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RESEARCH ARTICLE

Breeding for Higher Ascorbic Acid and Mineral Nutrients in Snowball Cauliflower (*Brassica oleracea* var. *botrytis* L.)

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Abstract

The components of genetic variance and gene action effects for ascorbic acid and mineral nutrient contents in snowball cauliflower lines were estimated through line × tester analysis involving 5 Ogura based CMS lines and 7 male fertile testers. The mean squares due to lines and testers were significant for ascorbic acid and mineral nutrients (Ca, Mg, Na, K, S, Fe, Mn and Zn). Ogu 103 was best performing CMS line for K (182.32 mg/100 g), S (29.48 mg/100 g), Ca (23.19 mg/100 g), Mg (13.22 mg/100 g), Zn (313.33 µg/100 g) and Mn (235.00 µg/100 g) whereas maximum ascorbic acid (81.26), Na (24.37) and Fe content (645.03 µg/100 g) was noted in Ogu 119, Ogu 13-85 and Ogu 13-01, respectively. Among the testers, Kt-18 recorded maximum value (mg/100 g) for Na (98.03), K (277.52), S (42.87), Ca (43.73) and Mg (29.44), respectively, whereas Kt-22 had highest ascorbic acid (70.84 mg/100 g) and Mn content (343.50 µg/100 g) and Sel-26 had maximum Fe (1424.93 µg/100 g) and Zn (458.70 µg/100 g) contents. The best-performing hybrids for different macro-nutrients (mg/100 g) were, Ogu 101 × Sel-26 for ascorbic acid (94.05), Ogu 103 × Sel-26 for Na (98.63), Ogu 13-01 × Sel-26 for K (300.18), Ogu 101 × Lalchowk Maghi for S (49.34), Ogu 119 × Suprimax Late for Ca (54.65), Ogu 13-85 × DB-187 for Mg (35.60). For micronutrients (µg/100 g FW), the best hybrids were Ogu 13-01 × DB-187 for Fe (1775.60), Ogu 101 × Lalchowk Maghi for Zn (642.10) and Ogu 101 × Kt-22 for Mn content (381.60). Predominance of dominance component of variance was observed for vitamin C and mineral nutrients. The traits studied had narrow differences among GCV, PCV and broad sense heritability values, suggesting low effect of environment. The variance due to general (σ^2gca) and specific combining abilities (σ^2sca) were highly significant indicating the importance of both additive (σ^2A) as well as non-additive (σ^2D) type of gene actions. However, the ratios of σ^2gca/ σ^2sca (<1) and σ^2A/σ^2D (<1) revealed the preponderance of non-additive variance for the inheritance of traits studied. The study's results suggest the possibility of improving these traits through recurrent selection and hybridization.

Keywords: Cauliflower, Cytoplasmic male sterility, Gene action, Line × tester, Minerals.

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Introduction

Cauliflower (*Brassica oleracea* var. *botrytis* L., 2n = 2x = 18) is a popular brassica vegetable grown mostly as winter season crop in India. It is used as a vegetable in curries, soups, pickles (Rakshita *et al*., 2021; Dey *et al*., 2013). Pieces of cauliflower (buttons) can be fried with *besan* for preparation of *pakoras*. Cauliflower is grown worldwide in 1.42 mha area with annual production of 26.50 million tonnes. China (40.5%) and India (33.2%) are the major global producers of cauliflower (FAOSTAT, 2018). In India, cauliflower is grown in 0.47 mha area with annual production of 9.22 million tonnes (Agricultural Statistics at a Glance 2021). Cauliflower is classified into four maturity groups, group I (September to early November), group II (mid-November to early December), group III (mid-December to mid-January) and group IV (mid-January to early March). First three groups are Indian cauliflower and the last group is called Erfurt or alpha types *i.e.,* snowball (late group) type as per Swarup and Chatterjee (1972). In this crop, breeding work has

primarily been focussed on early and mid-groups, but not on the snowball group due to insufficient genetic variability and specific geographical conditions for seed production. Snowball or European cauliflower is the main vegetable crop grown during winter season in the Indian sub-continent.

The macro- and micronutrients are vital for human beings and plants. Knowledge of mineral element concentrations in plants would be beneficial in monitoring and managing the plant, human and animal nutrition balance in a food-chain cycle (Ram *et al*., 2018). Billions of people in developing countries suffer from micronutrient malnutrition or 'hidden hunger' caused by intake of insufficient micronutrients such as Vitamin-A, Zn, and Fe (Harvest Plus, 2007). Vegetable *Brasiccas* are good sources of different phytochemicals and mineral elements. Cauliflower supplies ascorbic acid (47.14 mg/100 g) and minerals like calcium (25.16 mg/100 g), magnesium (23.08 mg/100 g), phosphorus (47.33 mg/100 g), potassium (329 mg/100 g), manganese (0.23 mg/100 g), iron (0.96 mg/100 g), copper (0.05 mg/100 g) and zinc (0.31 mg/100 g) (Longvah *et al.* 2017).

The line × tester analysis is one of the most appropriate approaches in preliminary screening of the materials for gene action effects and variances since it can evaluate more germplasm at a time and also provides information for selecting suitable parents and adopting breeding methodology for improving the crop. Most of the genetic studies and breeding efforts have been targeted to limited vegetable crops such as peppers, tomatoes, eggplant and cucurbits. The information regarding breeding for mineral elements in cauliflower is limited. Therefore, the present investigation has been undertaken to determine the gene action for mineral elements using line × tester mating design in snowball cauliflower to suggest suitable breeding approaches for increasing the mineral content of cauliflower curd.

Materials and Methods

Five genetically diverse Ogura based CMS lines of snowball cauliflower *viz*. Ogu 13-01, Ogu 101, Ogu 103, Ogu 119 and Ogu 13-85 and seven testers *viz*. Kt-18, Kt-22, DB-1305, DB-187, Lalchowk Maghi, Sel-26 and Suprima × Late were crossed in line × tester mating scheme (Kempthorne, 1957) to obtain 35 F_1 hybrid combinations during spring summer season at IARI Regional Station, Katrain, H.P. The 35 F_1 hybrids along with their twelve parental lines were evaluated in a randomized block design with three replications during the winter season at the research farm of Division of Vegetable Science, Indian Agricultural Research Institute, New Delhi. Seedlings (38 days old) were transplanted providing inter- and intra-row spacing of 45 cm between plants. All recommended package of practices were followed to grow a healthy successful crop (Thamburaj and Singh, 2001). Each treatment comprised of 5 rows and 8 plants per row and was replicated thrice. Five curds of each genotype in replicated trial were chopped at fresh marketable stage and homogenized for analysis of ascorbic acid and mineral nutrients.

Ascorbic Acid Content Estimation

Ascorbic acid was determined by titrating a known weight of sample with 2,6-dichlorophenol indophenol dye using meta-phosphoric acid as a stabilizing agent (Albrecht, 1993). 3% metaphosphoric acid (HPO_3) was prepared by dissolving the sticks or pellets of HPO_3 in distilled water and diluting it to 100 mL with 3% HPO_3. Ascorbic acid standard is prepared by weighing 100 mg of L-ascorbic acid, dissolving in 3% HPO_3, and making the final volume 100 mL. This was further diluted by taking 10 mL of the above mixture to 100 mL with 3% HPO_3 (1 mL = 0.1 mg of ascorbic acid). For making dye solution, 50 mg of the sodium salt of 2,6-dichlorophenol indophenol in approximately 150 mL of hot glass distilled water containing 42 mg of sodium bicarbonate was dissolved. It was cooled and diluted with distilled water to 200 mL and stored in a refrigerator.

For standardization of dye, 5 mL of standard ascorbic acid solution was taken and 5 mL of HPO_3 was added into it. A micro burette was filled with the dye. It was then titrated with the dye solution to a pink color which persisted for about 15 seconds. The dye factor was determined *i.e.*, mg of ascorbic acid per mL of the dye, using the following formula:

$$\text{Dye factor} = \frac{0.5}{\text{Titre value}}$$

Five gram of cauliflower curd sample was taken and crushed with some amount of 3% HPO_3 in mortar and pestle. The volume was made up to 100 mL with 3% HPO_3 and then filtered and centrifuged. The prepared sample was taken in a conical flask and titrated against standardized dye. The titre value was noted and used for calculation of ascorbic acid content in the sample.

The ascorbic acid content of the sample was calculated with the following formula:

$$\text{Ascorbic acid content (mg/100g)} = \frac{\text{Titre value} \times \text{Dye factor} \times \text{Vol. made up}}{\text{Aliquot of extract} \times \text{volume of sample taken}} \times 100$$

Mineral Nutrients Analyses

Procedure for sample preparation, digestion and estimation of nutrients as described by Tandon (1998) and Jones (2001) were followed. Composite samples of five curds selected randomly from each replication genotype were collected at the edible maturity stage. The curds were chopped into slices, homogenized and 100g of fresh material was kept in oven at 60°C till the samples were dried properly. Dried pieces were then grinded thoroughly in mortar and pestle to a fine powder, passed through a 1-mm sieve, and stored in a butter paper bag inside the desiccator until further use.

Just before the use, the powder was again heated for 2 to 3 hours at 60°C to make it free from any moisture and

then 2.0 g dry powder was transferred into the digestion tube. Tissue samples were pre-digested by adding 20 mL of concentrated HNO_3 in digestion tubes. Samples were then heated at 60°C for 30 minutes, 120°C for 30 minutes and 255°C for 2 hours or till the digestion mixture became transparent on the digestion block. Tubes were then removed from the block and allowed to cool down to room temperature. Volume was made up to 20 mL by adding concentrated HNO_3. The volume of 1-mL taken from digested solution was diluted to 100 mL by adding double distilled water and then it was filtered through Whatman filter paper (number 42). Now samples were used for the estimation of Ca, Mg, Na, K, S, Fe, Mn and Zn. Standard solutions for each nutrient element were also prepared to make standard curves for the respective element.

Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Iron (Fe), Manganese (Mn) and Zinc (Zn) were determined using atomic absorption spectrophotometer (AAS). Absorptions were recorded at 422.7, 285.2, 589.0, 766.5, 248.3, 279.5 and 213.9 nm for Ca, Mg, Na, K, Fe, Mn and Zn, respectively using standard specifications and their respective standard curves. All the elemental concentrations were expressed as per 100 g fresh weight (FW) basis.

In the estimation of total sulphur in the plant sample, wet digest was taken from di-acid digestion method and then determined by barium sulfate turbidimetry method. During wet digestion of the sample, all the plant sulfur is converted to sulfate form, which when treated with $BaCl_2$ is precipitated as $BaSO_4$. This provides turbidity to the solution which is proportional to the amount of sulphate present. Measurement of this turbidity provides the means for the quantitative determination of sulphur. Gum acacia solution was added to help stabilize turbidity.

Statistical analysis for estimation of analysis of variance, components of variance (coefficient of variance, genotypic and phenotypic coefficient of variation), and components of genetic variance (additive variance, σ^2A and dominance variance, σ^2D) was carried out as per Kempthorne (1957) and Singh and Chaudhary (1995).

Results and Discussion

Evaluation of Parents for Ascorbic Acid and Different Mineral Nutrients

The mean value of CMS lines for ascorbic acid (mg/100 g) content ranged from 46.67 (Ogu 103) to 81.26 (Ogu 119). The Na, K, S, Ca and Mg content (mg/100g) ranged from 14.02 (Ogu 101) to 24.37 (Ogu 13-85), 77.22 (Ogu 101) to 182.32 (Ogu 103), 11.12 (Ogu 119) to 29.48 (Ogu 103), 8.84 (Ogu 101) to 23.19 (Ogu 103) and 7.45 (Ogu 101) to 13.22 (Ogu 103), respectively. The Fe, Zn and Mn content (µg/100 g) ranged from 172.20 (Ogu 101) to 645.03 (Ogu 13-01), 45.30 (Ogu 119) to 313.33 (Ogu 103) and 49.43 (Ogu 101) to 235.00 (Ogu 103), respectively. The mean value of testers for ascorbic acid (mg/100 g) content varied from 37.28 (Sel-26) to 70.84 (Kt-22). The Na, K, S, Ca and Mg content (mg/100 g) ranged from 36.81 (Lalchowk Maghi) to 98.03 (Kt-18), 142.57 (Lalchowk Maghi) to 277.52 to (Kt-18), 16.32 (Lalchowk Maghi) to 42.87 (Kt-18), 23.22 (DB-1305) to 43.73 (Kt-18) and 14.23 (Lalchowk Maghi) to 29.44 (Kt-18), respectively. The micronutrients Fe, Zn and Mn content (µg/ 100 g) ranged from 544.33 (Lalchowk Maghi) to 1424.93 (Sel-26), 108.87 (Lalchowk Maghi) to 458.70 (Sel-26) and 147.73 (DB-1305) to 343.50 (Kt-22), respectively (Table 1). Among the CMS lines, Ogu 103 had highest content of K, S, Ca, Mg, Zn and Mn. Ogu 101 recorded minimum values for Na, K, Ca, Mg, Fe and Mn contents. CMS line Ogu 13-01 was second best for Na (21.28 mg/100 g FW), K (137.81 mg/100 g FW), S (21.15 mg/100 g FW) and Ca (15.97 mg/100 g FW). Among testers, Kt-18 had highest Na, K, S, Ca and Mg, Sel-26 recorded highest Fe and Zn, while Kt-22 had the maximum ascorbic acid and Mn content. Kt-18 also had second highest value for Fe (1413.43 µg/100 g) and Zn (292.40 µg/100 g) contents. The best-performing lines and testers can be utilized as parents to develop mineral nutrient-rich hybrids.

Evaluation of Hybrids for Ascorbic Acid and Different Mineral Nutrients

The *per se* performance of 35 F_1 hybrids for ascorbic acid and different mineral nutrients is presented in Table 2. The ascorbic acid content (mg/100 g FW) in hybrids ranged from 31.79 (Ogu 103 × Sel-26) to 94.05 (Ogu 101 × Sel-26). The hybrid Ogu 101 × Sel-26 has a maximum concentration (mg/100 g) of ascorbic acid (94.05), followed by Ogu 119 × Lalchowk Maghi (87.58), Ogu 101 × DB-1305 (82.29) and Ogu 101 × Suprimax Late (81.07). The hybrid Ogu 101 × Sel-26 also recorded higher concentration of ascorbic acid in comparison of the best parent i.e., Ogu119 (81.26) and checks PSB Kt 25 (62.21) and Mamta (52.81).

The mean value for Na, K, S, Ca and Mg (mg/100g FW) ranged from 13.92 (Ogu 13-01 × Suprimax Late) to 98.63 (Ogu 103 × Sel-26), 93.46 (Ogu 101 × DB-1305) to 300.18 (Ogu 13-01 × Sel-26), 18.21 (Ogu 101 × DB-187) to 49.34 (Ogu 101 × Lalchowk Maghi), 12.63 (Ogu 103 × Suprimax Late) to 54.65 (Ogu 119 × Suprimax Late), 7.55 (Ogu 13-85 × Kt-18) to 35.60 (Ogu 13-85 × DB-187), respectively.

The Na content (mg/100 g FW) was recorded highest in the hybrid Ogu 103 × Sel-26 (98.63), followed by Ogu 101 × DB-1305 (97.49), Ogu 119 × Suprimax Late (94.95) and Ogu 13-85 × DB-1305 (92.72). Potassium content (mg/100 g FW) was maximum in the hybrid Ogu 13-01 × Sel-26 (300.18), followed by Ogu 101 × Lalchowk Maghi (299.49), Ogu 13-01 × Kt-18 (290.13), Ogu 119 × Suprimax Late (283.56) and Ogu 13-01 × DB-187 (282.47). For S content (mg/100 g FW), the highest value was recorded in the hybrid Ogu 101 × Lalchowk Maghi (49.34), followed by Ogu 103 × DB-187

Table 1: Mean performance of parental lines for ascorbic acid and different mineral nutrients in snowball cauliflower

Nutrients *Genotypes*	*Ascorbic acid* *(mg/100 g FW)*	*Na* *(mg/100 g FW)*	*K* *(mg/100 g FW)*	*S* *(mg/100 g FW)*	*Ca* *(mg/100 g FW)*	*Mg* *(mg/100 g FW)*	*Fe* *(µg/100 g FW)*	*Zn* *(µg/100 g FW)*	*Mn* *(µg/100 g FW)*
Lines									
Ogu 13-01	47.64^{c}	21.18^{b}	137.81^{b}	21.15^{b}	15.97^{b}	12.06^{b}	645.03^{a}	194.30^{b}	129.53^{c}
Ogu 101	66.67^{b}	14.02^{d}	77.22^{e}	12.89^{c}	8.84^{d}	7.45^{e}	172.20^{c}	98.87^{c}	49.43^{d}
Ogu 103	46.67^{c}	19.35^{c}	182.32^{a}	29.48^{a}	23.19^{a}	13.22^{a}	600.03^{a}	313.33^{a}	235.00^{a}
Ogu 119	81.26^{a}	18.95^{c}	85.26^{b}	11.12^{d}	12.79^{c}	9.49^{d}	331.57^{b}	45.30^{d}	181.20^{b}
Ogu 13-85	62.39^{b}	24.37^{a}	127.34^{c}	20.08^{b}	11.96^{c}	10.45^{c}	194.60^{c}	194.60^{b}	129.73^{c}
Mean	60.93	19.57	121.99	18.94	14.55	10.53	388.69	169.28	144.98
Range	46.67-81.26	14.02-24.37	77.22-182.32	11.12-29.48	8.84-23.19	7.45-13.22	172.20-645.03	45.30-313.33	49.43-235.00
SE	2.21	0.29	2.46	0.37	0.28	0.18	15.03	5.08	4.25
CD 5%	4.38	0.57	4.87	0.74	0.55	0.35	29.76	10.06	8.42
CD 1%	5.41	0.71	6.03	0.91	0.68	0.43	36.82	12.45	10.41
Testers									
Kt-18	39.72^{e}	98.03^{a}	277.52^{a}	42.87^{a}	43.73^{a}	29.44^{a}	1413.43^{a}	365.50^{b}	292.40^{b}
Kt-22	70.84^{a}	49.59^{c}	153.25^{f}	32.85^{c}	37.16^{b}	22.47^{c}	1053.57^{b}	274.80^{c}	343.50^{a}
DB-1305	53.68^{b}	88.58^{a}	176.30^{d}	38.82^{b}	23.22^{e}	20.25^{d}	588.93^{c}	147.73^{e}	147.73^{e}
DB-187	41.91^{d}	37.94^{c}	167.88^{e}	23.02^{e}	28.28^{d}	19.04^{e}	654.43^{c}	226.80^{d}	226.80^{c}
Lalchowk Maghi	38.86^{e}	36.81^{c}	142.57^{g}	16.32^{f}	23.96^{e}	14.23^{f}	544.33^{c}	108.87^{f}	163.30^{e}
Sel-26	37.28^{f}	70.42^{b}	250.16^{b}	23.45^{e}	37.26^{b}	25.31^{b}	1424.93^{a}	458.70^{a}	206.80^{d}
Suprimax Late	45.22^{c}	62.21^{b}	203.99^{c}	27.57^{d}	35.05^{c}	20.68^{d}	1347.80^{a}	134.67^{ef}	336.67^{a}
Mean	46.79	63.37	195.95	29.27	32.67	21.63	1003.92	245.30	245.31
Range	37.28-70.84	36.81-98.03	142.57-277.52	16.32-42.87	23.22-43.73	14.23-29.44	544.33-1424.93	108.87-458.70	147.73-343.50
SE	0.420	3.97	2.59	0.484	0.367	0.242	43.63	11.14	5.85
CD 5%	0.83	7.86	5.13	0.96	0.73	0.48	86.39	22.06	11.58
CD 1%	1.03	9.73	6.35	1.19	0.90	0.59	106.89	27.29	14.33
PSB Kt 25 (C)	62.21	35.37	196.66	55.67	19.56	12.34	1078.97	258.73	141.27
Mamta (C)	52.81	36.90	167.44	24.07	34.45	22.59	1164.33	320.80	152.60

CD: Critical difference, SE: Standard error, Values within columns with different letters (superscript) are significantly different according to Duncan's test at P = 0.05.

Table 2: Mean performance of hybrids (crosses) for ascorbic acid and different mineral nutrients in snowball cauliflower

Nutrients *Hybrids*	*Ascorbic acid (mg/100 g FW)*	*Na (mg/100 g FW)*	*K (mg/100 g FW)*	*S (mg/100 g FW)*	*Ca (mg/100 g FW)*	*Mg (mg/100 g FW)*	*Fe (µg/100 g FW)*	*Zn (µg/100 g FW)*	*Mn (µg/100 g FW)*
Ogu 13-01 × Kt-18	51.53^{hijkl}	21.59^{k}	290.13^{ab}	37.05^{efg}	32.99^{de}	7.75^{n}	1248.23^{de}	288.00^{l}	216.00^{cd}
Ogu 13-01 × Kt-22	61.58^{efg}	23.55^{k}	207.79^{cdefgh}	22.28^{qr}	17.94^{hijk}	10.45^{lmn}	509.17^{lmno}	203.87^{no}	101.93^{ghijk}
Ogu 13-01 × DB-1305	67.45^{def}	65.49^{de}	118.89^{ijk}	26.78^{mnopq}	18.77^{hij}	20.66^{gh}	435.40^{nop}	327.00^{j}	130.80^{fghij}
Ogu 13-01 × DB-187	49.77^{ijkl}	43.09^{hij}	282.47^{abc}	35.56^{efghij}	39.17^{c}	28.74^{c}	1775.60^{a}	574.93^{c}	321.40^{ab}
Ogu 13-01 × Lalchowk Maghi	59.02^{fgh}	48.08^{gh}	212.52^{bcdefgh}	37.16^{efg}	33.68^{de}	22.71^{fg}	1256.87^{de}	337.00^{j}	202.20^{de}
Ogu 13-01 × Sel-26	72.65^{cd}	75.35^{bc}	300.18^{a}	33.35^{fghijk}	25.49^{f}	27.26^{cd}	824.59^{fgh}	150.53^{r}	350.57^{a}
Ogu 13-01 × Suprimax Late	62.90^{efg}	13.92^{k}	133.19^{hijk}	26.72^{mnopq}	21.43^{ghi}	13.40^{jkl}	590.47^{jklmn}	204.60^{no}	136.40^{efghi}
Ogu 101 × Kt-18	56.71^{ghijk}	35.30^{ij}	139.56^{hijk}	38.34^{ef}	19.31^{ghij}	12.10^{klm}	767.57^{ghij}	230.50^{m}	127.37^{fghijk}
Ogu 101 × Kt-22	48.84^{klm}	61.21^{ef}	140.23^{hijk}	30.34^{jklmn}	22.89^{fgh}	24.43^{def}	359.83^{opq}	360.47^{hi}	381.60^{a}
Ogu 101 × DB-1305	82.29^{b}	97.49^{a}	93.46^{k}	44.02^{bcd}	33.29^{de}	26.78^{cd}	699.20^{hijk}	336.43^{j}	233.50^{cd}
Ogu 101 × DB-187	46.86^{lmno}	14.32^{k}	109.17^{ijk}	18.21^{r}	18.67^{hij}	13.26^{jkl}	476.57^{lmnop}	352.97^{i}	144.73^{efg}
Ogu 101 × Lalchowk Maghi	39.89^{nopq}	54.80^{fg}	299.49^{a}	49.34^{a}	33.49^{de}	24.41^{def}	1384.53^{cd}	642.10^{a}	204.73^{de}
Ogu 101 × Sel-26	94.05^{a}	66.59^{cde}	252.67^{abcdef}	35.94^{efghi}	33.79^{de}	26.37^{cde}	656.13^{hijkl}	310.93^{k}	280.93^{bc}
Ogu 101 × Suprimax Late	81.07^{b}	18.17^{k}	165.05^{ghijk}	38.67^{ef}	19.84^{ghij}	14.90^{ijk}	749.90^{ghij}	183.07^{pq}	137.07^{efghi}
Ogu 103 × Kt-18	38.51^{opq}	65.11^{de}	179.80^{efghij}	31.14^{hijklmn}	13.01^{kl}	8.08^{n}	632.71^{ijklm}	189.60^{opq}	71.13^{hijk}
Ogu 103 × Kt-22	46.12^{lmnop}	63.58^{ef}	109.36^{ijk}	22.97^{pqr}	36.80^{cd}	14.06^{jk}	170.30^{r}	132.60^{s}	56.77^{k}
Ogu 103 × DB-1305	70.02^{de}	36.71^{ij}	201.59^{defgh}	38.08^{ef}	25.66^{f}	26.10^{cde}	1174.40^{e}	276.93^{l}	64.33^{ijk}
Ogu 103 × DB-187	48.04^{klmn}	17.27^{k}	215.22^{bcdefgh}	48.03^{ab}	22.51^{fgh}	9.35^{mn}	557.43^{klmn}	198.47^{op}	104.77^{ghijk}
Ogu 103 × Lalchowk Maghi	40.22^{mnopq}	23.65^{k}	136.26^{hijk}	25.84^{nopq}	26.69^{f}	16.64^{ij}	950.27^{f}	383.87^{g}	54.93^{k}
Ogu 103 × Sel-26	31.79^{q}	98.63^{a}	117.50^{ijk}	31.77^{ghijklm}	46.00^{b}	10.41^{lmn}	1501.47^{bc}	605.67^{b}	72.83^{ghijk}
Ogu 103 × Suprimax Late	37.94^{pq}	73.95^{cd}	167.61^{ghijk}	37.92^{ef}	12.63^{l}	24.56^{def}	782.80^{fghi}	182.93^{pq}	122.80^{fghijk}
Ogu 119 × Kt-18	72.11^{d}	44.60^{hi}	167.69^{ghijk}	24.62^{opq}	22.18^{fgh}	22.04^{fg}	921.00^{fg}	179.60^{q}	60.20^{jk}
Ogu 119 × Kt-22	57.68^{ghij}	69.16^{cde}	280.05^{abcd}	41.16^{cde}	15.30^{jkl}	15.65^{ij}	210.70^{qr}	232.87^{m}	70.23^{hijk}
Ogu 119 × DB-1305	51.65^{hijkl}	37.37^{ij}	175.44^{fghijk}	31.25^{hijklmn}	25.09^{f}	16.64^{ij}	457.47^{mnop}	189.80^{opq}	57.40^{k}
Ogu 119 × DB-187	59.30^{fgh}	42.07^{hij}	151.63^{hijk}	27.73^{lmnopq}	47.06^{b}	14.24^{jk}	348.87^{opq}	217.40^{mn}	131.47^{fghij}
Ogu 119 × Lalchowk Maghi	87.58^{ab}	40.95^{hij}	145.86^{hijk}	27.93^{klmnop}	16.33^{ijkl}	23.17^{efg}	639.23^{ijklm}	189.80^{opq}	189.80^{def}
Ogu 119 × Sel-26	62.16^{efg}	54.68^{fg}	184.22^{efghi}	45.67^{abc}	24.43^{fg}	20.18^{gh}	1147.87^{e}	180.47^{q}	121.53^{fghijk}
Ogu 119 × Suprimax Late	42.99^{lmnop}	94.95^{a}	283.56^{abc}	36.55^{efgh}	54.65^{a}	32.58^{b}	1581.43^{b}	374.70^{gh}	355.47^{a}
Ogu 13-85 × Kt-18	58.17^{ghi}	19.33^{k}	98.69^{jk}	22.81^{pqr}	45.93^{b}	7.55^{n}	1110.63^{e}	423.73^{f}	282.13^{bc}

Ogu 13-85 × Kt-22	65.44^{defg}	69.33^{cde}	233.62^{abcdefg}	27.49^{mnopq}	16.75^{jkl}	17.80^{hi}	881.80^{fg}	618.67^{b}	216.93^{cd}
Ogu 13-85 × DB-1305	72.92^{cd}	92.72^{a}	276.21^{abcd}	29.35^{klmno}	31.51^{e}	19.90^{gh}	474.63^{lmnop}	136.20^{rs}	136.20^{efghi}
Ogu 13-85 × DB-187	59.35^{fgh}	34.32^{l}	140.63^{hijk}	39.96^{de}	26.33^{f}	35.60^{a}	1448.50^{bc}	507.60^{d}	361.93^{a}
Ogu 13-85 × Lalchowk Maghi	49.22^{jkl}	62.40^{ef}	168.39^{ghijk}	30.52^{ijklmn}	40.43^{c}	9.93^{mn}	313.97^{pqr}	489.67^{e}	254.80^{cd}
Ogu 13-85 × Sel-26	44.37^{lmnop}	83.54^{b}	150.71^{hijk}	33.18^{fghijkl}	31.67^{de}	15.10^{ijk}	1245.40^{de}	330.30^{l}	141.67^{efgh}
Ogu 13-85 × Suprimax Late	80.54^{bc}	36.00^{jl}	258.17^{abcde}	27.43^{mnopq}	18.81^{hij}	9.21^{mn}	1433.70^{bc}	151.07^{r}	65.50^{ijk}
Mean	58.59	51.41	188.20	33.00	27.73	18.34	849.10	305.55	170.34
Range	31.79-94.05	13.92-98.63	93.46-300.18	18.21-49.34	12.63-54.65	7.55-35.60	170.3-1775.60	132.6-642.10	54.93-381.60
SE	2.69	3.06	23.66	1.67	1.60	1.04	55.43	5.42	21.28
CD 5%	5.33	6.06	46.85	3.31	3.17	2.06	109.75	10.73	42.13
CD 1%	6.59	7.50	57.97	4.09	3.92	2.55	135.80	13.28	52.14
PSB K 25 (C)	62.21	35.37	196.66	55.67	19.56	12.34	1078.97	258.73	141.27
Mamta (C)	52.81	36.90	167.44	24.07	34.45	22.59	1164.33	320.80	152.60

CD: Critical difference, SE: Standard error, Values within columns with different letters (superscript) are significantly different according to Duncan's test at P = 0.05.

(48.03), Ogu 119 × Sel-26 (45.67), Ogu 101 × DB-1305 (44.02) and Ogu 119 × Kt-22 (41.16). Calcium content (mg/ 100 g FW) was highest in Ogu 119 × Suprimax Late (54.65), followed by Ogu 119 × DB-187 (47.06), Ogu 103 × Sel-26 (46.00) and Ogu 13-85 × Kt-18 (45.93). The highest value for Mg content (mg/100 g FW) was exhibited by the hybrid Ogu 13-85 × DB-187 (35.60), followed by Ogu 119 × Suprimax Late (32.58), Ogu 13-01 × DB-187 (28.74) and Ogu 13-01 × Sel-26 (27.26) (Table 2). The hybrids Ogu 103 × Sel-26 (98.63), Ogu 13-01 × Sel-26 (300.18), Ogu 101 × Lalchowk Maghi (49.34), Ogu 119 × Suprimax Late (54.65) and Ogu 13-85 × DB-187 (35.60) recorded higher content of Na, K, S, Ca and Mg, respectively (mg/100 g FW) over the best parent Kt-18 (Na: 98.03, K: 277.52, S: 42.87, Ca: 43.73 and Mg: 29.44) and checks: PSB Kt 25 (Na: 35.37, K: 196.66, S: 55.67, Ca: 19.56 and Mg: 12.34) and Mamta (Na: 36.90, K: 167.44, S: 24.07, Ca: 34.45 and Mg: 22.59).

For Fe, Zn and Mn content (µg/100 g FW), the mean value ranged from 170.30 (Ogu 103 × Kt-22) to 1775.60 (Ogu 13-01 × DB-187), 132.60 (Ogu 103 × Kt-22) to 642.10 (Ogu 101 × Lalchowk Maghi) and 54.93 (Ogu 103 × Lalchowk Maghi) to 381.60 (Ogu 101 × Kt-22), respectively (Table 2). The maximum value for Fe content (µg/100g FW) was recorded in the hybrid Ogu 13-01 × DB-187 (1775.60), followed by Ogu 119 × Suprimax Late (1581.43), Ogu 103 × Sel-26 (1501.47), Ogu 13-85 x DB-187 (1448.50), Ogu 13-85 × Suprimax Late (1433.70), Ogu 101 × Lalchowk Maghi (1384.53), Ogu 13-01 × Lalchowk Maghi (1256.87) and Ogu 13-01 × Kt-18 (1248.23). Zinc content (µg/100 g FW) was highest in the hybrid Ogu 101 × Lalchowk Maghi (642.10), followed by Ogu 13-85 × Kt-22 (618.67), Ogu 103 × Sel-26 (605.67) and Ogu 13-01 × DB-187 (574.93). The maximum value for Mn content (µg/100g FW) was recorded in the hybrid Ogu 101 × Kt-22 (381.60), followed by Ogu 13-85 × DB-187 (361.93), Ogu 119 × Suprimax Late (355.47), Ogu 13-01 × Sel-26 (350.57) and Ogu 13-01 × DB-187 (321.40). The hybrids Ogu 13-01 × DB-187 (1775.60) and Ogu 101 × Lalchowk Maghi (642.10) exhibited higher Fe and zn content, respectively (µg/100 g FW) in comparison of the best parent: Sel-26 (1424.93) and checks: PSB Kt 25 (Fe: 1078.97 and Zn: 258.73) and Mamta (Fe: 1164.33 and Zn: 320.80). The hybrid Ogu 101 × Kt-22 (381.60) has higher concentration of Mn over the best parent (Kt-22) and checks: PSB Kt 25 (141.27) and Mamta (152.60).

The hybrids Ogu 101 × Sel-26, Ogu 103 × Sel-26, Ogu 13-01 × Sel-26, Ogu 101 × Lalchowk Maghi, Ogu 119 × Suprimax Late, Ogu 13-85 × DB-187, Ogu 13-01 × DB-187, Ogu 101 × Lalchowk Maghi and Ogu 101 × Kt-22 have the highest *per se* performance for ascorbic acid, Na, K, S, Ca, Mg, Fe, Zn and Mn concentration, respectively. Besides highest content of Fe, the hybrid Ogu 13-01 × DB-187 also showed high concentrations of Mg, K, Zn and Mn. Hybrid Ogu 101 × Lalchowk Maghi recorded maximum S and Zn content and had high K and Fe content. The hybrid Ogu 103 × Sel-26 exhibited the highest Na content and had high Ca, Fe and

Table 3: Genetic analysis for ascorbic acid and different mineral nutrients in snowball cauliflower

Source of variation	*Ascorbic Acid (mg/100 g FW)*	*Na (mg/100 g FW)*	*K (mg/100 g FW)*	*S (mg/100 g FW)*	*Ca (mg/100 g FW)*	*Mg (mg/100 g FW)*	*Fe (µg/100 g FW)*	*Zn (µg/100 g FW)*	*Mn (µg/100 g FW)*
Mean sum of squares									
Parents (P)	618.22**	2476.80**	10563.51**	288.66**	389.86**	141.52**	620022.55**	43847.47**	23633.19**
Crosses (C)	703.99**	1919.21**	12435.60**	171.98**	335.60**	169.28**	552179.09**	65465.56**	29977.39**
Parents v/s. Crosses	937.70**	1059.22**	14261.16**	1731.87**	182.78**	47.86**	276368.72**	226563.90**	29486.32**
Males (T)	621.35**	42.67*	5454.41**	161.16**	89.31**	15.13**	148634.90**	31760.67**	14261.79**
Female (L)	427.65**	1715.05**	7752.74**	266.30**	176.71**	69.80**	485623.37**	50786.55**	19138.67**
Male v/s Female (L×T)	1749.19**	16783.87**	47864.56**	932.82**	2870.99**	1077.46**	3311968.30**	50560.18**	88085.85**
Components of variance									
Mean	57.08	49.80	182.31	30.95	27.06	18.00	823.18	282.08	178.81
Range	31.79	13.92	77.22	11.12	8.84	7.45	170.30	45.30	49.43
	94.05	98.63	300.18	49.34	54.65	35.60	1775.60	642.10	381.60
CV %	5.74	7.61	13.79	6.24	6.97	6.75	7.91	20.66	12.87
σ^2g	688.56	2033.85	12027.61	233.79	345.25	160.01	562406.65	63798.15	28449.62
σ^2P	699.29	2048.23	12659.46	237.52	348.81	161.48	566645.93	67195.54	28979.52
h^2_{bs}	0.98	0.99	0.95	0.98	0.99	0.99	0.99	0.95	0.98
G. C. V.%	26.33	52.10	33.81	28.29	39.44	40.38	52.40	50.30	53.95
P. C. V.%	26.95	52.65	36.51	28.97	40.05	40.94	52.99	54.38	55.47
G. C. V. / P. C. V.	0.98	0.99	0.93	0.98	0.98	0.99	0.99	0.92	0.97
Components of genetic variance									
σ^2_{gca}	12.04	37.79	-464.06	-5.36	-15.63	-1.94	-74.34	459.80	945.80
σ^2_{sca}	218.18	538.27	4775.42	65.77	137.06	58.62	177555.83	19623.61	8711.24
$\sigma^2_{gca}/\sigma^2_{sca}$	0.06	0.07	-0.10	-0.08	-0.11	-0.03	-0.0004	0.02	0.11
σ^2A	24.072	75.587	-928.121	-10.713	-31.261	-3.875	-148.68	919.608	1,891.60
σ^2D	218.178	538.27	4775.42	65.767	137.061	58.617	177555.83	19623.61	8711.24

**Significant at p = 0.01
*Significant at p = 0.05

Zn concentrations. Besides highest content of Mg, the hybrid Ogu 13-85 × DB-187 also recorded high concentrations of S, Fe, Mn and Zn.

Analysis of Variance

The partitioning of mean squares into replications, lines, testers and line × tester interactions revealed that the mean sum of squares due to lines (female parents), testers (male parents) and lines × testers interactions were significant for all of the parameters under study. The parents v/s crosses (heterosis) mean square was highly significant for all the traits which indicated the expression of heterotic effects in the developed hybrids. The analysis of variance showed significant differences among the treatments for vitamin C and all mineral nutrients under study. Further, the parents and parents versus crosses also differed significantly for vitamin C and these mineral nutrients. The mean sum of squares due to lines and testers and lines versus testers interactions was highly significant for the estimated vitamin C and all mineral nutrients. Highly significant differences were also observed among the crosses (line × tester) for the vitamin C and mineral nutrients under study. Highly significant mean squares for lines indicate the existence of additive variance. The line × tester interaction showed highly significant mean squares for vitamin C and all the mineral elements under study, indicating the prevalence of non-additive variance. Similar results were obtained while analyzing different mineral elements by Singh *et al.* (2012) in cabbage and by Ram *et al.* (2017) in snowball cauliflower.

Components of Variance

The mean, range, coefficient of variance (C.V%), genotypic (σ^2g) and phenotypic variance (σ^2p), heritability in broad sense (h^2_{bs}), genotypic and phenotypic coefficient of variance (G.C.V & P.C.V%) and the ratio of G.C.V./ P.C.V. are presented in Table 3. The variance widely varied from one trait to another since the coefficient of variation (C.V%) ranged from 5.74 to 20.66%. The variance for a particular trait depends upon the genotype × environment interactions. The highest C.V. (20.66%) was recorded for zinc, followed by potassium (K) and manganese (Mn), suggesting that these three minerals had the highest variation among the studied genotypes. These parameters are obvious to exhibit higher variance due to their highly quantitative nature. On the contrary, the lowest variation (5.74%) was observed for ascorbic acid (vitamin C).

The difference between the genotypic (σ^2g) and phenotypic (σ^2p) variances indicated the contribution of environmental variance effects. Low values of differences between σ^2p and σ^2g indicated the lesser environmental effect on the character. Selection based on the phenotypic values will be effective only when the phenotypic and genotypic values are nearly identical. In this respect, all the characters studied have closer values of σ^2g and σ^2p as well as G.C.V.% and P.C.V.%, which is confirmed by the estimated G.C.V/P.C. V. ratios ranging from 0.92 to 0.99, and broad sense heritability (h^2_{bs}) ranging from 0.95 to 0.99 suggesting less effect of environment. Arivalagan *et al.* (2013) also observed high broad sense heritability (84.44–97.07%) for potassium, magnesium, copper, iron and zinc in eggplant.

Components of Genetic Variance (gene action)

Using line × tester mating design, the genetic variance could be divided into components of genetic variance *i.e.,* additive and non-additive genetic variances. Both the lines variance (σ^2L) and tester variance (σ^2T) determine the σ^2gca which is an indicator of additive and additive × additive element of the genetic variance. While, the line x tester variance ($\sigma^2L \times T$) determines the σ^2sca and it indicates the non-additive genetic elements, including dominance. According to Kalloo (1988), the additive (σ^2A) and dominance (σ^2D) were the most important elements.

The estimates of variance components for earliness and yield attributing traits are presented in Table 1. The values of σ^2gca were lower than the σ^2sca for all the parameters. For potassium (K), sulphur (S), calcium (Ca), magnesium (Mg) and iron (Fe) the σ^2gca was in negative direction. The proportions of σ^2gca/σ^2sca were less than unity (<1) in all parameters, indicating the preponderance of non-additive variance in the inheritance of these traits, suggesting that heterosis breeding is effective for improving these traits. Similarly, σ^2D was greater than σ^2A for all the parameters.

The results of present findings are in agreement with the earlier work of Verma and Singh (2019) and Kumari (2014) in cauliflower. Singh *et al.* (2012) also found the role of non-additive gene actions in the accumulation of Fe, Zn, Mn, K and Ca in cabbage head. Sit and Sirohi (2000) reported overdominance for phosphorus, calcium, iron and vitamin C in bottle gourd and found more frequency of dominant alleles for these traits. Saha *et al*. (2018) studied gene action of nutritional and quality traits (acidity, vitamin C, TSS, sodium, potassium, zinc, manganese, copper, iron, magnesium, calcium, respiration rate and ethylene emission rate) in muskmelon and reported the predominance of dominant gene action over additive gene action for all these parameters. The value of σ^2gca was negative for K, S, Ca, Mg and Fe, probably because of the high degree of mean square value for line × tester interaction. The results indicated the importance of heterosis breeding and recurrent selection schemes for effectively utilizing non-additive genetic variance to improve such traits.

Summary and Conclusion

Among the CMS lines, Ogu 103 had highest content of K, S, Ca, Mg, Zn and Mn. Ogu 101 recorded minimum values for Na, K, Ca, Mg, Fe and Mn contents. The hybrids Ogu 101 × Sel-26, Ogu 103 × Sel-26, Ogu 13-01 × Sel-26, Ogu 101 × Lalchowk Maghi, Ogu 119 × Suprimax Late, Ogu 13-85 × DB-187, Ogu 13-01 × DB-187, Ogu 101 × Lalchowk Maghi

and Ogu 101 × Kt-22 have the highest *per se* performance for ascorbic acid, Na, K, S, Ca, Mg, Fe, Zn and Mn concentration, respectively. The present investigation revealed the predominance of dominance component of variance for vitamin C and mineral nutrients in snowball cauliflower curd. The general and specific combining abilities variance was highly significant, indicating the importance of both additive as well as non-additive gene actions. However, the ratios of σ^2gca/ σ^2sca revealed the preponderance of non-additive variance for the inheritance of traits studied. The results of the experiment suggest the possibility of improvement of these traits through recurrent selection and hybridization.

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