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Path analysis and quality characters in cauliflower

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Abstract
The present investigation entitled "Path analysis and quality characters in cauliflower (*Brassica oleracea var. botrytis* L.)" was conducted at Horticulture Complex, Department of Horticulture, College of Agriculture JNKVV, Jabalpur (M.P.) during the year 2016-17. In the present study total plant weight, core length, curd circumference, net curd weight, days to curd initiation, number of leaves per plant at 45 DAT, days to harvest, stalk length at 45 DAT had high positive direct effect on curd yield per plant of these traits may rewarded in other words these traits showed given importance, while practicing selection aimed at improvement of yield in cauliflower. However days to 50% curd formation, curd width and curd length had the highest negative direct effect on curd yield per plant. Path coefficient analysis of different characters contributing towards curd yield per plant showed that total plant weight (0.7553) had highest positive direct effect followed by core length (0.1223), curd circumference (0.1135), net curd weight (0.0233), days to curd initiation (0.0227), number of leaves per plant at 45 DAT (0.0227), days to harvest (0.0200), stalk length at 45 DAT (0.0056).

Keywords: Path analysis, Qualitative characters, Direct effects, Improvement

1. Introduction
Cauliflower (*Brassica oleracea var. botrytis* L.) commonly known as "phoolgobhi" is the most popular vegetable introduced in India in 1822 by Dr. Jemson, who was the In-charge of Botanical Garden, Saharanpur, Uttar Pradesh (Nath *et al*., 1994) [12]. The original introduction were Cornish type which originated in England, followed by temperate types, originated in Germany and Netherland in 18th Century (Swarup and Chatterjee, 1972)[19]. India is the second largest producer of cauliflower in the world**.** Area under cauliflower in India is 433.9 thousand hectare with production of 8573.3 thousand metric tonnes and productivity is 19.8 tonnes/ha. It is grown in 25.1 thousand hectare area in Madhya Pradesh with a total annual production of 703.8 thousand metric tonnes and with productivity 28.1 metric tonnes/hectare (Anon, 2014) [2]. The important cauliflower growing states are West Bengal, Bihar, Haryana, Gujarat, Assam, Uttar Pradesh, Rajasthan, Karnataka and Tamilnadu. The edible part of cauliflower botanically known as prefloral fleshy apical meristem or flowering primordial or immature inflorescence and is also called as curd (Sidki, 1962) [16]. Cauliflower contains vitamins to the tune of 70 IU vitamin A, 50 mg/100 g vitamin B and 75 mg/100 g vitamin C and among minerals, 0.73 per cent Ca, 0.38 per cent P, 2.71 per cent K, 205 ppm Iron and 15 ppm Cu. Besides vitamins and minerals, cauliflower also contains 2.47 per cent protein, 4.8 per cent total carbohydrate, 0.2 per cent fat and 91.7 per cent water. According to Boswell (1949)[3] cauliflower is originated in the Iceland of Cyprus from where it moved to other areas like Syria, Turkey, Egypt, Spain and North Western Europe. According to Allard (1960) [1] cabbage, cauliflower, broccoli, Brussels sprout and other varieties of oleracea have been reported morphologically on the basis of few gene differences. The varieties of *B. oleracea* have same chromosome number (n=9). *Brassica oleracea* is a triple tetrasomic with the genomic formula ABBCCDEEF with 6 basic genomes and showing some secondary pairing (Gerhard, 1960) [6].

Studies on genetic variability with the help of suitable biometrical tools such as coefficient of variability and heritability become indispensable in breeding programmes for tangible results of desired values. To give a better insight of ancillary characters under selection, path coefficient analysis is one of the tools, which is being effectively used for determining the rate of various yield components in different crops, leading to the selection of superior genotypes.

2. Materials and Methods

The present investigation on **"**Path analysis and quality characters in cauliflower**"** was conduct at Horticulture complex, Department of Horticulture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) during the year 2016-17. The experimental material includes 30 genotypes with two checks of the cauliflower collected from different states of India. The experiment was laid out in Randomized Complete Block Design with three replications and each replication consisted of thirty two genotypes. All the genotypes were randomized separately in each replication.

Table 1: Details of genotypes used in study

S. No.	Treatment	Symbol	Source	S. No.	Treatment	Symbol	Source
1.	JBOB-1	T1	IIVR,VARANASI	17.	JBOB-17	T17	IIVR,VARANASI
2.	JBOB-2	T2	IIVR,VARANASI	18.	JBOB-18	T18	IIVR,VARANASI
3.	JBOB-3	T3	IIVR,VARANASI	19.	JBOB-19	T19	IIVR,VARANASI
4.	JBOB-4	T4	IIVR,VARANASI	20.	JBOB-20	T20	IIVR,VARANASI
5.	JBOB-5	T5	IIVR,VARANASI	21.	JBOB-21	T21	IIVR,VARANASI
6.	JBOB-6	T6	IIVR,VARANASI	22.	JBOB-22	T22	IIVR,VARANASI
7.	JBOB-7	T7	IIVR,VARANASI	23.	JBOB-23	T23	IIVR,VARANASI
8.	JBOB-8	T8	IIVR,VARANASI	24.	JBOB-24	T24	IIVR,VARANASI
9.	JBOB-9	T9	IIVR,VARANASI	25.	JBOB- 25	T25	IIVR,VARANASI
10.	JBOB-10	T10	IIVR,VARANASI	26.	JBOB-26	T26	IIVR,VARANASI
11.	JBOB-11	T11	IIVR,VARANASI	27.	JBOB-27	T27	IIVR,VARANASI
12.	JBOB-12	T12	IIVR,VARANASI	28.	JBOB-28	T28	IIVR,VARANASI
13.	JBOB-13	T13	IIVR,VARANASI	29.	JBOB-29	T29	IIVR,VARANASI
14.	JBOB-14	T14	IIVR,VARANASI	30.	JBOB-30	T30	IIVR,VARANASI
15.	JBOB-15	T15	IIVR,VARANASI	31.	Pusa sharad (C)	T31	IIVR,VARANASI
16.	JBOB-16	T16	IIVR,VARANASI	32.	PH-2 (C)	T32	IIVR,VARANASI

2.1 Path coefficients analysis

Path coefficients analysis was worked out to show the cause and effect relationship between yield and various yield components and to partition the total correlation coefficient into direct and indirect effects. This procedure was developed by Wright (1921) [20] and as per consent used by Li (1956) [11] and followed by Dewey and Lu (1959) [5]. Path coefficients are the standardized partial regression coefficients and as such measure the direct influence of one variable upon anotherrariable and permits partition of correlation coefficient into components of direct and indirect effects. The sum of the direct and all possible indirect effects via all other traits must be equal to correlation coefficient of dependent traits with independent characters under consideration. The analysis of variance was carried out as per methods suggested by Panse and Sukhatme (1985) [13].

Path coefficients were obtained by setting simultaneous equations which express basic relationship between correlation and path coefficient analysis.

1. r1, y = P1,y + r 1, 2 P2,y +r 1,2 P 1yt +……..……+ r 1, 10 P10,y
2. r2, y = P2,y + r 2, 1 P1,y +r 2,2 P 3yt +……...…+ r 2, 10 P10,y
10. r10, y = P10,y + r 10, 1 P1,y +r 10,2 P 3yt +…….……..…+ r 10, 9 P9,y

Where,

1, 2, 10 are the component characters and y is dependent upon which direct and indirect effects are studied.

Unexplained variation of the residual effect was obtained from the following equation:

$$R = \sqrt{1 - \Sigma d_i r_{ij}}$$

Where,

R = Residual effect.

d_i = Direct effect of the ith character.

r_{ij} = Correlation coefficient between the ith character and jth dependent character.

Direct and indirect effects of curd yield per plant were calculated at both genotypic and phenotypic levels.

3. Results and discussion

3.1 Path coefficient analysis

To measure the direct as well as indirect association of one variable (cause) through another on the end product (effect), path coefficients were calculated at genotypic and phenotypic levels for all the yield attributing traits. The observed correlation coefficients of yield with its contributing traits were partitioned into direct and indirect effects. In the present investigation, important characters viz., curd yield per plant have been used as dependable variables with other traits. The estimates of path coefficient were furnished in the Table 2 and 3. In general the genotypic direct as well as indirect effects were slightly higher in magnitude as compared to corresponding phenotypic direct and indirect effects. In the present study total plant weight, core length, curd circumference, net curd weight, days to curd initiation, number of leaves per plant at 45 DAT, days to harvest, stalk length at 45 DAT had high positive direct effect on curd yield per plant of these traits may rewarded in other words these traits showed given importance, while practicing selection aimed at improvement of yield in cauliflower. Similar results were observed by Kumar *et al.* (2005) [9] for stalk length, Kumar *et al.* (2010) [10], Sheemar *et al.* (2012) [15] for net curd weight, Singh and dogra (2013) [18], Singh *et al.* (2014) [14] for net curd weight, Kibar *et al.* (2014) [8] for head weight. However days to 50% curd formation, curd width and curd length had the highest negative direct effect on curd yield per plant. The results corroborated the findings of Rai *et al.* (2003) [14] for head length, Kumar *et al.* (2010) [10] for 50% curd formation. Rest of the traits viz., curd length did not exhibit, higher direct effect on curd yield, they expressed higher indirect effect on it through core length, total plant weight and curd circumference and hence, simultaneous selection for these characters can be made for further improvement of yield.

Path coefficient analysis revealed that Stalk length at 45 DAT, number of leaves per plant at 45 DAT, days to curd initiation,

days to harvest, curd circumference, core length, total plant weight and net curd weight were the most important characters contributing towards curd yield per plant and hence purposeful and balanced selection based on these characters would be made rewarding for improvement of cauliflower.

3.2 Direct effect

Path coefficient analysis of different characters contributing towards curd yield per plant showed that total plant weight (0.7553) had highest positive direct effect followed by core length (0.1223), curd circumference (0.1135), net curd weight (0.0233), days to curd initiation (0.0227), number of leaves per plant at 45 DAT (0.0227), days to harvest (0.0200), stalk length at 45 DAT (0.0056). Whereas days to 50% curd formation (-0.0605) had the highest negative direct effect on curd yield per plant followed by curd width (-0.0395) and curd length (-0.0185).

3.3 Indirect effect

3.3.1 Stalk length at 45 DAT

Stalk length at 45 DAT imparted highest positive indirect effect on days to 50% curd formation (0.0202), curd width (0.0042) and curd length (0.0020). Whereas negative indirect effect was visible to be highest via. Total plant weight (-0.1269), days to curd initiation (-0.0258), curd circumference (-0.0178) and curd length (-0.0151).

3.3.2 Number of leaves per plant at 45 DAT

Number of leaves per plant at 45 DAT exhibited significant positive indirect effect via total plant weight (0.5348), curd circumference (0.0902) and core length (0.0782). Highest negative indirect effect was observed through days to 50% curd formation (-0.0397), curd width (-0.0289) and curd length (-0.0127).

3.3.3 Days to curd initiation

Days to curd initiation was reported to have highest positive indirect effect on total plant weight (0.6813), core length (0.1080), curd circumference (0.0973) and number of leaves per plant at 45 DAT (0.0160). Whereas it was expressed high negative indirect effect via days to 50% curd formation (-0.0555), curd width (-0.0303) and curd length (-0.0154).

3.3.4 Days to 50% curd formation

Days to 50% curd formation was reported to have highest positive indirect effect on total plant weight (0.6393), core length (0.1030), curd circumference (0.0981) and days to curd initiation (0.0208). Whereas it was expressed high negative indirect effect via curd width (-0.0292), curd length (-0.0152) and stalk length at 45 DAT (-0.0019).

3.3.5 Days to harvest

Days to harvest expressed highest positive indirect effect through total plant weight (0.5720), curd circumference (0.0924), core length (0.0883), and days to curd initiation (0.0173). Its indirect negative effect was high via days to 50% curd formation (-0.0516), curd width (-0.0273) and curd length (-0.0137).

3.3.6 Curd length

Curd length manifested highest positive indirect effect on total plant weight (0.6308), core length (0.1093), curd circumference (0.0846) and days to curd initiation (0.0189). Its indirect negative effect was high via. days to 50% curd formation (-0.0499) and curd width (-0.0254).

3.3.7 Curd circumference

Curd circumference revealed high values of positive indirect on total plant weight (0.6524), core length (0.0951), days to curd initiation (0.0194) and number of leaves at 45 DAT (0.0180). While the high negative indirect effect through days to 50% curd formation (-0.0523), curd width (-0.0364) and curd length (-0.0138).

3.3.8 Curd width

Curd width expressed a positive indirect effect on total plant weight (0.5952), curd circumference (0.1046), core length (0.0902) and days to curd initiation (0.0174). While the negative indirect effect through days to 50% curd formation (-0.0449) and curd length (-0.0119).

3.3.9 Core length

Core length manifested positive indirect effect through total plant weight (0.6883), curd circumference (0.0883) and days to curd initiation (0.0200). It was expressed high negative indirect effect via. days to 50% curd formation (-0.0510), curd width (-0.0291) and curd length (-0.0165).

3.3.10 Total plant weight

Total plant weight exhibited significant positive indirect effect via core length (0.1114), curd circumference (0.0981) and days to curd initiation (0.0205). Highest negative indirect effect was observed through days to 50% curd formation (-0.0512), curd width (-0.0311) and curd length (-0.0154).

3.3.11 Net curd weight

Net curd weight expressed a positive indirect effect on total plant weight (0.3100), core length (0.0597) and curd circumference (0.0151). It was expressed high negative indirect effect via days to 50% curd formation (-0.0206), curd length (-0.0070) and curd width (-0.0053).

3.4 Qualitative characters

Qualitative characters like leaf colour and leaf waxiness are summarized in table 4.

3.4.1 Leaf colour

Based on leaf colour of genotype were categorized in two distinct groups i.e. dark green and green. Genotype JBOB-2, JBOB-3, JBOB-6, JBOB-8, JBOB-10, JBOB-13, JBOB-17, JBOB-23, JBOB-27, JBOB-29 were recorded in dark green colour while remaining genotypes showed green colour. The finding of Zhang (2010) [21] are similar to that of the present findings.

3.4.2 Leaf waxiness

No variation was observed among the genotypes for presence of leaf waxiness. Waxiness is present in all the genotypes.

3.4.3 Curd colour

Based on colour of curd, genotypes were categorized in three distinct groups i.e. Yellow, creamish white, white. Genotypes JBOB-15 was recorded in yellow curd, JBOB-2, JBOB-3, JBOB-5, JBOB-8, JBOB-20, JBOB-22, JBOB-25, JBOB-28, JBOB-30 were recorded in creamish white curd colour, while remaining genotype were recorded in white curd colour. The similar findings are also reported by Kanwar and Korla (2002) [7], Chittora and Singh (2015) [4].

3.4.4 Curd compactness

Based on the compactness of the curd, genotypes were categorized in two distinct groups i.e. loose and compact. All the genotypes showed compactness. None of the genotype had loose curd. The findings of Kanwar and Korla (2002), Kumar *et al.* (2010) [10], Chittora and Singh (2015) [4] are accordance with present investigation.

3.4.5 Self blanched / Unblanched

Based on the blanching habit, genotypes were categorized in two distinct groups i.e. self-blanched or unblanched. Genotypes JBOB-9, JBOB-10, JBOB-12, JBOB-22, JBOB-26, JBOB-27, JBOB-28, JBOB-29 and PH-2 were showed self unblanching habit, while remaining genotypes showed self-blanching habit.

Table 2: Genotypic pathcoefficients showing direct and indirect effects of different characters on curd yield per plant (g)

Characters	Stalk length (cm) 45 DAT	No. of leaves / plant at 45 DAT	Days to curd initiation	Days to 50% curd formation	Days to harvest	Curd length (cm)	Curd circumference (cm)	Curd width (cm)	Core length (cm)	Total plant weight (kg)	Net curd weight (g)	"r" value curd yield /plant (g)
Stalk length (cm) 45 DAT	0.0056	-0.0104	-0.0258	0.0202	-0.0005	0.0020	-0.0178	0.0042	-0.0151	-0.1269	-0.0019	-0.167
No. of leaves / plant at 45 DAT	-0.0026	0.0227	0.0160	-0.0397	0.0097	-0.0127	0.0902	-0.0289	0.0782	0.5348	0.0010	0.708
Days to curd initiation	-0.0018	0.0160	0.0227	-0.0555	0.0153	-0.0154	0.0973	-0.0303	0.1080	0.6813	0.0090	0.903
Days to 50% curd formation	-0.0019	0.0149	0.0208	-0.0605	0.0171	-0.0152	0.0981	-0.0292	0.1030	0.6393	0.0079	0.846
Days to harvest	-0.0001	0.0110	0.0173	-0.0516	0.0200	-0.0137	0.0924	-0.0273	0.0883	0.5720	0.0056	0.757
Curd length (cm)	-0.0006	0.0156	0.0189	-0.0499	0.0149	-0.0185	0.0846	-0.0254	0.1093	0.6308	0.0088	0.835
Curd circumference (cm)	-0.0009	0.0180	0.0194	-0.0523	0.0163	-0.0138	0.1135	-0.0364	0.0951	0.6524	0.0031	0.863
Curd width (cm)	-0.0006	0.0166	0.0174	-0.0449	0.0138	-0.0119	0.1046	-0.0395	0.0902	0.5952	0.0031	0.787
Core length (cm)	-0.0007	0.0145	0.0200	-0.0510	0.0144	-0.0165	0.0883	-0.0291	0.1223	0.6883	0.0114	0.912
Total plant weight (kg)	-0.0009	0.0161	0.0205	-0.0512	0.0151	-0.0154	0.0981	-0.0311	0.1114	0.7553	0.0096	0.978
Net curd weight (g)	-0.0005	0.0010	0.0087	-0.0206	0.0048	-0.0070	0.0151	-0.0053	0.0597	0.3100	0.0233	0.411

Residual effect Genotypic = 0.0386

Table 3: Phenotypic path coefficients showing direct and indirect effects of different characters on curd yield per plant (g)

Characters	Stalk length (cm) 45 DAT	No. of leaves / plant at 45 DAT	Days to curd initiation	Days to 50% curd formation	Days to harvest	Curd length (cm)	Curd circumference (cm)	Curd width (cm)	Core length (cm)	Total plant weight (kg)	Net curd weight (g)	"r" value curd yield /plant (g)
Stalk length (cm) 45 DAT	-0.0028	0.0020	0.0001	-0.0009	0.0001	-0.0005	-0.0008	0.0001	0.0002	-0.1059	-0.00004	-0.108
No. of leaves / plant at 45 DAT	0.0010	-0.0056	-0.0003	0.0022	-0.0026	0.0031	0.0053	-0.0007	-0.0014	0.6689	0.00003	0.670
Days to curd initiation	0.0006	-0.0038	-0.0005	0.0030	-0.0041	0.0038	0.0057	-0.0008	-0.0020	0.8699	0.00033	0.872
Days to 50% curd formation	0.0007	-0.0035	-0.0004	0.0034	-0.0045	0.0037	0.0057	-0.0007	-0.0019	0.7917	0.00027	0.794
Days to harvest	0.0001	-0.0026	-0.0004	0.0028	-0.0054	0.0034	0.0054	-0.0007	-0.0017	0.7252	0.00020	0.726
Curd length (cm)	0.0003	-0.0037	-0.0004	0.0027	-0.0039	0.0046	0.0050	-0.0006	-0.0020	0.7923	0.00031	0.795
Curd circumference (cm)	0.0003	-0.0043	-0.0004	0.0028	-0.0043	0.0034	0.0069	-0.0009	-0.0018	0.8197	0.00011	0.822
Curd width (cm)	0.0002	-0.0039	-0.0004	0.0024	-0.0036	0.0028	0.0060	-0.0011	-0.0016	0.7439	0.00012	0.745
Core length (cm)	0.0003	-0.0034	-0.0004	0.0027	-0.0038	0.0040	0.0051	-0.0007	-0.0024	0.8639	0.00041	0.866
Total plant weight (kg)	0.0003	-0.0038	-0.0004	0.0027	-0.0040	0.0037	0.0056	-0.0008	-0.0020	0.9977	0.00041	0.999
Net curd weight (g)	0.0001	-0.0002	-0.0002	0.0010	-0.0012	0.0016	0.0008	-0.0001	-0.0011	0.4527	0.00090	0.454

Table 4: Qualitative characters in cauliflower genotypes

Genotype	Leaf colour	Leaf waxiness	Curd colour	Curd compactness	Self-blanched/unblanched
JBOB-1	Green	Present	White	Compact	Self-Blanched
JBOB-2	Dark Green	Present	Creamish White	Compact	Self-Blanched
JBOB-3	Dark Green	Present	Creamish White	Compact	Self-Blanched
JBOB-4	Green	Present	White	Compact	Self-Blanched
JBOB-5	Green	Present	Creamish White	Compact	Self-Blanched
JBOB-6	Dark Green	Present	White	Compact	Self-Blanched
JBOB-7	Green	Present	White	Compact	Self-Blanched
JBOB-8	Dark Green	Present	Creamish White	Compact	Self-Blanched

JBOB-9	Green	Present	White	Compact	Self Unblanched
JBOB-10	Dark Green	Present	White	Compact	Self Unblanched
JBOB-11	Green	Present	White	Compact	Self-Blanched
JBOB-12	Green	Present	White	Compact	Self Unblanched
JBOB-13	Dark Green	Present	White	Compact	Self-Blanched
JBOB-14	Green	Present	White	Compact	Self-Blanched
JBOB-15	Green	Present	Yellow	Compact	Self-Blanched
JBOB-16	Green	Present	White	Compact	Self-Blanched
JBOB-17	Dark Green	Present	White	Compact	Self-Blanched
JBOB-18	Green	Present	White	Compact	Self-Blanched
JBOB-19	Green	Present	White	Compact	Self-Blanched
JBOB-20	Green	Present	Creamish White	Compact	Self-Blanched
JBOB-21	Green	Present	White	Compact	Self-Blanched
JBOB-22	Green	Present	Creamish White	Compact	Self Unblanched
JBOB-23	Dark Green	Present	White	Compact	Self-Blanched
JBOB-24	Green	Present	Dirty White	Compact	Self-Blanched
JBOB-25	Green	Present	Creamy White	Compact	Self-Blanched
JBOB-26	Green	Present	Dirty White	Compact	Self Unblanched
JBOB-27	Dark Green	Present	Dirty White	Compact	Self Unblanched
JBOB-28	Green	Present	Creamy White	Compact	Self Unblanched
JBOB-29	Dark Green	Present	Dirty White	Compact	Self Unblanched
JBOB-30	Green	Present	Creamy White	Compact	Self-Blanched
Pusa sharad (C)	Green	Present	Dirty White	Compact	Self-Blanched
PH-2 (C)	Green	Present	Dirty White	Compact	Self Unblanched

4. Conclusion

On the basis of above investigation it can be concluded that Path coefficient analysis of different characters contributing towards curd yield per plant showed that total plant weight had highest positive direct effect followed by core length, curd circumference, net curd weight, days to curd initiation, number of leaves per plant at 45 DAT, days to harvest, stalk length at 45 DAT.

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