Himachal Journal of Agricultural Research 49(2): 185-193 (2023)

Genetic variability, correlation and path analysis studies in cauliflower (*Brassica oleracea* var. *botrytis*)

Alisha Thakur* and Akhilesh Sharma
Department of Vegetable Science and Floriculture, College of Agriculture
Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur-176 062, India.

*Corresponding author: thakuralisha29.at@gmail.com
Manuscript Received: 15.07.2023; Accepted: 28.07.2023

Abstract

Fourteen cauliflower genotypes, including Palam Uphar as a standard check, were examined to determine parameters of variability, association and direct/indirect effects for marketable curd weight and its component traits. Analysis of variance showed significant differences among the genotypes for most of the traits. Based on marketable curd weight, DPCaf-SP2 significantly outperformed all genotypes though at par with DPCafCMS-4. Moderate GCV and PCV along with high heritability and moderate genetic advance were recorded for days to curd initiation, leaf length, leaf size index, marketable curd weight, gross plant weight, curd size index and harvest duration. Correlation studies revealed that marketable curd weight had a positive association with gross plant weight, curd diameter, net curd weight, curd size index, curd solidity, plant height, leaf size index, leaf length and harvest index at both genotypic and phenotypic levels. Path analysis indicated maximum positive direct effect of curd size index on marketable curd weight followed by gross plant weight, plant frame and harvest index at both phenotypic and genotypic levels signifying their effect on marketable curd weight. Based on these results, due consideration must be given on curd and leaf attributes for genetic improvement of cauliflower.

Key words: Cauliflower, correlation, heritability, genetic advance, path analysis

Cauliflower, a member of the Brassicaceae family is botanically known as *Brassica oleracea* L. var. *botrytis* and has a chromosome number of 2n = 2x = 18. It is cultivated all over the world for its soft and retentive white curds (Nimkar and Korla 2014). Cauliflower is low in calories but abundant in dietary fibres and essential vitamins (like A, B, C and K) and minerals (iron, phosphorus, calcium, potassium, sodium, manganese, molybdenum and magnesium). It also contains fair amount of glucosinolates and isothiocyanates, having antioxidant and anti-inflammatory properties along with an anti-cancer substance (sulforaphane) that lowers the risk of prostate cancer (Kushwaha *et al*. 2013). With an area and production of 473 thousand hectares and 9225 thousand metric tonnes, respectively, India is the second-largest producer of cauliflower in the world (NHB 2020) with average productivity of 19.50 metric tonnes/hectare. It is a highly remunerative crop in Himachal Pradesh which is grown commercially as an off- season vegetable crop during summer – rainy season in many districts like Kullu, Mandi, Shimla, Lahaul & Spiti and Kangra. Cauliflower cultivation in Himachal Pradesh occupies an area of about 5.56 thousand hectares with the production of 131.01 thousand metric tonnes and productivity of 23.56 metric tonnes/ hectare (NHB 2018).

Genetic diversity is the foundation of all plant developmental programmes. It is one of the potential parameter which is utilized to achieve higher yield potential by breeding varieties to enhance agricultural production (Ameta *et al*. 2016). The degree of genetic diversity in the germplasm is correlated with a crop's capacity for improvement and offers a chance to enhance yield and quality through a deliberate breeding effort (Singh *et al*. 2009). Genetic and phenotypic variability for the important agro-morphological traits can be utilised to produce improved varieties. The phenotype is frequently not a reliable predictor since it is the result of interaction of genotype and environment. The genotype makes up a proportionate amount of the heritable component in continuous variation and directs selection efficacy whereas the non-heritable component primarily caused by environmental variables, hinders selection. Therefore, it would be crucial to separate total variability into heritable and non-heritable components. Heritability estimations clarify genotypic and phenotypic coefficients of variation to calculate character transmission and selection efficacy (Singh *et al*. 2013). Estimating variability parameters like genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability and genetic advance of the major yield-contributing characteristics help to draw strategy of genetic improvement.

Cauliflower has substantial genetic diversity for yield and yield contributing characteristics. Indirect selection via linked, less complicated and more easily measured traits is the most effective strategy for boosting yield. The relationship among characteristics can be used to choose traits whose genotypic values are affected by environmental influences and cannot be clearly detected (Sharma *et al*. 2006). Genotypic and phenotypic correlations show the degree of relationship with distinct traits but they don't explain the reason for this association between the traits (Toker and Cagirgan 2004). Therefore, path coefficient analysis evaluates cause-effect relationships for effective selection. Correlations coefficient and path coefficient analysis would show the impact of complicated characters and provide a clear image of each character's contribution to the ultimate expression of complex traits.

Keeping this in mind, the current study was designed to analyse 14 cauliflower genotypes for genetic variability, heritability, correlation and path analysis to identify traits of interest for genetic improvement of cauliflower.

Materials and Methods

The present investigation was carried out at Vegetable Research Farm, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur consecutively for two years during winter seasons of 2021-22 and 2022-23. The experimental material comprised of 14 genotypes of mid late/late cauliflower which were developed at CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. These 14 genotypes were evaluated in randomised complete block design with three replications. Data were collected on five randomly selected plants from each genotype in each replication *viz*., days to curd initiation, days to marketable curd maturity, leaf length (cm), leaf width (cm), leaf size index (cm^2), number of leaves per plant, stalk length (cm), plant height (cm), plant frame (cm), curd depth (cm), curd diameter (cm), curd size index (cm^2), gross plant weight (g), marketable curd weight (g), net curd weight (g), curd solidity(g/ cm), per cent marketable curds (%), curd compactness (degrees), harvest duration (days), harvest index (%), ascorbic acid (mg/100g fresh weight basis), total soluble solids (°Brix) and dry matter content (%).

Statistical Analysis: The mean values of each of the traits were subjected to analysis of variance as per standard procedures of Panse and Sukhatme (1985). The components of genetic variability were computed following methods proposed by different researchers namely, genotypic and phenotypic variances and heritability (Burton and De Vanes, 1953), genetic advance (Burton and De Vane, 1953 and Johnson *et al*. 1955). Coefficients of correlation were calculated as suggested by Al-Jibouri *et al*. 1958) while path coefficients of different traits with marketable curd weight were carried out as per Dewey and Lu (1959).

Results and Discussion

Mean performance

Cauliflower genotypes showed wide range of variability for most of the traits in 2021-22, 2022-23 and pooled over years (Table 1). Genotype 'DPCaCMS-2' took minimum number of days for curd initiation (53.50) whereas genotype 'DPCaf-SP1' took minimum days to marketable curd maturity (87.67) over the check 'Palam Uphar' (102.83). The highest leaf length (47.10 cm), leaf width (17.54 cm), leaf size index (820.27 cm^2) and stalk length (3.22 cm) were found in cytoplasmic male sterile line 'DPCafCMS-4'. Plant height and plant spread showed distinct variation among the cultivars. 'DPCaf-SP2' among all genotypes showed highest curd diameter

Table 1. Mean performance of cauliflower genotypes for various traits during pooled over years (2021-22 and 2022-23)

Sr, No.	Genotype	DCI	DMCM	LL	LW	LSI	No. of Leaves	SL	PH	PF	CD	C Dia	CSI	GPW	MCW	NCW	CS	%MC	CC	HD	HI	AA	TSS	DMC
1	DPCaCMS-1	62.33	91.00	42.07	15.93	672.39	13.20	2.83	41.40	52.37	7.29	11.88	86.71	1011.05	708.87	400.34	55.03	90.00	108.67	20.50	70.42	7.97	5.88	7.35
2	DPCaCMS- 2	53.50	97.67	42.34	14.20	614.98	13.33	3.01	41.64	54.89	6.50	11.06	72.48	881.36	563.50	334.23	52.19	88.33	105.17	15.33	64.09	7.86	5.83	9.07
3	DPCaCMS- 3	59.33	90.17	46.35	16.17	750.40	13.28	2.94	40.84	61.19	6.36	10.65	68.03	787.78	526.12	320.44	50.46	83.33	108.33	18.00	66.70	8.11	6.20	8.61
4	DPCafCMS- 4	60.00	94.67	47.10	17.54	820.27	13.97	3.22	40.76	56.39	7.05	11.40	80.78	980.61	640.49	326.97	46.13	86.67	109.60	16.50	65.52	7.70	5.28	8.20
5	DPCaf-W4	61.00	93.17	40.48	14.56	580.75	13.24	2.70	35.16	50.69	6.76	10.73	72.84	889.60	594.29	363.31	53.77	81.67	108.48	15.00	66.85	11.43	6.32	9.39
6	DPCaf-W 131	61.17	88.33	43.05	14.98	653.25	14.33	2.61	39.25	51.39	6.54	10.90	72.09	862.20	543.33	309.29	47.78	81.67	102.97	24.33	62.95	7.69	5.90	11.24
7	DPCaf- SP1	56.17	87.67	45.89	16.10	730.23	14.20	2.89	43.95	57.19	6.73	11.30	77.03	964.54	636.60	374.91	56.34	91.67	104.90	21.17	66.08	14.24	6.20	9.30
8	DPCaf- SP2	60.67	88.33	46.09	16.05	728.46	14.83	2.85	41.34	56.15	7.40	12.39	92.09	1117.20	740.27	403.08	54.32	90.00	105.97	20.17	66.71	11.40	5.77	14.89
9	DPCaf-5	61.33	93.17	42.12	15.90	668.54	15.00	2.77	40.09	54.48	6.70	10.89	72.97	840.07	517.90	318.60	47.73	91.67	107.20	19.83	61.67	9.85	6.55	9.40
10	DPCaf- 29	60.83	88.83	43.69	14.07	607.67	15.16	2.67	40.71	50.68	7.09	11.68	83.24	965.10	644.87	334.93	47.54	88.33	105.73	21.00	66.90	9.78	6.18	9.84
11	DPCaf- S121	56.50	92.17	44.12	15.92	684.94	14.97	3.10	38.32	57.34	7.08	10.81	76.45	871.35	589.57	354.17	50.19	93.33	108.13	15.17	67.91	9.63	5.75	12.29
12	DPCaf- 13	60.50	89.67	46.73	16.53	772.12	12.86	2.85	42.99	54.09	7.26	12.13	88.37	1050.87	676.20	360.95	49.60	81.67	106.80	20.50	65.31	10.30	6.42	9.76
13	DPCaf- 18	58.17	91.50	43.36	16.45	720.27	14.50	2.79	39.55	54.42	6.96	11.63	81.14	1035.81	656.57	377.77	54.25	85.00	107.17	21.00	63.97	10.41	6.72	8.97
14	Palam Uphar	82.67	102.83	26.38	15.86	420.06	11.23	2.69	35.28	44.89	8.28	11.08	91.77	762.08	531.37	365.01	44.06	92.55	110.64	18.67	69.71	11.84	7.50	9.64
	CD	2.22	2.276	2.38	0.84	55.32	0.97	0.17	2.52	2.49	0.47	0.41	6.54	44.14	35.98	24.65	4.28	8.23	3.34	1.30	N/A	0.708	0.18	0.29
	SE (m)	0.76	0.78	0.82	0.29	18.93	0.33	0.06	0.86	0.85	0.16	0.14	2.24	15.10	12.31	8.43	1.47	2.82	1.14	0.44	1.81	0.24	0.06	0.10
	SE (d)	1.08	1.10	1.15	0.40	26.77	0.47	0.08	1.22	1.20	0.23	0.20	3.17	21.36	17.41	11.93	2.07	3.98	1.62	0.63	2.56	0.34	0.09	0.14
	CV	2.15	1.46	3.29	3.15	4.87	4.15	3.40	3.72	2.73	4.00	2.14	4.86	2.81	3.48	4.14	5.01	5.57	1.85	3.98	4.74	4.25	1.76	1.73

DCI: Days to curd initiation; DMCM: Days to marketable maturity; LL: Leaf length; LW: Leaf width; LSI: Leaf size index; SL: Stalk length; PH: Plant height; PF: Plant frame; PD: Curd depth; C Dia: Curd diameter; CSI: Curd size index; GPW: Gross plant weight; MCW: Marketable curd weight; NCM: Net curd weight; CS: Curd solidity; %MC: Per cent marketable curds; CC: Curd compactness; HD: Harvest duration; HI: Harvest index; AA: Ascorbic acid; DMC: Dry matter content

(12.39 cm) and curd size index (92.09 cm^2), gross plant weight (1117.20 g), marketable curd weight (740.27 g) and net curd weight (403.08 g) along with good curd solidity. 'DPCaCMS-1', 'DPCaf-W4' and 'DPCaf-SP1', 'DPCaf-S121', 'DPCaf- 13' and 'DPCaf- 18' were significantly superior over the check 'Palam Uphar' for marketable curd weight and curd solidity. The variations in per cent marketable curds were recorded highest in genotype 'DPCaf-S121' (93.33%) and lowest in 'DPCaf-W4' and 'DPCaf-W131' (81.67%). Check 'Palam Uphar' reported highly compact curds with compactness of 110.64° whereas lowest curd compactness was observed in 'DPCaf-W131' (102.97°). Seven genotypes were significantly superior over the check 'Palam Uphar'(18.67) with longest harvest duration. 'DPCaf-SP1' (14.24mg/100g) showed significantly maximum average ascorbic acid over the check 'Palam Uphar' (11.84mg/100g). 'DPCaf-SP2' (14.89%), 'DPCaf-S121' (12.29%) and 'DPCaf-W131' (11.24%) recorded significantly higher dry matter content than the check 'Palam Uphar' (9.64%). Variations among majority of the characters using variable genetic material have also been reported by many research workers namely, Chittora and Singh (2015), Chatterjee *et al*. (2018), Sharma *et al*. (2018) Singh (2020) and Kumar *et al*. (2021).

Variability studies

All of the variables under investigation had lower genotypic coefficients of variation than phenotypic coefficients of variation, suggesting that environmental factors have a role in expression of these traits among various genotypes. Knowledge of phenotypic (PCV) and genotypic (GCV) coefficients of variation aids in predicting the amount of variation present in the germplasm, thereby facilitating the formulation of an effective breeding programme.

Estimation of parameters of variability (Table 2) revealed that all the genotypes differed for each trait.

Table 2. Estimates of parameters of variability for various traits of cauliflower in pooled over years

Trait	Mean ± SE (m)	Range	GCV (%)	PCV (%)	h^2_{bs}	GA as per cent of mean
Days to curd initiation	61.26 ± 0.76	53.50- 82.67	10.84	11.05	96.22	21.91
Days to marketable curd maturity	92.26 ± 0.78	87.67- 102.83	4.50	4.73	90.47	8.82
Leaf length	42.84 ± 0.81	26.38- 47.10	11.89	12.34	92.89	23.60
Leaf width	15.73 ± 0.29	14.07- 17.54	5.84	6.63	77.51	10.59
Leaf size index	673.17 ± 18.93	420.06- 20.27	14.40	15.20	89.73	28.09
Number of leaves	13.87 ± 0.33	11.23- 15.16	7.44	8.51	76.28	13.38
Stalk length	2.85 ± 0.06	2.61- 3.22	5.70	6.63	73.77	10.08
Plant height	40.09 ± 0.86	35.16- 43.95	5.88	6.96	71.39	10.24
Plant frame	54.01 ± 0.85	44.89- 61.19	7.07	7.58	87.02	13.59
Curd depth	7.00 ± 0.16	6.36- 8.28	6.56	7.69	72.89	11.54
Curd diameter	11.32 ± 0.14	10.65- 12.39	4.68	5.14	82.65	8.75
Curd size index	79.71 ± 2.24	68.03- 92.09	9.40	10.59	78.89	17.20
Gross plant weight	929.97 ± 15.10	762.08- 1117.20	11.08	11.43	93.94	22.12
Marketable curd weight	612.14 ± 12.31	517.90- 740.27	11.38	11.90	91.43	22.42
Net curd weight	353.14 ± 8.43	309.29- 403.08	8.14	9.13	79.49	14.95
Curd solidity	50.67 ± 1.47	44.06- 56.34	6.79	8.44	64.77	11.26
Per cent marketable curd	87.56 ± 2.82	81.67- 93.33	3.63	6.65	29.82	4.08
Curd compactness	107.13 ± 1.14	102.97- 110.64	1.59	2.44	42.53	2.14
Harvest duration	19.31 ± 0.44	15.00-24.33	14.66	15.19	93.15	29.15
Harvest Index	66.06 ± 1.81	61.67- 70.42	2.43	5.33	20.81	2.28
Ascorbic acid	9.87 ± 0.24	7.69- 14.24	19.42	19.88	95.43	39.08
Total soluble solids	6.21 ± 0.06	5.28- 7.50	8.50	8.68	95.91	17.15
Dry matter content	9.85 ± 0.10	7.35- 14.89	19.05	19.13	99.18	39.08

PCV and GCV represent phenotypic and genotypic coefficients of variation, respectively; h^2bs: Heritability in broad sense; GA (%): Genetic advance (%) as per cent of mean

Moderate estimates of GCV and PCV were observed for days to curd initiation, leaf length, leaf size index, gross plant weight, marketable curd weight, harvest duration, ascorbic acid and dry matter content, while, curd size index only exhibited moderate PCV estimates indicating a cautious selection process for these traits to be improved (Chauhan *et al*. 2023). Earlier workers have also found moderate PCV and GCV for days to curd initiation (Singh 2020), marketable curd weight and gross curd weight (Chittora and Singh 2015) and ascorbic acid (Kumar *et al*. 2011). The knowledge on heritability estimates along with PCV and GCV estimates gives better understanding of the inheritance of quantitative traits. Heritability estimates in the broad sense are reliable if they are accompanied by a high genetic advance and thus are the most favourable for selection. In the present study, high heritability along with high genetic advance was observed for ascorbic acid (Singh *et al*. 2013) and dry matter content suggesting that a significant amount of additive gene activity was involved in the expression, and as a result, selection would be beneficial for the genetic development of these traits (Sood *et al*. 2020). High heritability along with moderate genetic advance were observed for days to curd initiation, leaf length (Singh *et al*. 2013), leaf sixe index, curd size index, gross plant weight (Chittora and Singh 2015), marketable curd weight (Kumar *et al*. 2011) and harvest duration indicating the role of non-additive gene action in their inheritance (Kumar *et al*. 2017).

Correlation and Path analysis

Correlation coefficient is a statistical method used to determine the mutual relationship among several plant traits to enhance genetic improvement programmes. Therefore, this study examined phenotypic and genotypic association between twenty- three characters (Table 3). Magnitude of phenotypic correlation was lower than the genotype correlation. This indicated a significant genetic relationship among the traits and that environmental factors suppressed the phenotypic expression.

Marketable curd weight revealed a positive and significant correlation with gross plant weight followed by curd diameter, net curd weight, curd size index, curd solidity, plant height, leaf size index, leaf length and harvest index at both genotypic and phenotypic levels. Curd depth and curd diameter showed positive and significant correlation between themselves and also with curd size index, gross plant weight and net curd weight at both phenotypic and genotypic levels. A positive and significant association of plant height was observed with leaf length, leaf size index, plant spread, curd diameter and gross plant weight. In addition, positive and significant association at both genotypic and phenotypic level was recorded for days to curd initiation, days to marketable curd maturity, curd depth, curd compactness, TSS among themselves while leaf size index had the same with leaf length, leaf width, number of leaves, stalk length, plant height, plant frame and gross plant weight. Similarly, a positive association was found between curd depth and curd diameter (Sharma *et al*. 2006 and Singh *et al*. 2014), curd size index (Sharma *et al*. 2006) and net curd weight (Singh *et al*. 2014, Shruthy and Celine 2016 and Vanlalneihi *et al*. 2017), while, gross curd weight showed the similar association except for curd depth.

Similarly, a positive association was found between curd depth and curd diameter (Sharma *et al*. 2006 and Singh *et al*. 2014), curd size index (Sharma *et al*. 2006) and net curd weight (Singh *et al*. 2014, Shruthy and Celine 2016 and Vanlalneihi *et al*. 2017), while, gross curd weight showed the similar association except for curd depth. Harvest index also showed the positive association with curd depth and curd size index. As a result, selections for improvement in cauliflower based on these attributes must be approached with caution. Genotypic correlation, rather than phenotypic correlation, provides more accurate genetic relationship assessments between traits, assisting in identifying traits to be considered for selection during breeding programmes.

The path coefficient analysis was carried out (Table 4) in order to comprehend the reasons behind the correlations between the traits under study as well as the estimations of the direct and indirect contributions of various factors to marketable curd weight. The direct effects at genotypic level and phenotypic level were different. Path coefficient analysis revealed that curd size index had the maximum positive direct effect on marketable curd weight followed by gross plant weight, plant spread and harvest index at both

Table 3. Estimates of phenotypic and genotypic correlations for different pair of traits in cauliflower during pooled over years (2021-22 & 2022-23)

		DCI	DMCM	LL	LW	LSI	No. of Leaves	SL	PH	PF	CD	C Dia	CSI	GPW	NCW	CS	%MC	CC	HD	HI	AA	TSS	DMC
DMCM	G	0.625**																					
	P	0.600**																					
LL	G	-0.886**	-0.812**																				
	P	-0.850**	-0.743**																				
LW	G	0.089	-0.018	0.228																			
	P	0.059	-0.030	0.232																			
LSI	G	-0.699**	-0.652**	0.914**	0.596**																		
	P	-0.665**	-0.600**	0.905**	0.612**																		
No. of Leaves	G	-0.695**	-0.702**	0.679**	-0.061	0.504**																	
	P	-0.582**	-0.565**	0.571**	-0.093	0.393*																	
SL	G	-0.461**	0.112	0.456**	0.584**	0.604**	0.080																
	P	-0.364*	0.099	0.403**	0.409**	0.507**	0.128																
PH	G	-0.631**	-0.634**	0.750**	0.253	0.741**	0.363*	0.367*															
	P	-0.517**	-0.477**	0.645**	0.228	0.628**	0.259	0.276															
PF	G	-0.769**	-0.528**	0.817**	0.396**	0.830**	0.487**	0.701**	0.619**														
	P	-0.717**	-0.455**	0.790**	0.372*	0.794**	0.388*	0.588**	0.551**														
CD	G	0.839**	0.509**	-0.699**	0.264	-0.492**	-0.534**	-0.177	-0.431**	-0.668**													
	P	0.709**	0.409**	-0.536**	0.202	-0.374*	-0.337*	-0.097	-0.186	-0.533**													
C Dia	G	-0.014	-0.334*	0.267	0.250	0.319*	0.106	-0.011	0.537**	-0.054	0.464**												
	P	-0.054	-0.309*	0.255	0.278	0.320*	0.096	-0.046	0.438**	-0.019	0.396**												
CSI	G	0.547**	0.153	-0.321*	0.294	-0.161	-0.302	-0.126	-0.002	-0.469**	0.886**	0.822**											
	P	0.460**	0.119	-0.237	0.270	-0.097	-0.188	-0.101	0.099	-0.378*	0.888**	0.771**											
GPW	G	-0.384*	-0.544**	0.555**	0.282	0.565**	0.364*	0.115	0.573**	0.198	0.144	0.937**	0.577**										
	P	-0.352*	-0.482**	0.517**	0.265NS	0.523**	0.325*	0.121	0.469**	0.160	0.112	0.816**	0.485**										
NCW	G	0.126	-0.065	-0.102	0.220	-0.024	-0.141	-0.053	0.048	-0.129	0.560**	0.683**	0.716**	0.648**									
	P	0.114	-0.102	-0.095	0.146	-0.036	-0.152	-0.046	0.090	-0.106	0.483**	0.560**	0.610**	0.543**									
CS	G	-0.608**	-0.503**	0.466**	-0.045	0.355*	0.290	0.078	0.444**	0.431**	-0.263	0.322*	-0.001	0.564**	0.647**								
	P	-0.479**	-0.425**	0.322*	-0.063	0.235	0.091	0.018	0.250	0.331*	-0.378*	0.200	-0.163	0.426**	0.621**								
%MC	G	0.286	0.357*	-0.410**	0.062	-0.356*	0.129	0.356*	0.048	-0.074	0.611**	0.011	0.396**	-0.131	0.432**	-0.015							
	P	0.133	0.245	-0.236	0.093	-0.190	0.152	0.133	0.014	-0.031	0.263	0.071	0.209	-0.066	0.160	-0.036							
CC	G	0.643**	0.803**	-0.532**	0.553**	-0.245	-0.590**	0.389*	-0.529**	-0.197	0.743**	-0.155	0.391*	-0.282	0.231	-0.451**	0.480**						
	P	0.390*	0.391*	-0.320*	0.331*	-0.113	-0.422**	0.191	-0.437**	-0.124	0.300	-0.062	0.159	-0.170	0.169	-0.094	0.021						
HD	G	0.134	-0.509**	0.070	0.050	0.093	0.220	-0.638**	0.373*	-0.197	0.062	0.434**	0.273	0.285	0.054	-0.002	-0.112	-0.633**					
	P	0.126	-0.482**	0.062	0.045	0.082	0.195	-0.547**	0.286	-0.198	0.055	0.335*	0.214	0.278	0.063	0.009	-0.130	-0.400**					
HI	G	0.688**	0.360*	-0.598**	0.153	-0.502**	-0.751**	0.140	-0.341*	-0.440**	0.919**	0.219	0.719**	0.114	0.814**	0.138	0.741**	1.115**	-0.336*				
	P	0.282	0.116	-0.227	-0.038	-0.210	-0.270	-0.003	-0.182	-0.130	0.434**	0.171	0.381*	-0.086	0.432**	0.067	0.121	0.255	-0.153				
AA	G	0.231	-0.054	-0.234	0.049	-0.219	-0.061	-0.279	-0.065	-0.177	0.353*	0.173	0.326*	0.154	0.534**	0.344*	0.409**	0.018	0.091	0.266			
	P	0.227	-0.055	-0.220	0.032	-0.207	-0.057	-0.254	-0.047	-0.165	0.322*	0.126	0.289	0.145	0.483**	0.266	0.228	-0.026	0.095	0.103			
TSS	G	0.719**	0.460**	-0.757**	-0.078	-0.651**	-0.516**	-0.641**	-0.475**	-0.596**	0.491**	-0.122	0.252	-0.370*	0.137	-0.246	0.105	0.372*	0.212	0.158	0.487**		
	P	0.689**	0.443**	-0.711**	-0.052	-0.596**	-0.466**	-0.556**	-0.386*	-0.542**	0.432**	-0.107	0.238	-0.359*	0.091	-0.243	0.078	0.204	0.186	0.075	0.459**		
DMC	G	-0.040	-0.283	0.106	-0.104	0.002	0.426**	-0.082	-0.066	0.078	0.191	0.256	0.266	0.240	0.213	0.046	0.259	-0.426**	0.089	-0.058	0.257	-0.165	
	P	-0.040	-0.274	0.099	-0.090	0.001	0.350*	-0.073	-0.081NS	0.063	0.152	0.216	0.221	0.235	0.184	0.043	0.107	-0.256	0.093	-0.054	0.253	-0.160	
MCW	G	-0.240	-0.463**	0.419**	0.281	0.438**	0.219	0.136	0.487**	0.107	0.306*	0.932**	0.682**	0.976**	0.783**	0.581**	0.042	-0.060	0.209	0.325*	0.190	-0.347*	0.214
	P	-0.225	-0.423**	0.399**	0.220	0.404**	0.204	0.110	0.368*	0.097	0.273	0.837**	0.605**	0.905**	0.688**	0.436**	-0.003	-0.057	0.202	0.343*	0.169	-0.329*	0.197

*Significant at 1% level of significance, **Significant at 5% level of significance. DCI: Days to curd initiation; DMCM: Days to marketable curd maturity; LL: Leaf length; LW: Leaf width; LSI: Leaf size index; SL: Stalk length; PH: Plant height; PF: Plant frame; CD: Curd depth; C Dia: Curd diameter; CSI: Curd size index; GPW: Gross plant weight; MCW: Marketable curd weight; NCM: Net curd weight; CS: Curd solidity; %MC: Per cent marketable curds; CC: Curd compactness; HD: Harvest duration; HI: Harvest index; AA: Ascorbic acid; DMC: Dry matter content

Table 4. Estimates of direct and indirect effects of different traits on marketable curd weight at genotypic (G) and phenotypic (P) levels during pooled over years (2021-22 & 2022-23)

		DCI	DMCM	LL	LW	LSI	No. of Leaves	SL	PH	PF	CD	C Dia	CSI	GPW	NCW	CS	%MC	CC	HD	HI	AA	TSS	DMC	MCW
DCI	G	0.454	-0.250	1.918	-0.064	-1.043	-0.342	0.034	0.240	-0.787	0.861	0.021	1.774	-0.642	-0.516	-1.884	-0.034	-0.032	-0.038	0.170	-0.012	-0.085	0.015	-0.240
	P	-0.015	-0.022	-0.024	0.002	0.072	0.013	0.001	-0.003	-0.004	-0.113	0.001	0.012	-0.337	0.016	0.072	0.003	0.006	0.002	0.120	0.001	-0.029	0.000	-0.225
DMCM	G	0.284	-0.399	1.758	0.013	-0.973	-0.345	-0.008	0.241	-0.540	0.522	0.488	0.498	-0.909	0.266	-1.559	-0.042	-0.040	0.144	0.089	0.003	-0.054	0.103	-0.463
	P	-0.009	-0.036	-0.021	-0.001	0.065	0.013	0.000	-0.003	-0.003	-0.065	0.006	0.003	-0.461	-0.014	0.064	0.005	0.006	-0.007	0.049	0.000	-0.018	0.003	-0.423
LL	G	-0.402	0.324	-2.166	-0.164	1.365	0.334	-0.034	-0.285	0.837	-0.718	-0.390	-1.042	0.927	0.418	1.444	0.049	0.026	-0.020	-0.148	0.013	0.090	-0.039	0.419
	P	0.012	0.027	0.028	0.007	-0.098	-0.013	-0.001	0.004	0.004	0.085	-0.005	-0.006	0.494	-0.013	-0.049	-0.005	-0.005	0.001	-0.096	-0.001	0.030	-0.001	0.399
LW	G	0.040	0.007	-0.493	-0.721	0.889	-0.030	-0.044	-0.096	0.406	0.271	-0.365	0.956	0.471	-0.905	-0.140	-0.007	-0.027	-0.014	0.038	-0.003	0.009	0.038	0.281
	P	-0.001	0.001	0.006	0.029	-0.066	0.002	-0.001	0.002	0.002	-0.032	-0.006	0.007	0.253	0.020	0.010	0.002	0.005	0.001	-0.016	0.000	0.002	0.001	0.220
LSI	G	-0.317	0.260	-1.980	-0.429	1.493	0.248	-0.045	-0.281	0.850	-0.505	-0.464	-0.523	0.944	0.097	1.099	0.042	0.012	-0.026	-0.124	0.012	0.077	-0.001	0.438
	P	0.010	0.022	0.025	0.018	-0.109	-0.009	-0.001	0.004	0.005	0.059	-0.006	-0.002	0.500	-0.005	-0.035	-0.004	-0.002	0.001	-0.089	-0.001	0.025	0.000	0.404
No. of	G	-0.315	0.280	-1.470	0.044	0.752	0.492	-0.006	-0.138	0.499	-0.548	-0.154	-0.980	0.609	0.579	0.900	-0.015	0.029	-0.062	-0.186	0.003	0.061	-0.155	0.219
Leaves	P	0.009	0.020	0.016	-0.003	-0.043	-0.023	0.000	0.002	0.002	0.054	-0.002	-0.005	0.311	-0.021	-0.014	0.003	-0.006	0.003	-0.115	0.000	0.019	-0.004	0.204
SL	G	-0.209	-0.045	-0.988	-0.420	0.902	0.039	-0.075	-0.140	0.718	-0.181	0.016	-0.409	0.193	0.220	0.242	-0.042	-0.019	0.181	0.035	0.015	0.076	0.030	0.136
	P	0.005	-0.004	0.011	0.012	-0.055	-0.003	-0.002	0.002	0.003	0.015	0.001	-0.003	0.116	-0.006	-0.003	0.003	0.003	-0.007	-0.001	-0.002	0.023	0.001	0.110
PH	G	-0.286	0.253	-1.625	-0.182	1.106	0.179	-0.027	-0.380	0.633	-0.443	-0.783	-0.008	0.957	-0.196	1.375	-0.006	0.026	-0.106	-0.084	0.003	0.056	0.024	0.487
	P	0.008	0.017	0.018	0.007	-0.068	-0.006	0.000	0.007	0.003	0.030	-0.009	0.003	0.448	0.012	-0.038	0.000	-0.006	0.004	-0.078	0.000	0.016	0.001	0.368
PF	G	-0.349	0.211	-1.770	-0.286	1.240	0.240	-0.052	-0.235	1.024	-0.686	0.079	-1.522	0.331	0.528	1.336	0.009	0.010	0.056	-0.109	0.009	0.071	-0.028	0.107
	P	0.011	0.016	0.022	0.011	-0.086	-0.009	-0.001	0.004	0.006	0.085	0.000	-0.010	0.153	-0.015	-0.050	-0.001	-0.002	-0.003	-0.055	-0.001	0.023	-0.001	0.097
CD	G	0.381	-0.203	1.514	-0.190	-0.735	-0.262	0.013	0.164	-0.684	1.026	-0.677	2.876	0.241	-2.298	-0.814	-0.072	-0.037	-0.018	0.228	-0.019	-0.058	-0.069	0.306
	P	-0.010	-0.015	-0.015	0.006	0.041	0.008	0.000	-0.001	-0.003	-0.159	-0.008	0.023	0.107	0.066	0.057	0.006	0.004	0.001	0.184	0.002	-0.018	-0.002	0.273
C Dia	G	-0.006	0.134	-0.579	-0.180	0.476	0.052	0.001	-0.204	-0.056	0.476	-1.458	2.668	1.566	-2.805	0.998	-0.001	0.008	-0.123	0.054	-0.009	0.014	-0.093	0.932
	P	0.001	0.011	0.007	0.008	-0.035	-0.002	0.000	0.003	0.000	-0.063	-0.020	0.020	0.780	0.077	-0.030	0.002	-0.001	0.005	0.073	0.001	0.004	-0.002	0.837
CSI	G	0.248	-0.061	0.695	-0.212	-0.240	-0.148	0.009	0.001	-0.480	0.909	-1.198	3.246	0.964	-2.937	-0.005	-0.047	-0.019	-0.077	0.178	-0.017	-0.030	-0.096	0.682
	P	-0.007	-0.004	-0.007	0.008	0.011	0.004	0.000	0.001	-0.002	-0.141	-0.016	0.025	0.464	0.084	0.025	0.004	0.002	0.003	0.162	0.002	-0.010	-0.002	0.605
GPW	G	-0.174	0.217	-1.201	-0.203	0.843	0.179	-0.009	-0.218	0.203	0.148	-1.366	1.873	1.671	-2.660	1.747	0.016	0.014	-0.081	0.028	-0.008	0.044	-0.087	0.976
	P	0.005	0.017	0.014	0.008	-0.057	-0.007	0.000	0.003	0.001	-0.018	-0.016	0.012	0.956	0.074	-0.064	-0.001	-0.002	0.004	-0.037	0.001	0.015	-0.003	0.905
NCW	G	0.057	0.026	0.221	-0.159	-0.035	-0.069	0.004	-0.018	-0.132	0.574	-0.996	2.323	1.083	-4.104	2.007	-0.051	-0.011	-0.015	0.202	-0.029	-0.016	-0.077	0.783
	P	-0.002	0.004	-0.003	0.004	0.004	0.003	0.000	0.001	-0.001	-0.077	-0.011	0.016	0.519	0.137	-0.094	0.003	0.002	0.001	0.184	0.003	-0.004	-0.002	0.688
CS	G	-0.276	0.201	-1.009	0.033	0.529	0.143	-0.006	-0.168	0.441	-0.270	-0.469	-0.005	0.942	-2.658	3.099	0.002	0.022	0.000	0.034	-0.018	0.029	-0.017	0.581
	P	0.007	0.015	0.009	-0.002	-0.026	-0.002	0.000	0.002	0.002	0.060	-0.004	-0.004	0.407	0.085	-0.151	-0.001	-0.001	0.000	0.028	0.002	0.010	0.000	0.436
%MC	G	0.130	-0.142	0.888	-0.045	-0.532	0.064	-0.027	-0.018	-0.076	0.627	-0.017	1.284	-0.219	-1.772	-0.048	-0.119	-0.024	0.032	0.184	-0.022	-0.012	-0.094	0.042
	P	-0.002	-0.009	-0.007	0.003	0.021	-0.003	0.000	0.000	0.000	-0.042	-0.001	0.005	-0.063	0.022	0.005	0.021	0.000	-0.002	0.052	0.001	-0.003	-0.001	-0.003
CC	G	0.292	-0.320	1.152	-0.399	-0.365	-0.290	-0.029	0.201	-0.202	0.763	0.226	1.270	-0.471	-0.947	-1.399	-0.057	-0.049	0.179	0.276	-0.001	-0.044	0.154	-0.060
	P	-0.006	-0.014	-0.009	0.010	0.012	0.010	0.000	-0.003	-0.001	-0.048	0.001	0.004	-0.163	0.023	0.014	0.000	0.015	-0.005	0.108	0.000	-0.009	0.003	-0.057
HD	G	0.061	0.203	-0.152	-0.036	0.138	0.108	0.048	-0.142	-0.202	0.064	-0.632	0.886	0.477	-0.222	-0.005	0.013	0.031	-0.284	-0.083	-0.005	-0.025	-0.032	0.209
	P	-0.002	0.017	0.002	0.001	-0.009	-0.004	0.001	0.002	-0.001	-0.009	-0.007	0.005	0.266	0.009	-0.001	-0.003	-0.006	0.014	-0.065	0.001	-0.008	-0.001	0.202
HI	G	0.312	-0.144	1.295	-0.111	-0.749	-0.369	-0.010	0.130	-0.450	0.943	-0.319	2.334	0.191	-3.342	0.426	-0.088	-0.055	0.095	0.248	-0.014	-0.019	0.021	0.325
	P	-0.004	-0.004	-0.006	-0.001	0.023	0.006	0.000	-0.001	-0.001	-0.069	-0.003	0.010	-0.083	0.059	-0.010	0.003	0.004	-0.002	0.425	0.001	-0.003	0.001	0.343
AA	G	0.105	0.021	0.507	-0.035	-0.326	-0.030	0.021	0.025	-0.181	0.363	-0.253	1.057	0.257	-2.193	1.065	-0.048	-0.001	-0.026	0.066	-0.053	-0.058	-0.093	0.190
	P	-0.003	0.002	-0.006	0.001	0.023	0.001	0.000	0.000	-0.001	-0.051	-0.003	0.007	0.139	0.066	-0.040	0.005	0.000	0.001	0.044	0.006	-0.019	-0.003	0.169
TSS	G	0.326	-0.184	1.640	0.056	-0.971	-0.254	0.048	0.181	-0.611	0.504	0.177	0.819	-0.618	-0.563	-0.762	-0.012	-0.018	-0.060	0.039	-0.026	-0.118	0.060	-0.347
	P	-0.010	-0.016	-0.020	-0.002	0.065	0.011	0.001	-0.003	-0.003	-0.069	0.002	0.006	-0.343	0.013	0.037	0.002	0.003	0.003	0.032	0.003	-0.042	0.002	-0.329
DMC	G	-0.018	0.113	-0.230	0.075	0.003	0.209	0.006	0.025	0.080	0.196	-0.374	0.863	0.400	-0.872	0.143	-0.031	0.021	-0.025	-0.014	-0.014	0.020	-0.363	0.214
	P	0.001	0.010	0.003	-0.003	0.000	-0.008	0.000	-0.001	0.000	-0.024	-0.004	0.006	0.225	0.025	-0.007	0.002	-0.004	0.001	-0.023	0.002	0.007	-0.011	0.197

Residual effect at phenotypic level (P)= 0.00180 and genotypic level (G)=-0.00102. Significant at P ≤0.05; bold values indicate direct effects of correlation coefficient with marketable curd weight

DCI: Days to curd initiation; DMCM: Days to marketable curd maturity; LL: Leaf length; LW: Leaf width; LSI: Leaf size index; SL: Stalk length; PH: Plant height; PF: Plant frame; CD: Curd depth; C Dia: Curd diameter; CSI: Curd size index; GPW: Gross plant weight; MCW: Marketable curd weight; NCM: Net curd weight; CS: Curd solidity; %MC: Per cent marketable curds; CC: Curd compactness; HD: Harvest duration; HI: Harvest index; AA: Ascorbic acid; DMC: Dry matter content phenotypic and genotypic levels. Earlier researchers have also given account of positive and direct effects of different traits with marketable curd weight e.g., curd size index (Singh 2020), gross plant weight and harvest index (Sharma *et al*. 2006 and Singh 2020). Besides, curd solidity followed by leaf size index, curd depth, number of leaves and days to curd initiation contributed directly to marketable curd weight only at genotypic level while net curd weight, leaf width, leaf length, per cent marketable curds, curd compactness plant height, harvest duration, plant frame, ascorbic acid contributed the similar effects at phenotypic level. Such a shift in the direction and magnitude of direct and indirect effects may be attributable to environmental factors influencing different characters. The negative direct effects of curd diameter, days to marketable curd maturity, dry matter content, TSS and stalk length were also recorded with marketable curd weight at both genotypic and phenotypic levels.

Conclusion

In the current study, findings on mean performance 'DPCaf-SP2', 'DPCaCMS 1', 'DPCafCMS-4', 'DPCaf-SP1' and 'DPCaf-W131' were the most promising genotypes for marketable curd weight and other related traits. Based on variability, heritability and genetic advance studies, the potential of traits like ascorbic acid, dry matter content, days to curd initiation, leaf length, leaf size index, curd size index, gross plant weight, marketable curd weight and harvest duration could be exploited for improvement through selection. These parameters are crucial for the cauliflower breeding programme due to the presence of sufficient genetic variation in all the traits and role of additive gene effects in some traits. Based on correlation and path analysis studies, gross plant weight, curd size index, leaf size index and harvest index must be focused on for genetic improvement of cauliflower yield.

Conflict of interest: The authors declare no competing interest.

References

Al-Jibouri HA, Miller PA and Robinson HF. 1958. Genotypic and environmental variance and co-variance in upland cotton crops of inter-specific origin. Agronomy Journal **50** (10): 633-636.

Ameta HK, Ranjan JK, Kakani RK, Mehta RS, Solanki RK, Panwar A, *et al*. 2016. Genetic variability studies in Coriander (*Coriandrum sativum* L.). International Journal of Seed Spices **6**: 103-105.

Ansari M, Trivedi J and Sharma D. 2017. Genetic variability in mid-season cauliflower (*Brassica oleracea* L. var. botrytis): a review. Trends in Biosciences **10** (42): 8758-8763.

Burton GW and De Vane EH. 1953. Estimating heritability in tall fescue (*Festuca arundinacea*) from replicated clonal material. Agronomy Journal **45** (10): 478-481.

Chatterjee S, Mukherjee D, Choudhuri P and Kanwar HS. 2018. Path analysis and quality character studies in some mid late and late cauliflower (*Brassica oleracea* var. *botrytis* L.) genotypes. Current Journal of Applied Science and Technology **31** (1): 1-7.

Chauhan A, Sharma A, Sharma P, Katoch V, Chadha S and Kumari V. 2023. Genetic variability for pod yield and component traits in Sugar Snaps (*Pisum sativum* var. *saccharatum*). Legume Research **46** (5): 548-554.

Chittora A and Singh DK. 2015. Genetic variability studies in early cauliflower (*Brassica oleracea* L. var. *botrytis*). Electronic Journal of Plant Breeding **6** (3): 842–847.

Dewey DR and Lu KH. 1959. A correlation and path analysis of components of crested wheat-grass seed production. Agronomy Journal **51** (9): 515-518.

FAOSTAT Statistical Year Book 2019. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.faostat.org [11.00AM, 28th May, 2021].

Gariya RS, Pant SC, Thilak JC and Bahuguna P. 2019. Studies on genetic variability among different genotypes of cauliflower (*Brassica oleracea* L. var. *botrytis*) under hilly region of Bharsar, Uttarakhand, India. International Journal of Current Microbiology and Applied Sciences **8**: 644-651.

Johnson HW, Robinson HF and Comstock RE. 1955. Estimates of phenotypic and genotypic correlation in soybean and their implications in selection. Agronomy Journal **47**: 477-482.

Kumar L, Gayen R, Singh J and Mehat N. 2019. Estimation of genetic variability, heritability and genetic advance in Indian cauliflower (*Brassica oleracea* var. *botrytis* L.). Journal of Pharmacognosy and Phytochemistry **8** (6): 233-235.

Kumar M, Sharma SR, Kalia P and Saha P. 2011. Genetic variability and character association for yield and quality traits in early maturing Indian cauliflowers. Indian

Journal of Horticulture **68** (2): 206-211.

Kumar S, Ali B, Khaldun ABM, Islam SS, Uddin S, Akanda MMJ and Miah MS. 2021. Genetic diversity, correlations and path coefficient analysis among the F_5 populations of Brassica species. Asian Journal of Advances in Agricultural Research **16**: 20-31.

Kumar V, Singh DK and Panchbhaiya A. 2017. Genetic variability studies in mid- season cauliflower (*Brassica oleracea* var. *botrytis* L.). Bulletin of Environment, Pharmacology and Life Sciences **6** (9): 99- 104.

Kushwaha A, Baily SB, Maxton A, Ram GD. 2013. Isolation and characterization of PGPR associated with cauliflower roots and its effect on plant growth. The Bioscan **8** (1): 95-99.

Mehra D and Singh DK. 2013. Studies on genetic variability for yield and its contributing attributes in early cauliflower (*Brassica oleracea* L. var. *botrytis*). Pantnagar Journal of Research **11** (2): 261-265.

NHB. 2018. Indian Horticulture Database. National Horticulture Board. Gurgaon, Haryana 142- 44.

NHB. 2020. Indian Horticulture Database. National Horticulture Board. Gurgaon, Haryana.

Nimkar SA, Korla BN. 2014. Studies on comparison of biparental and F4 progenies in late cauliflower (*Brassica oleracea* L. var. *botrytis*). International Journal of Farm Sciences **4** (1): 27-34.

Panse VG and Sukhatme PV. 1985. Statistical Methods for Agricultural Workers. Ed. 4th, Indian Council of Agricultural Research, New Delhi.

Sharma A, Sharma S, Pathak S and Sood S. 2006. Genetic variability for curd yield and its component traits in cauliflower (*Brassica oleracea* L. var. *botrytis*) under high hills dry temperate conditions. Vegetable Science **33** (1): 82-84.

Sharma S, Singh Y, Sharma S, Vishalakshi and Sekhon BS. 2018. Variability studies in cauliflower (*Brassica oleracea* L. var. *botrytis*) for horticultural traits under mid hill conditions of North-Western Himalayas, India. Journal of Pharmacognosy and Phytochemistry **7** (2): 100-103.

Shruthy ON and Celine VA 2016. Genetic variability in tropical cauliflower (*Brassica oleracea* L. var. *botrytis*) under the plains of Southern Kerala. International Journal of Science and Research **7** (9): 578-583.

Singh J. 2020. Evaluation of cauliflower (*Brassica oleracea* L. *var. botrytis*) genotypes and determination of selection parameters for its genetic improvement. M Sc Thesis, p 117. Department of Vegetable Science and Floriculture, CSK HPKV, Palampur (unpublished).

Singh KP, Kant K, Roy RK and Jha RN. 2014. Correlation and path co-efficient analysis in cauliflower (*Brassica oleracea* L. var. *botrytis*). International Journal of Agricultural Sciences **10** (1): 387-389.

Singh P, Kumar S, Maji S, Singh A. 2013. Genetic variability, heritability and genetic advance in cauliflower (*Brassica oleracea* L. var. *botrytis*). International Journal of Plant Sciences **8** (1): 179-82.

Singh Y, Sharma M and Sharma A. 2009. Genetic variation, association of characters, and direct and indirect contributions for improvement in cauliflower. International Journal of Vegetable Science **15** (4): 340-68.

Sood T, Basandrai D, Rana V and Basandrai AK. 2020. Genetic diversity analysis for various agro morphological, yield and yield related traits in wheat (*Triticum aestivum* L.). Himachal Journal of Agricultural Research **46** (2): 136-144.

Toker C and Cagirgan MI. 2004. The use of phenotypic correlations and factor analysis in determining characters for grain yield selection in chickpea (*Cicer arietinum* L.). Hereditas **140** (3): 226-228.

Vanlalneihi B, Saha P and Srivastava M. 2017. Assessment of genetic variability and character association for yield and its contributing components in mid maturing Indian cauliflower. International Journal of Current Microbiology and Applied Sciences **6** (11): 2907-2913.