight, plant height, leaf length, plant spread, leaf width, curd size index, curd length, marketable curd weight, petiole length, number of leaves, curd breadth and stalk length, whereas net curd weight and days to maturity laid a maximum negative indirect effect on curd yield per hectare. Curd size index was observed to have a positive indirect effect on curd yield per hectare through harvest index, days to maturity and number of leaves, whereas curd length, curd breadth, plant spread, stalk length, gross plant weight, leaf length, leaf width, marketable curd weight, net curd weight, petiole length and plant height had a maximum negative indirect effect on curd yield per hectare.

Path coefficient analysis by Kumar *et al*. (2010) [8] and Kumar *et al*. (2011) [9] revealed that net curd weight had high positive direct effect towards the total yield while harvest index exerts a negative direct effect on curd yield per hectare. Similar to the above findings Soni *et al*. (2013)[19] also observed that at phenotypic level head weight and plant spread exhibit a high order direct effect on curd yield whereas at genotypic level, head weight and leaf length retains a high order direct effect on curd yield. Nimkar (2013) [11], Sheemar *et al*. (2012) [15] and Kumar *et al*. (2011) [9] reported high direct effect on net curd weight by marketable curd weight which further supports the findings.

Table 1: Correlation coefficient between different characters at phenotypic and genotypic level

Character	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Plant height (cm)	Plant spread (cm)	Number of leaves per plant	Stalk length (cm)	Days to maturity	Gross plant weight (g)	Marketable curd weight (g)	Net curd weight (g)	Curd length (cm)	Curd breadth (cm)	Harvest index	Curd size index (cm²)	Curd yield (q/ha.)
Leaf length (cm) P	1															
G	1															
Leaf width (cm) P	0.847**	1														
G	0.894**	1														
Petiole length (cm) P	0.549**	0.261**	1													
G	0.571**	0.269**	1													
Plant height (cm) P	0.595**	0.395**	0.522**	1												
G	0.628**	0.401**	0.532**	1												
Plant spread (cm) P	0.627**	0.569**	0.345**	0.623**	1											
G	0.669**	0.571**	0.350**	0.640**	1											
No. of leaves per plant P	0.320**	0.226*	0.120	0.445**	0.299*	1										
G	0.356**	0.223*	0.135	0.475**	0.295	1										
Stalk length (cm) P	0.227	0.209	0.081	-0.075	0.153	-0.187	1									
G	0.236	0.209	0.080	-0.079	0.152	-0.195	1									
Days to maturity P	0.023	0.011	0.128	-0.004	-0.134	-0.123	-0.373	1								
G	0.004	0.025	0.117	0.017	-0.143	-0.163	-0.429	1								
Gross plant weight (g) P	0.676**	0.544**	0.473**	0.710**	0.681**	0.459**	0.081	-0.170	1							
G	0.696**	0.555**	0.472**	0.723**	0.698**	0.481**	0.082	-0.203	1							
Marketable curd wt. (g) P	0.633**	0.516**	0.383**	0.632**	0.597**	0.455**	-0.026	-0.124	0.897**	1						
G	0.644**	0.532**	0.390**	0.654**	0.613**	0.467**	-0.024	-0.154	0.910**	1						
Net curd weight (g) P	0.461**	0.352**	0.331**	0.402**	0.508**	0.278**	0.017	-0.178	0.714**	0.798**	1					
G	0.465**	0.358**	0.336**	0.412**	0.518**	0.294**	0.020	-0.199	0.722**	0.806**	1					
Curd length (cm) P	0.067	0.098	0.007	-0.062	0.224	-0.269*	0.346*	-0.216	0.061	-0.115	-0.121	1				
G	0.082	0.093	0.002	-0.064	0.223	-0.283*	0.347*	-0.253	0.060	-0.112	-0.120	1				
Curd breadth (cm) P	0.458**	0.387**	0.241*	0.334**	0.504**	0.187*	0.061	-0.094	0.661**	0.689**	0.634**	0.075	1			
G	0.486**	0.397**	0.241*	0.355**	0.499**	0.200*	0.062	-0.086	0.682**	0.704**	0.647**	0.074	1			
Harvest index P	-0.432**	-0.393**	-0.270	-0.485**	-0.393**	-0.218	-0.071	0.015	-0.502**	-0.277*	0.178	-0.283*	-0.184	1		
G	-0.438**	-0.405**	-0.273	-0.494**	-0.403**	-0.234	-0.072	0.014	-0.507**	-0.276*	0.181	-0.289*	-0.185	1		
Curd size index (cm²) P	0.250*	0.239	0.091	0.071	0.397**	-0.151	0.347**	-0.240	0.344*	0.211	0.180	0.879**	0.524**	-0.310*	1	
G	0.260*	0.248	0.093	0.073	0.414**	-0.149	0.351**	-0.269	0.349*	0.212	0.180	0.886**	0.543**	-0.308*	1	
Curd yield (q/ha.) p	0.623**	0.512**	0.384**	0.634**	0.594**	0.455**	-0.025	-0.127	0.894**	0.995**	0.795**	-0.117	0.683**	-0.275*	0.209	1
G	0.667**	0.534**	0.391**	0.650**	0.617**	0.472**	-0.026	-0.143	0.914**	1.000**	0.812**	-0.119	0.713**	-0.280*	0.206	1

Table 2: Estimates of direct and indirect effect of different characters on marketable yield at phenotypic and genotypic level in cauliflower

Character	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Plant height (cm)	Plant spread (cm)	Number of leaves per plant	Stalk length (cm)	Days to maturity	Gross plant weight (g)	Marketable curd weight (g)	Net curd weight (g)	Curd length (cm)	Curd breadth (cm)	Harvest index	Curd size index (cm²)
Leaf length (cm) P	-0.0665	-0.0563	-0.0365	-0.0395	-0.0417	-0.0213	-0.0151	-0.0015	-0.0449	-0.0421	-0.0307	-0.0044	-0.0305	0.0287	-0.0166
G	0.4565	0.4080	0.2608	0.2866	0.3051	0.1627	0.1079	0.0018	0.3177	0.2941	0.2122	0.0375	0.2219	-0.2000	0.1188
Leaf width (cm) P	0.0402	0.0474	0.0124	0.0187	0.0270	0.0107	0.0099	0.0005	0.0258	0.0245	0.0167	0.0046	0.0184	-0.0186	0.0113
G	-0.3177	-0.3554	-0.0955	-0.1423	-0.2028	-0.0792	-0.0742	-0.0087	-0.1972	-0.1890	-0.1274	-0.0331	-0.1412	0.1440	-0.0881
Petiole length (cm) P	0.0118	0.0056	0.0215	0.0112	0.0074	0.0026	0.0017	0.0027	0.0102	0.0082	0.0071	0.0001	0.0052	-0.0058	0.0019
G	-0.0716	-0.0337	-0.1253	-0.0666	-0.0438	-0.0169	-0.0100	-0.0146	-0.0592	-0.0488	-0.0421	-0.0003	-0.0302	0.0342	-0.0116
Plant height (cm) P	0.0147	0.0097	0.0129	0.0247	0.0154	0.0110	-0.0018	-0.0001	0.0175	0.0156	0.0099	-0.0015	0.0082	-0.0120	0.0017
G	-0.0784	-0.0500	-0.0664	-0.1249	-0.0799	-0.0593	0.0099	-0.0021	-0.0903	-0.0817	-0.0515	0.0080	-0.0443	0.0616	-0.0091
Plant spread (cm) P	-0.0002	-0.0001	-0.0001	-0.0002	-0.0002	-0.0001	0.0000	0.0000	-0.0002	-0.0001	-0.0001	-0.0001	-0.0001	0.0001	-0.0001
G	0.0044	0.0037	0.0023	0.0042	0.0066	0.0019	0.0010	-0.0009	0.0046	0.0040	0.0034	0.0015	0.0033	-0.0026	0.0027
No. of leaves/plant P	0.0014	0.0010	0.0005	0.0020	0.0013	0.0045	-0.0008	-0.0006	0.0021	0.0020	0.0012	-0.0012	0.0008	-0.0010	-0.0007
G	-0.0130	-0.0081	-0.0049	-0.0173	-0.0107	-0.0364	0.0071	0.0059	-0.0175	-0.0170	-0.0107	0.0103	-0.0073	0.0085	0.0054
Stalk length (cm) P	0.0004	0.0004	0.0001	-0.0001	0.0003	-0.0003	0.0017	-0.0006	0.0001	0.0000	0.0000	0.0006	0.0001	-0.0001	0.0006
G	-0.0039	-0.0034	-0.0013	0.0013	-0.0025	0.0032	-0.0165	0.0071	-0.0014	0.0004	-0.0003	-0.0057	-0.0010	0.0012	-0.0058
Days to maturity P	0.0000	0.0000	-0.0002	0.0000	0.0002	0.0002	0.0005	-0.0013	0.0002	0.0002	0.0002	0.0003	0.0001	0.0000	0.0003
G	0.0001	0.0004	0.0019	0.0003	-0.0023	-0.0026	-0.0069	0.0161	-0.0033	-0.0025	-0.0032	-0.0041	-0.0014	0.0002	-0.0043
Gross plant wt. (g) P	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0000	0.0002	0.0002	0.0001	0.0000	0.0001	-0.0001	0.0001
G	-0.0977	-0.0778	-0.0663	-0.1014	-0.0979	-0.0675	-0.0116	0.0285	-0.1403	-0.1277	-0.1013	-0.0085	-0.0956	0.0711	-0.0489
Marketable curd wt. (g) P	0.6271	0.5106	0.3794	0.6254	0.5906	0.4507	-0.0257	-0.1230	0.8885	0.9901	0.7901	-0.1140	0.6818	-0.2744	0.2091
G	0.7081	0.5844	0.4281	0.7190	0.6742	0.5136	-0.0264	-0.1690	1.0004	1.0991	0.8856	-0.1228	0.7736	-0.3032	0.2335
Net curd weight (g) P	0.0007	0.0005	0.0005	0.0006	0.0008	0.0004	0.0000	-0.0003	0.0011	0.0012	0.0015	-0.0002	0.0010	0.0003	0.0003
G	0.0403	0.0311	0.0291	0.0357	0.0448	0.0255	0.0017	-0.0173	0.0626	0.0698	0.0866	-0.0104	0.0561	0.0157	0.0156
Curd length (cm) P	-0.0098	-0.0143	-0.0010	0.0090	-0.0329	0.0394	-0.0506	0.0316	-0.0090	0.0169	0.0178	-0.1465	-0.0109	0.0415	-0.1288
G	0.0143	0.0162	0.0004	-0.0111	0.0387	-0.0493	0.0603	-0.0441	0.0105	-0.0194	-0.0210	0.1740	0.0128	-0.0502	0.1542
Curd breadth (cm) P	-0.0375	-0.0317	-0.0197	-0.0273	-0.0412	-0.0153	-0.0050	0.0077	-0.0541	-0.0563	-0.0518	-0.0061	-0.0818	0.0150	-0.0429
G	0.0339	0.0277	0.0168	0.0247	0.0347	0.0139	0.0043	-0.0060	0.0475	0.0490	0.0451	0.0051	0.0696	-0.0129	0.0378
Harvest index P	-0.0025	-0.0023	-0.0016	-0.0029	-0.0023	-0.0013	-0.0004	0.0001	-0.0030	-0.0016	0.0010	-0.0017	-0.0011	0.0059	-0.0018
G	0.0519	0.0480	0.0323	0.0585	0.0477	0.0277	0.0086	-0.0016	0.0600	0.0327	-0.0215	0.0342	0.0219	-0.1184	0.0365
Curd size index (cm²) P	0.0435	0.0416	0.0158	0.0123	0.0690	-0.0262	0.0604	-0.0419	0.0600	0.0368	0.0314	0.1531	0.0913	-0.0539	0.1741
G	-0.0600	-0.0571	-0.0213	-0.0167	-0.0953	0.0344	-0.0809	0.0619	-0.0803	-0.0489	-0.0415	-0.2042	-0.1251	0.0710	-0.2304
Curd yield (q/ha.) P	0.6234	0.5122	0.3842	0.6341	0.5937	0.4551	-0.0253	-0.1266	0.8944	0.9953	0.7946	-0.1169	0.6826	-0.2745	0.2086
G	0.6671	0.5339	0.3907	0.6498	0.6166	0.4717	-0.0256	-0.1431	0.9138	1.0141	0.8124	-0.1185	0.7130	-0.2797	0.2064
Partilal R^2 P	-0.0415	0.0243	0.0083	0.0156	-0.0001	0.0020	0.0000	0.0002	0.0002	0.9854	0.0012	0.0171	-0.0558	-0.0016	0.0363
G	0.3045	-0.1897	-0.0490	-0.0812	0.0040	-0.0172	0.0004	-0.0023	-0.1282	1.1146	0.0704	-0.0206	0.0497	0.0331	-0.0475

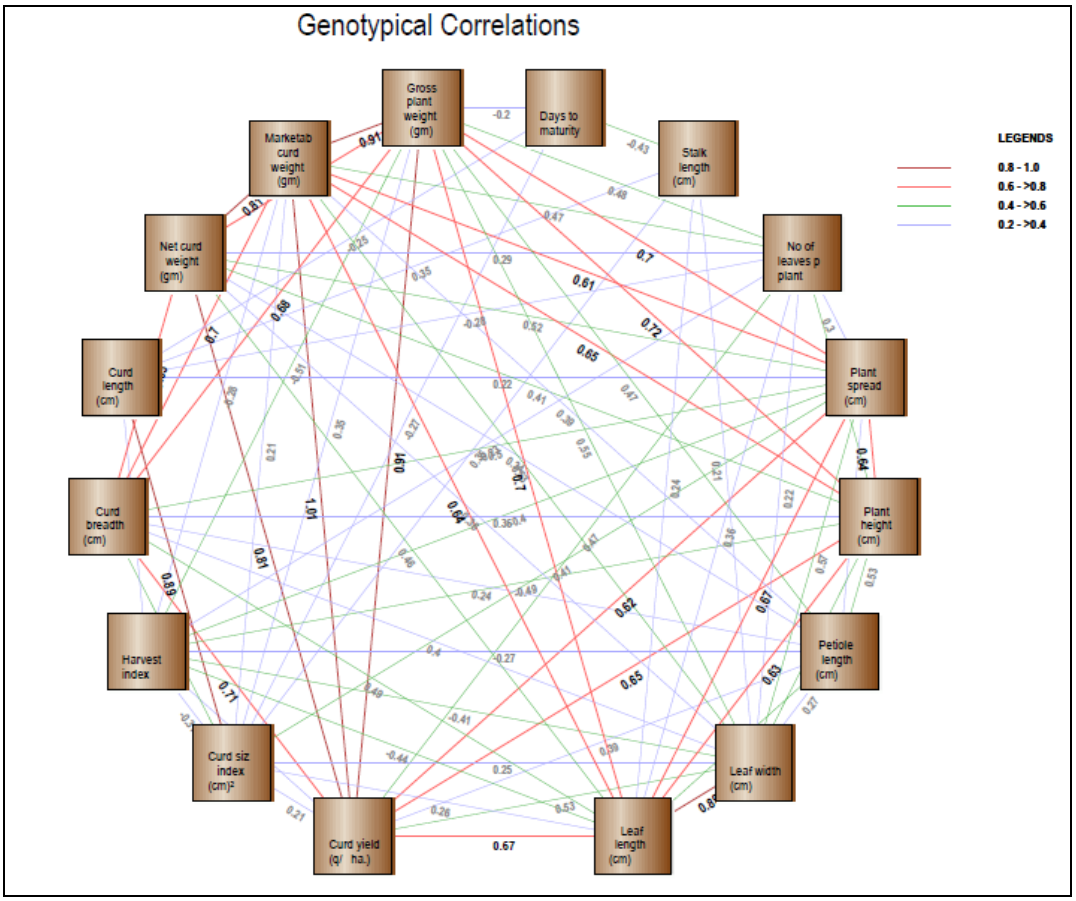

Fig 1: Genotypic correlation coefficient among characters

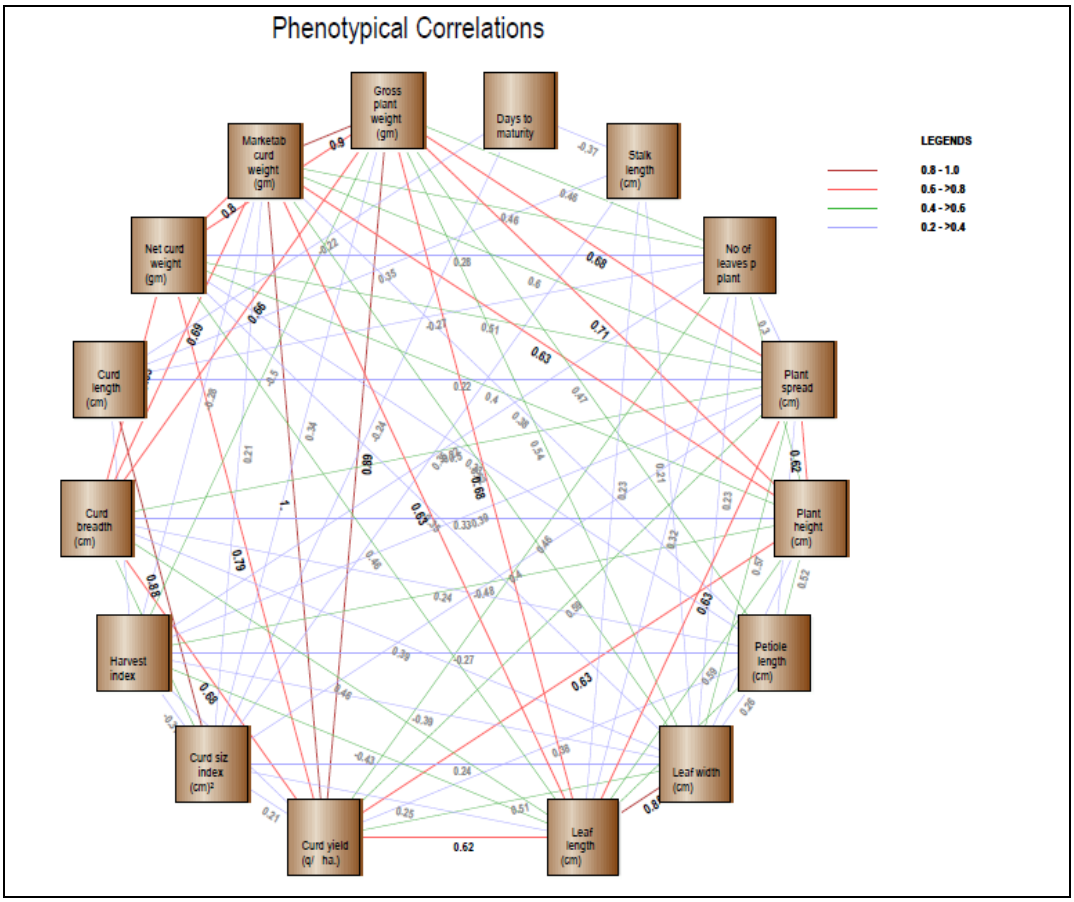

Fig 2: Phenotypic correlation coefficient among characters

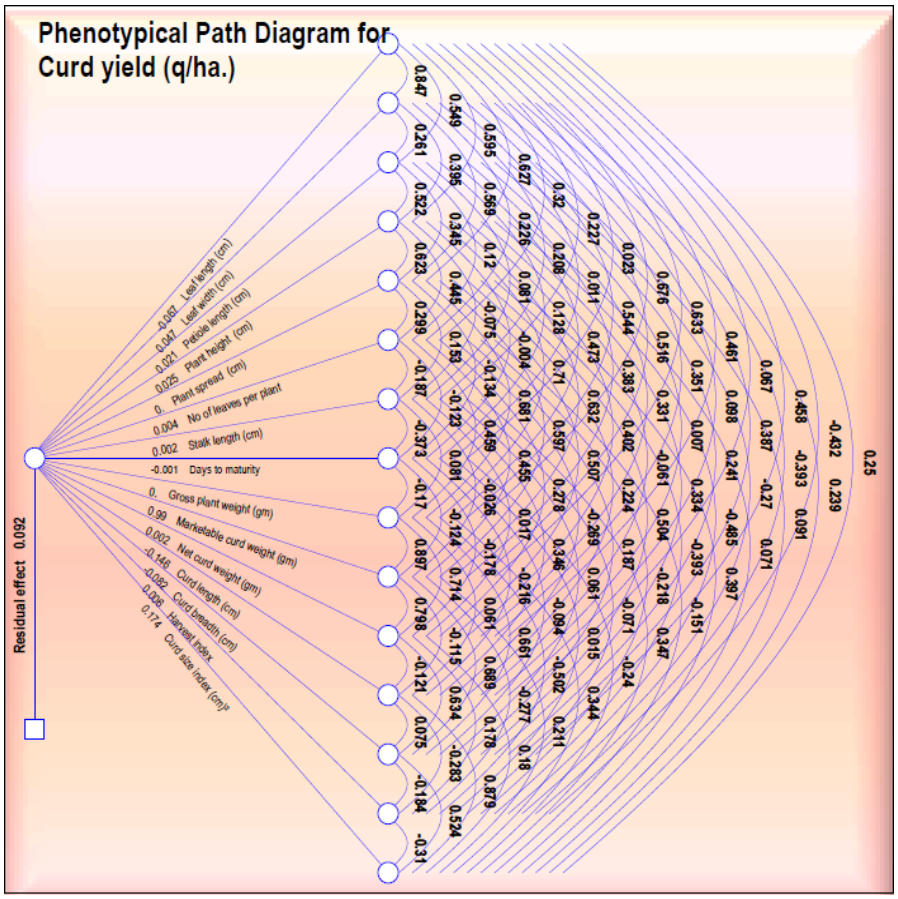

Fig 3: Phenotypic path coefficient analysis for different traits

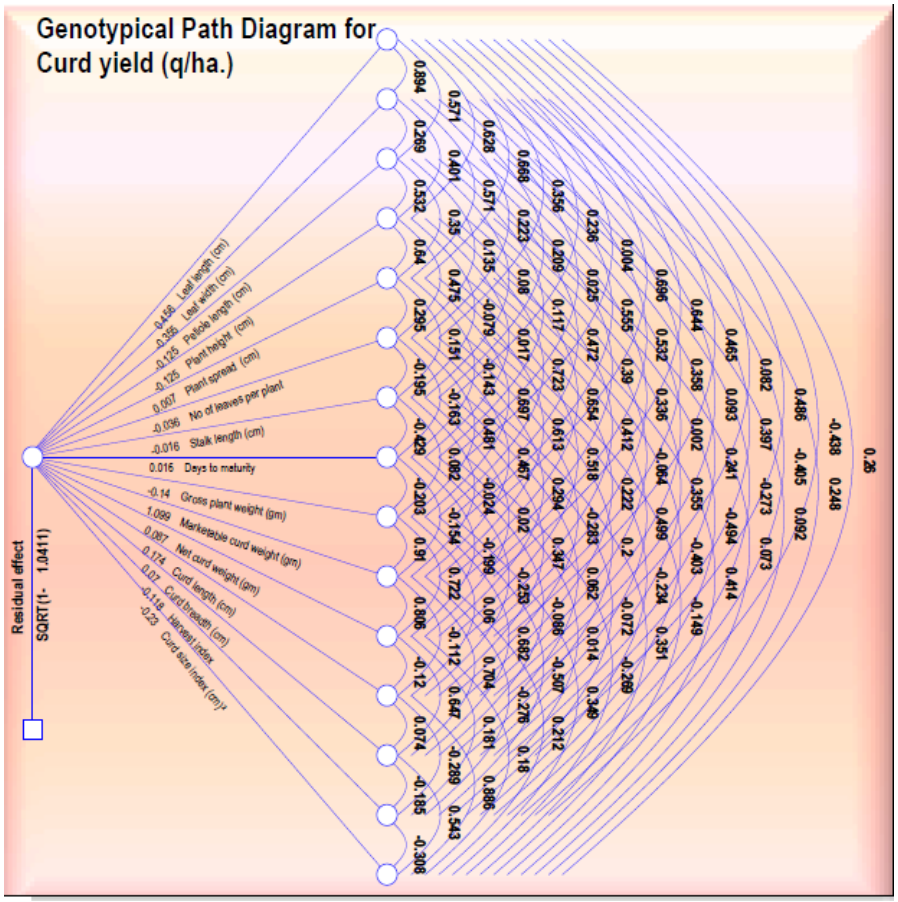

Fig 4: Genotypic path coefficient analysis for different traits

Conclusion

Estimates of phenotypic and genotypic correlation revealed curd yield per hectare to be highly positive and significantly correlated with marketable curd weight, net curd weight, curd diameter, number of leaves per plant and gross plant weight and Path coefficient analysis revealed net curd weight having a high positive direct effect towards the total yield while harvest index exerting a negative direct effect on curd yield per hectare, so it could be concluded that these parameters could be considered for the development of elite hybrids via heterosis breeding or for the development of inbred lines followings pure line selection in succeeding generations.

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