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Research Article

Assessment of genetic variability and character association in mid-late/late cauliflower genotypes

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Abstract
The present investigation comprising 36 diverse cauliflower genotypes along with three checks were raised during winter season of 2021-22 to study genetic variability, association between different characters, and direct and indirect effects of component traits to formulate selection criteria for utilization in crop improvement programme. The analysis of variance indicated exitance of sufficient genetic variability for all morphological and yield traits taken for the study. High PCV and GCV were reported for marketable curd weight, net curd weight and stalk length. Similarly, high heritability coupled with high genetic advance was observed for gross plant weight, marketable curd weight and curd solidity which indicates that these traits can be easily improved through simple selection. Correlation and path coefficient analysis revealed that gross plant weight, net curd weight, curd size index, curd solidity, plant frame and stalk length could be considered as the best selection parameters for evolving high yielding cauliflower genotypes.

Keywords: Cauliflower, genetic variability, heritability, correlation, path analysis

INTRODUCTION

Cauliflower (*Brassica oleracea* var. *botrytis* L.), also known as "*Phoolgobhi*" belongs to the family *Brassicaceae* and is one of the vegetables among the Cole crops grown worldwide (Kumar *et al.,* 2017). All the cultivated forms of the cole crops have evolved from the wild cabbage, *Brassica oleracea* var. *sylvestris* L., a leafy kale-like plant that became fully domesticated and many varieties were developed from it in the Eastern Mediterranean region about 2000 years ago (Boriss *et al.,* 2006). Cauliflower is diploid with chromosome number 2n =2x=18 and the centre of origin for cauliflower is the Island of Cyprus (Topwal *et al.,* 2019). In India, it was introduced by Jemson in 1822 (Nath *et al.,* 1987). Globally, cauliflower occupies an area of 1.42 million hectares with production of 26.50 million metric tonnes and productivity of 18.69 metric tonnes per hectare (FAO, 2019). In India, it is cultivated in an area of 4.67 lakh hectares, with production of 89.41 lakh metric tonnes and productivity of 19.14 metric tonnes per hectare (Anonymous, 2019). It is grown under for its white, soft curd which is consumed as a vegetable, soups, curries and pickles (Savita *et al.,* 2014).

Development of high yielding genotypes is the ultimate goal in any crop improvement programme. To achieve this target, it is essential to generate information on the available genetic variability and its heritable quotient is very essential. Correlation studies help to scrutinize the magnitude and direction of association between one character and another whereas path coefficient analysis provides the information on direct and indirect effects of independent variables on the dependent variable (Rathi and Dhaka, 2007). To improve the selection efficiency in crops, it is important to ascertain which traits are associated with yield.

Therefore, the present study was undertaken with the objective of assessing the genetic variability parameters *viz.,* genotypic and phenotypic coefficient of variation, heritability coupled with genetic advance as percent of mean, correlation and path coefficient analysis for marketable curd weight and other contributing traits that would help in selecting superior genotypes with desirable traits, which can further be used in hybridization programme to either exploit heterosis or isolation of transgressive segregants.

MATERIALS AND METHODS

Thirty-six genotypes including three checks namely, Palam Uphar, Pusa Snowball K-1, Pusa Snowball K-25 were evaluated at the Research Farm, Department of Vegetable Science and Floriculture, College of Agriculture, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur during winter season 2021-22. The experimental material was raised in α-RBD design with three replications including nine blocks per replication and four entries per block. The experimental site is situated 32°1' North latitude and 76°5' East longitude and at an elevation of about 1290.8 m above mean sea level. The seedlings raised in nursery beds of size 3m × 1m × 0.15 m were transplanted at the spacing of 45 × 45 cm between rows and between plants. All the recommended package of practices and plant protection measures were followed throughout the cropping period. Observations were recorded on five randomly selected plants from each entry in all the replications for 20 traits *viz.,* days to curd initiation, days to first marketable curd harvest, stalk length (cm), leaf length (cm), leaf width (cm), number of leaves per plant, plant height (cm), plant frame (cm), curd polar diameter (cm), curd equatorial diameter (cm), curd size index (cm^2), curd solidity (g/cm), gross plant weight (g), marketable curd weight (g), net curd weight (g), non-marketable curds (%), harvest duration (days), harvest index (%), total soluble solids (°Brix) and ascorbic acid (mg per 100g fresh weight basis). The analysis of variance (ANOVA) was carried out as suggested by Parsad *et al.* (2007). Genotypic, phenotypic and environmental coefficients of variation were estimated by following the method of Burton and De Vane (1953). Heritability in broad sense (h^2_{bs}) and expected genetic advance (GA) as percent of mean was calculated as per Burton and De Vane (1953) and Johnson *et al.* (1955). The interrelationships between yield and yield contributing traits (genotypic and phenotypic correlation coefficients) were examined by the method of analysis of variance and covariance matrix as per Al- Jibouri *et al.* (1958). The direct and indirect effect of component traits on marketable curd weight as the dependent variable was computed by following the method of Dewey and Lu (1959). The ascorbic acid contents were estimated by titration method as described by AOAC (1970).

RESULTS AND DISCUSSION

Analysis of variance: The degree of genetic variability present in the germplasm determines the success of any plant breeding program (Kumar *et al.,* 2011, Subbulakshmi *et al.*, 2023). The analysis of variance for 20 characters revealed significant differences among the genotypes (**Table 1**) which indicates the existence of enormous amount of genetic variability for various morphological and yield attributes in cauliflower. Similar findings were reported earlier by Vanlalneihi *et al.* (2017), Chatterjee *et al.* (2018), Kumar *et al.* (2018), Sharma *et al.* (2018a), Gariya *et al.* (2019), Shree *et al.* (2019) and Kumar *et al.* (2021).

Phenotypic and genotypic coefficient of variation: Knowing the genotypic and phenotypic coefficients of variation aids in forecasting the amount of variation present in a genetic population (Sharma *et al.,* 2018a). In the present investigation, PCV values were slightly higher than GCV for all the characters taken for the study which indicates the presence of environmental influence in the expression of various traits (**Table 2**). High PCV and GCV were observed for marketable curd weight (20.26% and 20.13%), net curd weight (26.66% and 26.52%), stalk length (23.13% and 23.01%), curd solidity (22.84% and 22.67%), harvest duration (25.07% and 22.65%), ascorbic acid (22.66% and 22.23%) and non-marketable curds (38.61% and 35.87) which indicated that the population had sufficient variability and selection could be practiced for the improvement of these traits. This finding is in concordance with Ansari (2017), Kumar *et al.* (2019) for net curd weight; Sharma *et al.* (2006) for stalk length; Gariya *et al.* (2019), Kumar *et al.* (2019) for marketable curd weight; Sharma *et al.* (2018b) for curd solidity and Singh *et al.* (2013) for ascorbic acid.

The traits namely days to curd initiation (17.20% and 16.95%), plant frame (11.64% and 10.94%), curd size index (14.35% and 14.85%), gross plant weight (19.80% and 19.70%) and total soluble solids (12.94% and 12.50%) showed moderate PCV and GCV, indicating that selection for improvement of the genotypes for these traits should be undertaken with caution. Moderate PCV and GCV for gross plant weight were earlier reported by Nimkar and Korla (2011) and Chittora and Singh (2015).

Heritability and genetic advance: Resemblance of progenies with their parents is regulated by heritability while genetic advance provides the information regarding the magnitude of expected gain for any particular trait following the selection. An estimate of broad-sense heritability provides valuable knowledge about the relative magnitude of genetic variation and environmental variation present in the population and helps in the recognition of genotypes through phenotypic expression (Lush, 1940). The genetic advance represents the improvement in the genetic value of the new population over the original one. The understanding of heritability

Table 1. Analysis of variance for marketable curd weight and other traits in cauliflower genotypes

Source of variation	Replication	Blocks with in replication	Genotype	Error
df	**2**	**24**	**35**	**47**
Days to curd initiation	3.90	6.16	419.51*	4.56
Days to first marketable curd harvest	26.84	4.70	196.07*	4.39
Stalk length (cm)	0.032	0.006	0.968*	0.004
Leaf length (cm)	23.00	5.73	19.92*	2.45
Leaf width (cm)	6.00	0.89	3.78*	0.81
Number of leaves per plant	1.44	0.44	1.73*	0.35
Plant height (cm)	33.16	3.21	31.81*	2.47
Plant frame (cm)	12.22	3.81	61.97*	3.75
Curd polar diameter (cm)	0.14	0.05	0.61*	0.02
Curd equatorial diameter (cm)	0.39	0.07	1.88*	0.09
Curd size index (cm^2)	63.61	9.99	250.94*	7.89
Curd solidity (g/cm)	1.63	1.30	197.36*	1.13
Gross plant weight (g)	1253.37	232.76	52798.53*	175.89
Marketable curd weight (g)	877.54	118.35	21361.16*	113.09
Net curd weight (g)	578.54	73.04	13212.01*	56.51
Non marketable curd (%)	10.17	6.53	70.25*	4.92
Harvest duration (days)	0.95	2.91	23.02*	1.65
Harvest Index	2.83	0.66	74.69*	0.96
Total soluble solid (^{0}Brix)	0.82	0.07	2.02*	0.06
Ascorbic acid content (mg/ 100g fresh weight basis)	0.01	0.35	20.66*	0.39

along with genetic advance provides an insight into how quantitative traits are passed down through generations and facilitates drawing conclusions to perform effective selection depending upon phenotypic performance (Johnson *et al.,* 1955). High heritability was recorded for days to curd initiation (97.05%), days to first marketable curd harvest (94.25%), stalk length (98.95%), plant height (82.49%), plant frame (88.42%), curd polar diameter (89.83%), curd equatorial diameter (91.50%), curd size index (93.30%), curd solidity (98.54%), gross plant weight (99.07%), marketable curd weight (98.92%), net curd weight (98.71%), non-marketable curd (86.33), harvest duration (81.63%), harvest index (95.21%), total soluble solids (93.30%) and ascorbic acid (96.20%). This showed the importance of genetic components of variation over environmental factors. Earlier workers also reported high heritability estimates for days to curd initiation and days to first marketable curd harvest (Kumar *et al.,* 2011, Chittora and Singh, 2015); stalk length (Sharma *et al.,* 2018b, Gariya *et al.,* 2019 and Kumar *et al.,* 2019); plant height (Shree *et al.,* 2019); harvest index (Nimkar and Korla, 2011); curd polar diameter, curd equatorial diameter (Ansari *et al.,* 2017 and Kumar *et al.,* 2019); gross plant weight, marketable curd weight, net curd weight (Chatterjee *et al.,* 2018, Sharma *et al.,* 2018b, Gariya *et al.,* 2019 and Kumar *et al.,* 2019); ascorbic acid content (Mehra and Singh, 2013, Chittora and Singh, 2015 and Gariya, 2019); curd size index and harvest index (Sharma *et al.,* 2018b).

The traits namely days to curd initiation (34.39%), stalk length (47.15%), curd solidity (46.36%), gross plant weight (66.66%), marketable curd weight (42.15%), harvest duration (44.91%), harvest index (40.40%), total soluble solids (54.33%), ascorbic acid (41.21%), plant frame (21.20%), curd size index (28.55%) and non-marketable curd (24.86%) recorded high genetic advance as percentage of mean. These findings are in consonance with Gariya *et al.* (2019) and Kumar *et al.* (2019).

High heritability coupled with higher genetic advance as percent of mean was recorded for gross plant weight, marketable curd weight, curd solidity, days to curd initiation, stalk length, harvest duration, harvest index, total soluble solids and ascorbic acid indicating that heritability is attributable to additive gene effect and hence selection method of breeding could be employed for improvement of these traits. (**Table 2**). Similar findings were also described by Chatterjee *et al.* (2018), Sharma *et al.* (2018b) and Kumar *et al.* (2019).

Correlation coefficient analysis: Knowledge of relationships between yield and its component traits is essential as this may help in constructing suitable selection criteria for yield characters (Kibar *et al.,* 2014). Searle (1961) proposed the mathematical model of correlation at the phenotypic, genotypic and environmental levels. The mechanism behind association among the characters is either pleiotropic gene action or linkage or maybe both

Table 2. Estimates of genetic variability parameters for various traits in cauliflower

Traits	Mean± SEm	Range	ECV (%)	GCV (%)	PCV (%)	h^2_{bs}	GA (%)
Days to curd initiation	77.01±1.31	57.33- 103.33	2.95	16.95	17.20	97.05	34.39
Days to first marketable curd harvest	97.71±1.23	89.67- 122.67	2.16	8.84	9.11	94.25	17.68
Stalk length	2.77±0.04	1.70-4.31	2.37	23.01	23.13	98.95	47.15
Leaf length	31.59±1.10	25.14-37.67	6.01	9.63	11.36	71.96	16.83
Leaf width	15.65±0.53	12.02-18.40	5.89	8.48	10.33	67.42	14.35
Number of leaves per plant	11.34±0.36	9.00-13.40	5.49	7.77	9.51	66.68	13.07
Plant height	38.79±0.96	32.00-46.39	4.28	9.29	10.23	82.49	17.39
Plant frame	49.40±1.13	37.97-61.51	3.96	10.94	11.64	88.42	21.20
Curd polar diameter	7.17±0.10	6.26-8.25	2.45	7.28	7.68	89.83	14.21
Curd equatorial diameter	10.67±0.16	9.07-12.50	2.66	8.74	9.13	91.50	17.22
Curd size index	76.84±1.71	56.77-98.11	3.84	14.35	14.85	93.30	28.55
Curd solidity	39.73±0.63	20.75-56.61	2.76	22.67	22.84	98.54	46.36
Gross plant weight	736.46±22.93	428.07-993.33	1.91	19.70	19.80	99.07	68.66
Marketable curd weight	468.62±17.62	285.36-654.77	2.30	20.13	20.26	98.92	42.15
Net curd weight	286.57±12.96	135.53-423.87	2.77	26.52	26.66	98.71	15.59
Non marketable curd	17.36±1.43	10.37-39.17	14.27	35.87	38.61	86.33	24.86
Harvest duration	13.64±0.85	7.33-22.00	7.75	22.65	25.07	81.63	44.91
Harvest Index	61.63±0.64	35.35-73.31	2.44	7.76	7.95	95.21	40.40
Total soluble solids	7.65±0.15	5.73-9.31	3.35	12.50	12.94	93.30	54.33
Ascorbic acid	13.96±0.36	7.94-20.31	4.42	22.23	22.66	96.20	41.21

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

(Kibar *et al.,* 2014). The phenotypic correlation consists of both genotypic and environmental effects and it provides basic knowledge about the overall association among phenotypic characters. Genotypic correlation provides a measure of genetic association among various characters and is most commonly utilized during selection programmes. A higher genotypic correlation coefficient than the phenotypic correlation coefficient, indicates a strong inherent association between various traits. Conversely, a low phenotypic correlation would be caused by the environment's masking and modifying effects on the association of traits at the genetic level.

In the present study, marketable curd weight showed the highest positively significant correlation with gross plant weight (0.923), net curd weight (0.899), curd solidity (0.876), curd equatorial diameter (0.701), curd size index (0.686), curd polar diameter (0.491) and harvest index (0.195). Further, a critical insight into correlation coefficients showed that days to curd initiation had a positive and significant correlation with days to first marketable curd harvest indicating that curd initiation corresponds to harvest of curds *i.e.,* early initiation results in early harvest of the crop (**Table 3**). Similar findings were reported for significant and positive association of marketable curd weight with net curd weight (Shruthy and Celine, 2016 and Vanlalneihi *et al.,* 2017); curd size index (Sharma *et al.,* 2006); curd equatorial diameter, number of leaves per plant, harvest index and plant height (Singh *et al.,* 2014). The overall study of association revealed that any positive increase in these traits will accelerate the yield improvement of cauliflower. Therefore, the selection of these traits may be beneficial for selecting superior genotypes from variable populations for improvement of yield in cauliflower.

Path coefficient analysis: Correlation coefficients are typically partitioned into direct and indirect effects using path coefficient analysis. This mutual relationship may vary both in direction as well as in magnitude and it tends to deviate the association of marketable curd weight with other traits. Hence, it is essential to partition the genotypic and phenotypic association into their direct and indirect effects.

The results of the path-coefficient analysis revealed that gross plant weight had a maximum positive and direct effect on marketable curd weight (0.929) followed by considerable contribution of harvest index (0.375) and curd size index (0.221). Net curd weight and days to first marketable curd harvest also contributed significantly to the total association directly at the genotypic level. In addition, stalk length, plant frame, harvest duration and total soluble solids had also very little direct contribution towards the total association with marketable curd weight (**Table 4**). Since the attributes were closely related, it is

Table 3. Estimates of phenotypic (P) and genotypic (G) correlation coefficients for different pair of traits in cauliflower

Traits		Days to curd initiation	Days to first marketable curd harvest	Stalk length	Leaf length	Leaf width	Number of leaves per plant	Plant height	Plant frame	Curd polar diameter	Curd equatorial diameter	Curd size index	Curd solidity	Non marketable curd	Harvest duration	Harvest Index	Total soluble solids	Ascorbic acid content	Gross plant weight	Net curd weight
Days to first marketable curd harvest	P	0.915*																		
	G	0.938*																		
Stalk length	P	-0.537*	-0.617*																	
	G	-0.550*	-0.640*																	
Leaf length	P	-0.107	-0.071	0.357*																
	G	-0.117	-0.087	0.418*																
Leaf width	P	0.095	0.162	0.226*	0.585*															
	G	0.129	0.197*	0.277*	0.524*															
Number of leaves per plant	P	-0.199*	-0.193*	0.136	0.185	0.106														
	G	-0.247*	-0.239*	0.161	0.211*	0.137														
Plant height	P	-0.171	-0.146	0.455*	0.796*	0.448*	0.218*													
	G	-0.184	-0.188	0.499*	0.839*	0.404*	0.267*													
Plant frame	P	-0.093	-0.074	0.415*	0.716*	0.549*	-0.001	0.680*												
	G	-0.096	-0.075	0.446*	0.771*	0.551*	0.001	0.732*												
Curd polar diameter	P	-0.305*	-0.266*	0.230*	0.230*	0.083	0.305*	0.243*	0.001											
	G	-0.315*	-0.274*	0.241*	0.231*	0.039	0.348*	0.265*	-0.026											
Curd equatorial diameter	P	-0.125	-0.132	0.174	0.182	0.151	0.466*	0.160	0.080	0.562*										
	G	-0.125	-0.137	0.180	0.164	0.115	0.574*	0.161	0.055	0.604*										
Curd size index	P	-0.236*	-0.224*	0.236*	0.236*	0.136	0.439*	0.233*	0.049	0.866*	0.898*									
	G	-0.237*	-0.229*	0.243*	0.222*	0.090	0.521*	0.240*	0.019	0.880*	0.908*									
Curd solidity	P	0.126	0.049	0.110	0.151	0.162	0.316*	0.196*	0.160	0.315*	0.611*	0.549*								
	G	0.130	0.050	0.113	0.165	0.180	0.390*	0.211*	0.160	0.352*	0.634*	0.575*								
Non marketable curd	P	0.152	0.161	-0.109	-0.401	-0.267*	-0.437*	-0.255*	-0.216*	-0.501*	-0.529*	-0.577*	-0.422*							
	G	0.164	0.163	-0.118	-0.463*	-0.299*	-0.554*	-0.298*	-0.232*	-0.533*	-0.583*	-0.619*	-0.455*							
Harvest duration	P	-0.013	-0.116	0.099	-0.090	0.183	-0.138	0.018	-0.063	-0.063	-0.164	-0.126	0.160	0.095						
	G	-0.013	-0.114	0.107	-0.133	0.192*	-0.227*	-0.007	-0.108	-0.092	-0.188	-0.153	0.185	0.125						
Harvest Index	P	-0.261*	-0.314*	0.316*	-0.157	-0.124	0.100	-0.188	-0.182	0.143	0.149	0.173	0.187	-0.184	-0.123					
	G	-0.275*	-0.335*	0.329*	-0.212*	-0.173	0.106	-0.222*	-0.203*	0.162	0.163	0.190*	0.181	-0.196*	-0.118					
Total soluble solids	P	-0.002	0.024	-0.152	-0.173	-0.002	-0.039	-0.149	-0.211*	-0.237*	-0.153	-0.220*	-0.251*	0.270*	0.003	-0.277				
	G	-0.006	0.025	-0.152	-0.202*	0.001	-0.062	-0.161	-0.226*	-0.256*	-0.154	-0.229*	-0.265*	0.312*	0.008	-0.304*				
Ascorbic acid content	P	0.226*	0.280*	-0.218*	-0.264*	-0.034	0.036	-0.198*	-0.189	-0.150	0.022	-0.077	-0.119	0.413*	-0.168	-0.191*	0.485*			
	G	0.231*	0.296*	-0.222*	-0.286*	-0.007	0.044	-0.216*	-0.191*	-0.142	0.026	-0.071	-0.127	0.453*	-0.177	-0.201*	0.511*			
Gross plant weight	P	0.355*	0.362*	-0.117	0.261*	0.277*	0.342*	0.272*	0.161	0.403*	0.600*	0.584*	0.794*	-0.394*	0.022	-0.190*	-0.125	-0.022		
	G	0.365*	0.379*	-0.119	0.282*	0.309*	0.411*	0.291*	0.154	0.416*	0.618*	0.594*	0.801*	-0.421*	0.015	-0.193*	-0.131	-0.018		
Net curd weight	P	0.022	-0.039	0.172	0.199*	0.165	0.365*	0.240*	0.141	0.566*	0.699*	0.734*	0.959*	-0.504*	0.103	0.212*	-0.282*	-0.139	0.806*	
	G	0.026	-0.038	0.175	0.207*	0.166	0.439*	0.255*	0.132	0.584*	0.723*	0.749*	0.964*	-0.535*	0.112	0.210*	-0.296*	-0.140	0.809*	
Marketable curd weight	P	0.236*	0.222*	0.025	0.203*	0.218*	0.375*	0.204*	0.100	0.471*	0.676*	0.669*	0.870*	-0.470*	-0.023	0.203*	-0.233*	-0.098	0.921*	0.896*
	G	0.243*	0.233*	0.025	0.208*	0.234*	0.443*	0.215*	0.087	0.491*	0.701*	0.686*	0.876*	-0.503*	-0.028	0.195*	-0.248*	-0.096	0.923*	0.899*

* Significant at P ≤ 0.05

Table 4. Estimates of direct and indirect effects of different traits on marketable curd weight at phenotypic (P) and genotypic (G) levels in cauliflower

Traits		Days to curd initiation	Days to first marketable curd harvest	Stalk length	Leaf length	Leaf width	Number of leaves per plant	Plant height	Plant frame	Curd polar diameter	Curd equatorial diameter
Days to curd initiation	P	**-0.029**	0.052	-0.008	-0.001	-0.004	0.001	0.001	-0.003	0.049	0.019
	G	**-0.184**	0.251	-0.028	0.001	-0.013	0.002	-0.002	-0.005	0.136	0.008
Days to first marketable curd harvest	P	-0.027	**0.057**	-0.010	0.000	-0.006	0.001	0.001	-0.002	0.043	0.020
	G	-0.173	**0.268**	-0.033	0.000	-0.020	0.002	-0.002	-0.004	0.118	0.009
Stalk length	P	0.016	-0.035	**0.016**	0.002	-0.009	-0.001	-0.004	0.013	-0.037	-0.026
	G	0.101	-0.171	**0.051**	-0.002	-0.028	-0.002	0.005	0.021	-0.104	-0.012
Leaf length	P	0.003	-0.004	0.006	**0.005**	-0.023	-0.001	-0.007	0.023	-0.037	-0.027
	G	0.022	-0.023	0.022	**-0.005**	-0.053	-0.002	0.008	0.037	-0.100	-0.011
Leaf width	P	-0.003	0.009	0.004	0.003	**-0.040**	-0.001	-0.004	0.018	-0.013	-0.023
	G	-0.024	0.053	0.014	-0.003	**-0.101**	-0.001	0.004	0.026	-0.017	-0.008
Number of leaves per plant	P	0.006	-0.011	0.002	0.001	-0.004	**-0.007**	-0.002	0.000	-0.049	-0.070
	G	0.046	-0.064	0.008	-0.001	-0.014	**-0.010**	0.003	0.000	-0.150	-0.039
Plant height	P	0.005	-0.008	0.007	0.004	-0.018	-0.002	**-0.008**	0.022	-0.039	-0.024
	G	0.034	-0.050	0.026	-0.005	-0.041	-0.003	**0.010**	0.035	-0.114	-0.011
Plant frame	P	0.003	-0.004	0.007	0.004	-0.022	0.000	-0.006	**0.033**	0.000	-0.012
	G	0.018	-0.020	0.023	-0.004	-0.056	0.000	0.007	**0.048**	0.011	-0.004
Curd polar diameter	P	0.009	-0.015	0.004	0.001	-0.003	-0.002	-0.002	0.000	**-0.160**	-0.084
	G	0.058	-0.073	0.012	-0.001	-0.004	-0.003	0.003	-0.001	**-0.431**	-0.041
Curd equatorial diameter	P	0.004	-0.008	0.003	0.001	-0.006	-0.003	-0.001	0.003	-0.090	**-0.149**
	G	0.023	-0.037	0.009	-0.001	-0.012	-0.005	0.002	0.003	-0.261	**-0.068**
Curd size index	P	0.007	-0.013	0.004	0.001	-0.005	-0.003	-0.002	0.002	-0.139	-0.134
	G	0.044	-0.061	0.013	-0.001	-0.009	-0.005	0.002	0.001	-0.380	-0.062
Curd solidity	P	-0.004	0.003	0.002	0.001	-0.006	-0.002	-0.002	0.005	-0.050	-0.091
	G	-0.024	0.013	0.006	-0.001	-0.018	-0.004	0.002	0.008	-0.152	-0.043
Non marketable curd	P	-0.004	0.009	-0.002	-0.002	0.011	0.003	0.002	-0.007	0.080	0.079
	G	-0.030	0.044	-0.006	0.003	0.030	0.005	-0.003	-0.011	0.230	0.040
Harvest duration	P	0.000	-0.007	0.002	0.000	-0.007	0.001	0.000	-0.002	0.010	0.025
	G	0.002	-0.031	0.005	0.001	-0.019	0.002	0.000	-0.005	0.040	0.013
Harvest Index	P	0.008	-0.018	0.005	-0.001	0.005	-0.001	0.002	-0.006	-0.023	-0.022
	G	0.051	-0.090	0.017	0.001	0.017	-0.001	-0.002	-0.010	-0.070	-0.011
Total soluble solids	P	0.000	0.001	-0.002	-0.001	0.000	0.000	0.001	-0.007	0.038	0.023
	G	0.001	0.007	-0.008	0.001	0.000	0.001	-0.002	-0.011	0.110	0.010
Ascorbic acid	P	-0.007	0.016	-0.003	-0.001	0.001	0.000	0.002	-0.006	0.024	-0.003
	G	-0.043	0.079	-0.011	0.002	0.001	0.000	-0.002	-0.009	0.061	-0.002
Gross plant weight	P	-0.010	0.021	-0.002	0.001	-0.011	-0.003	-0.002	0.005	-0.065	-0.089
	G	-0.067	0.101	-0.006	-0.002	-0.031	-0.004	0.003	0.007	-0.179	-0.042
Net curd weight	P	-0.001	-0.002	0.003	0.001	-0.007	-0.003	-0.002	0.005	-0.091	-0.104
	G	-0.005	-0.010	0.009	-0.001	-0.017	-0.004	0.002	0.006	-0.252	-0.049

Residual effect at phenotypic level (P) = 0.00233, and genotypic level (G) = 0.00048

*Significant at P ≤0.05; bold values indicate direct effects; r: correlation coefficient with marketable curd weights

Table 4. Continued..

Traits		Curd size index	Curd solidity	Non market-able curd	Harvest duration	Harvest Index	Total soluble solids	Ascorbic acid	Gross plant weight	Net curd weight	r
Days to curd initiation	P	-0.076	0.000	-0.002	0.000	-0.099	0.000	0.000	0.335	0.000	0.236*
	G	-0.052	-0.125	-0.011	-0.001	-0.103	0.000	0.001	0.340	0.029	0.243*
Days to first marketable curd harvest	P	-0.072	0.000	-0.002	-0.003	-0.119	0.000	0.000	0.342	-0.001	0.222*
	G	-0.050	-0.048	-0.011	-0.010	-0.126	0.000	0.002	0.352	-0.042	0.233*
Stalk length	P	0.077	0.000	0.001	0.002	0.120	-0.002	0.000	-0.110	0.003	0.025
	G	0.054	-0.109	0.008	0.010	0.124	-0.003	-0.001	-0.110	0.194	0.025
Leaf length	P	0.076	0.000	0.004	-0.002	-0.060	-0.002	0.000	0.246	0.003	0.203*
	G	0.049	-0.159	0.030	-0.012	-0.080	-0.004	-0.002	0.262	0.230	0.208*
Leaf width	P	0.044	0.000	0.003	0.004	-0.047	0.000	0.000	0.262	0.003	0.218*
	G	0.020	-0.173	0.019	0.017	-0.065	0.000	0.000	0.287	0.185	0.234*
Number of leaves per plant	P	0.142	-0.001	0.004	-0.003	0.038	-0.001	0.000	0.323	0.006	0.375*
	G	0.115	-0.375	0.036	-0.021	0.040	-0.001	0.000	0.382	0.488	0.443*
Plant height	P	0.075	-0.001	0.003	0.000	-0.071	-0.002	0.000	0.257	0.004	0.204*
	G	0.053	-0.203	0.019	-0.001	-0.083	-0.003	-0.001	0.270	0.283	0.215*
Plant frame	P	0.016	0.000	0.002	-0.001	-0.069	-0.003	0.000	0.152	0.002	0.100
	G	0.004	-0.154	0.015	-0.010	-0.076	-0.004	-0.001	0.143	0.147	0.087
Curd polar diameter	P	0.281	-0.001	0.005	-0.001	0.054	-0.003	0.000	0.381	0.010	0.471*
	G	0.194	-0.338	0.035	-0.008	0.061	-0.005	-0.001	0.387	0.650	0.491*
Curd equatorial diameter	P	0.291	-0.002	0.005	-0.004	0.057	-0.002	0.000	0.566	0.012	0.676*
	G	0.201	-0.610	0.038	-0.017	0.061	-0.003	0.000	0.574	0.804	0.701*
Curd size index	P	**0.324**	-0.002	0.006	-0.003	0.066	-0.003	0.000	0.551	0.013	0.669*
	G	**0.221**	-0.554	0.040	-0.014	0.071	-0.004	0.000	0.552	0.832	0.686*
Curd solidity	P	0.178	**-0.003**	0.004	0.004	0.071	-0.004	0.000	0.749	0.016	0.870*
	G	0.127	**-0.963**	0.030	0.017	0.068	-0.005	-0.001	0.744	1.072	0.876*
Non marketable curd	P	-0.187	0.001	**-0.010**	0.002	-0.070	0.004	0.001	-0.372	-0.009	-0.470*
	G	-0.137	0.438	**-0.065**	0.011	-0.074	0.006	0.003	-0.391	-0.595	-0.503*
Harvest duration	P	-0.041	0.000	-0.001	**0.022**	-0.047	0.000	0.000	0.021	0.002	-0.023
	G	-0.034	-0.179	-0.008	**0.091**	-0.044	0.000	-0.001	0.014	0.125	-0.028
Harvest Index	P	0.056	-0.001	0.002	-0.003	**0.380**	-0.004	0.000	-0.179	0.004	0.203*
	G	0.042	-0.174	0.013	-0.011	**0.375**	-0.006	-0.001	-0.180	0.234	0.195*
Total soluble solids	P	-0.071	0.001	-0.003	0.000	-0.105	**0.014**	0.001	-0.118	-0.005	-0.233*
	G	-0.051	0.256	-0.020	0.001	-0.114	**0.018**	0.003	-0.122	-0.329	-0.248*
Ascorbic acid	P	-0.025	0.000	-0.004	-0.004	-0.072	0.007	**0.002**	-0.021	-0.002	-0.098
	G	-0.016	0.122	-0.029	-0.016	-0.075	0.009	**0.006**	-0.017	-0.156	-0.096
Gross plant weight	P	0.189	-0.002	0.004	0.001	-0.072	-0.002	0.000	**0.944**	0.014	0.921*
	G	0.131	-0.771	0.027	0.001	-0.073	-0.002	0.000	**0.929**	0.900	0.923*
Net curd weight	P	0.238	-0.003	0.005	0.002	0.080	-0.004	0.000	0.761	**0.017**	0.896*
	G	0.165	-0.928	0.035	0.010	0.079	-0.005	-0.001	0.752	**1.112**	0.899*

Residual effect at phenotypic level (P) = 0.00233, and genotypic level (G) = 0.00048

*Significant at P ≤0.05; bold values indicate direct effects; r: correlation coefficient with marketable curd weights recommended that these traits could be given priority in selection for development of cauliflower genotypes with high yield. Earlier workers have also reported positive and direct effects of different traits with marketable curd weight *i.e.* gross plant weight and harvest index (Sheemar *et al.,* 2012); curd equatorial diameter (Liu *et al.,* 2004); curd polar diameter (Sheemar *et al.,* 2012) and net curd weight (Vanlalneihi *et al.,* 2017).

The partitioning of positive association of marketable curd weight with gross plant weight, net curd weight, curd solidity, curd polar diameter, curd equatorial diameter, curd size index, number of leaves per plant, leaf length, leaf width, plant height, plant frame, days to curd initiation and days to first marketable curd harvest revealed that indirect effects through gross plant weight were the main cause of the association. At the genotypic level, partitioning of association revealed that net curd weight had a significant indirect contribution towards the magnitude of association of marketable curd weight with most of these traits namely, leaf length, leaf width, number of leaves per plant, plant height, plant frame, curd polar diameter, curd equatorial diameter, curd size index, curd solidity, harvest index and gross plant weight. The contribution of different traits towards the marketable curd weight were reported earlier by Sharma *et al.* (2006) for days to marketable curd maturity; Sheemar *et al.* (2012) for harvest index; Kumar *et al.* (2011) and Sheemar *et al.* (2012) for curd depth; Kumar *et al.* (2011) for stalk length; Shree *et al.* (2019) for leaf length and leaf width.

From present research it can be concluded that sufficient genetic variability was detected for all the 20 traits taken for the study. PCV and GCV were high for marketable curd weight, net curd weight, stalk length, curd solidity, harvest duration, ascorbic acid and non-marketable curds ensuring ample scope for improvement of these traits through simple selection. High heritability along with high genetic advance was recorded for gross plant weight, marketable curd weight, curd solidity, days to curd initiation, days to first marketable curd harvest, stalk length, harvest index, total soluble solids and ascorbic acid suggesting the importance of additive gene action. Correlation studies revealed that marketable curd weight showed a positive and significant correlation with gross plant weight, net curd weight, curd solidity, curd equatorial diameter, curd size index, curd polar diameter, harvest index, number of leaves per plant, days to curd initiation, leaf width, days to first marketable curd harvest, plant height and leaf length. Path coefficient studies revealed that gross plant weight, harvest index, curd size index, stalk length, plant frame, harvest duration and total soluble solids were the important yield determinants as these traits displayed high direct/indirect effects on total association with marketable curd weight. Therefore, when planning for the selection approach of a breeding programme to create high yielding varieties of cauliflower, these traits could be given due consideration for tangible improvement in yield.

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