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Understanding the genetic variability, heritability and association pattern for the characters related to reproductive phase of carrots (*Daucus carota* L.) in tropical region

A. Poleshi Chaitra, D.S. Manikanta, and Sarvamangala Cholin*

*Plant Molecular Biology Lab, Department of Biotechnology and Crop Improvement, College of Horticulture, University of Horticultural Sciences, Bagalkot, Karnataka, India. *E-mail: sarugpb@gmail.com*

Abstract

Carrot is a sexully propagating, biennial root crop. Flowering related characters and germination parameters have a significant role on the root quality and productivity in the succeeding generations. Larger genetic variation exists in nature for seed and umbel characters due its out crossing behavior. In order to study, the nature of genetic variability, heritability and the association pattern, 48 open pollinated varieties were evaluated in tropical region of Karnataka, India during 2015 for 27 characters including seed, umbel and germination parameters. Both qualitative and quantitative characters were used for the study. The data was subjected to statistical analysis for genetic variability components such as genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability in broad sense (h^2) genetic advance (GA) and Genetic advance as percent mean (GAM) and Pearson's correlation. Genetic variability and heritability coupled with genetic advance as percent mean (GAM) were high for number of umbellates per umbel, bolting tendency and umbel weight. Many other characters showed low to moderate genetic variability coupled with moderate heritability and GAM. From the correlation coefficient analysis few characters *viz.*, density of flowers in umbels, number of umbellates/umbel, umbel shape, bolting tendency showed positive association with seed and umbel yield. Seed length and size of spines on the seeds affects the germination % negatively. Since, the present study involves maximum characters and good number of cultivars with wider genetic background; hence, detailed understanding of the genetic variability and association pattern for these characters in the reproductive phase of carrot would provide useful information for breeders as well as seed scientists.

Key words: Carrot, umbel, seed, association, genetic variability, tropical

Introduction

Carrot (*Daucus carota* L.), the most widely cultivated member of the Apiaceae family is a diploid species (2n = 2x =18) with a relatively small genome of 473 Mb (Budahn *et al*., 2014). Other members of this family include celery, dill, parsley, fennel, cumin, coriander, cilantro and many other vegetables and spices. It is the tenth most important vegetable crop in the world in terms of area, production and its market value (http://faostat.fao.org/ faostat) and is considered as a major source of pro-vitamin A in most of the countries including India where it is cherished by both rural and urban populations.

The inflorescence of carrot is called as umbel, classified as primary, secondary, tertiary umbels and so on, based on time of umbel initiation in individual plant. Umbels consist of hermaphrodite and staminate flowers *i.e.* andromonoecious and protandry nature favors cross pollination and selfing leads to high inbreeding depression. Although, root being an economic part but essentially propagated by seeds and possesses a very high reproductive potential of up to 50,000 seeds per plant (Rubatzky *et al*., 1999).

Carrot is mainly grown as a temperate crop, premature bolting is a common cause of losses in yield and quality of roots during vegetative phase of its growth. Hence, identification of genotypes which requires higher vernalization for flowering is one of the important breeding objectives for crop improvement in temperate conditions (Peterson and Simon, 1986). The rate of flowering and bolting in carrot increases linearly with an increase in temperature up to -1 to 5°C but will decline linearly from 7ºC onwards, hence the optimum temperature for vernalization would be 6.5ºC (Atherton *et al*., 1990).

In contrast, seed production is the major problem in tropical areas as it demands longer vernalization treatment prior seed production. Since, most of the carrot cultivars are biennials; this nature acts a hurdle to provide sufficient high quality seeds. Hence, selection of cultivars which can flower in tropical regions would offer a scope for the carrot growers thereby improving the carrot root as well as seed production in this region. Cultivars which are adaptable to warmer climates require lesser vernalization and they are considered as annuals. Annual flowering in carrot is a monogenic and a dominant character over biennials (Alessandro *et al*., 2012).

Improved knowledge on genetic control mechanisms for plant reproduction traits such as flowering time, fertility and seed set is essential for breeding, especially for the stabilization of seed yield under wide range of environmental conditions. Recently, mapping of the *cola-locus* associated with flower development and fertility was successfully demonstrated in the F2 mapping population derived from cross between a yellow leaf (yel) chlorophyll mutant and a compressed lamina (cola) mutant with unique flower defects of the sporophytic parts of male and female organs (Budahn *et al*., 2014). Great progress has been made in carrot root research by comprehensive study on the characterization of metabolite contents, morphological traits and resistances (Budahn *et al*., 2014; Brandeen and Simon, 2007; Simon *et al*., 2008). However, information on genetic variability, heritability and correlation among the characters controlling flowering is lacking. Genetic variability, heritability and association pattern in carrot

In this regard, for detailed understanding of the reproductive phase of the carrot, 27 characters involving seed characters, umbel related parameters and the germination parameters after harvesting were studied in 48 diverse cultivars of carrot by growing them in Bagalkot which represents tropical region of Karnataka, India during November 2015, temperature fluctuation during the growth period ranged from 10°C to 45ºC as the minimum and maximum temperatures respectively.

Table 1. List of observations with their description for 27 characters

No.	Character	Descriptor state
X1	Density of flowers in umbels (score)	3-Low, 5-Intermediate, 7-High
X2	Number of umbels/plant (no.s)	Umbels counted/plant
X3	Number of umbellates/ umbel (no.s)	Umbellates counted for each Umbel
X4	Width of primary open umbel (cm)	Using Measuring scale
X5	Type of bracts on primary umbel (score)	1-Relatively branched, 2-Relatively unbranched, 3- comparatively very broad, 4-Others
X6	Umbel shape (score)	1-Convex, 2-Flat, 3-Concave
X7	Umbel type (primary)-score	1-Simple, 2-Compound, 3-Both
X8	Umbel colour when immature-score	1-White, 2-Whitish, 3-Yellow, 4-Green, 5-Rosy Red, 6-Pink, 7-Purplish, 8-Others
X9	Colour of the central flower of the umbel-score	1-White, 2-Red, 3-Green, 4-Pink, 5-Purple, 6-Others
X10	No of leaves below the primary umbel-no.s	Numbers counted
X11	Leaf growth habit (attitude)-score	3-Prostrate, 5-Semi erect, 7-Erect
X12	Bolting tendency (score)	3-Low, 5-Intermediate, 7-High
X13	Seed colour (give score)	1-Browinish, 2-Grayinsh, 3-Dark Brown, 4-Red Brown,, 5-Red, 6-others
X14	Seed length (cm)	Measuring Scale
X15	Seed diameter(cm)	Digital Vernier caliper
X16	1000- seed weight (g)	Weight of 1000 seeds
X17	Size of spine	3-Small, 5-Intermediate, 7-Large
X18	No. of spines	3-Few, 5-Intermediate, 7-Many
X19	Seed Shuttering	3-Low, 5-Intermediate, 7-High
X20	% Seed Germination	No of seeds Germinated in petriplate/Total No. seeds (100)
X21	Seed germination index-i	Seed germination % x seedling length
X22	Seed germination index-ii	Seed germination % x dry seed weight
X23	% Dry weight	Dry Weight/Fresh Weight x 100
X24	Root/shoot ratio	Root Length/Shoot Length
X25	Speed of germination	Number of seeds germinated/no of days
X26	Seed yield /plant (g)	Total Seed Yield/Plant
X27	Umbel weight(gm)	Seed yield of Primary Umbel

Materials and Methods

Seeds of a total of 58 varieties of carrots including temperate and tropically adapted cultivars consisting of European and Asiatic types, collected from all over India were sown in a Randomized Block Design (RBD) with 2 replications during winter season when temperature was below 10 ºC. Approximately 20 plants were maintained in each plot for each replication. Bolting began after 12 weeks for only 48 cultivars (Table 1) out of the total 58 cultivars.

The observations were recorded for total of 27 characters of which 4 were plant morphological characters pertaining to the inflorescence, 9 umbel related characters, 8 seed characters including qualitative and quantitative traits total of characters. A standard descriptor (IPGRI, 1998) and ISTA rules were followed for recording the observations. Detailed information about 27 characters is given in Table 2. Five plants were randomly selected from each replication in each cultivar for recording the observations.

Germination study: The seeds harvested from primary umbel from each replication of all the 48 cultivars were subjected to germination study as per Standard ISTA rules. Each of the four replicates had 100 seeds per Petri plate. Petri plates were placed in growth chamber and maintained a constant temperature of 25ºC with 85 % RH. After eight days, the observations *viz.*, germination percentage, root-shoot length, root-shoot fresh and dry weights were recorded which were further utilized to calculate seed germination index-I and II, % dry weight, root/shoot ratio and speed of germination as per reference (Table 2). Although most of the characters were qualitative, but for the convenience for analysis; these were converted to quantitative data based on the scores (numerical data) available from descriptors. All the 27 characters were subjected to statistical analysis such as Analysis of variance (ANOVA), genetic variability parameters including genotypic and phenotypic coefficient of variation (PCV and GCV respectively), heritability parameters such as heritability (h^2), genetic advance (GA) and genetic advance as percent mean (GAM) and also Pearson's correlation analysis using softwares Indostat and SPSS.

Results

Analysis of variance revealed significant variation for most of the characters between the cultivars studied. Few of the qualitative characters (recorded as scores based on the descriptors), showed no significant variation among the cultivars *viz* ., type of bracts on primary umbel, umbel shape, color of primary umbel and central flower, leaf growth habit, seed colour, size of spines and % dry weight (Table 3). All the parameters were subjected to further analysis in order to know the association pattern across the parameters.

Mean performance, range, standard error (SE), genetic variability components such as Genotypic Coefficient of Variation (GCV), Phenotypic Coefficient of Variation (PCV), heritability in broad sense (h^2), Genetic Advance (GA) and Genetic Advance as percent Mean (GAM) were estimated for all the 27 characters (Table 4). For the interpretation of the results of genetic variability and heritability, we followed Hanson *et al.* (1956), Johnson *et al.* (1955), respectively.

Table 2. Analysis of variance (ANOVA) for seed, umbel and germination parameters for 48 open pollinated cultivars of carrot

	Characters	RMSS	GMSS	EMSS
	DF	1	47	47
X1	Density of flowers in umbels	0.1924	1.999***	0.555
X2	Number of umbels/plant	292.368	399.218***	98.061
X3	Number of umbellates/umbel	423.213	538.81***	258.246
X4	Width of primary open umbel (cm)	73.154*	21.404*	11.068
X5	Type of bracts on primary umbel	2.022*	0.5944	0.474
X6	Umbel shape	0.035	0.133	0.132
X7	Primary umbel type	0.01	0.12**	0.067
X8	Umbel colour when immature	0.086	1.86	1.28
X9	Colour of the central flower of the umbel	0.0567	0.333	0.245
X10	No of leaves below the primary umbel	22.57*	7.456***	3.65
X11	Leaf growth habit (attitude)	4.335*	1.331	0.872
X12	Bolting tendency	0	1.489***	0.255
X13	Seed colour	0.165	1.656	1.377
X14	Seed length (cm)	0.021*	0.011***	0.003
X15	Seed diameter(cm)	0.000025	0.000854***	0.000276
X16	1000- seed weight (gms)	0.927**	0.225***	0.06
X17	Size of spine	1.5	1.738	1.206
X18	No. Of spines	0.0046	4.314***	1.252
X19	Seed Shuttering	6.168*	2.745**	1.305
X20	% Seed Germination	541.5	680.86**	220.52
X21	Seed germination index-i	11399.18	18208.5**	8594.95
X22	Seed germination index-ii	1.373	0.769*	0.473
X23	% Dry wt	0.033	0.0247	0.0211
X24	Root/shoot ratio	0.867	0.98*	0.661
X25	Speed of germination	8.46	10.638***	3.445
X26	Seed yield/ plant (gms)	1215.285**	274.564**	151.168
X27	Primary umbel yield (gm)	0.287	9.924 ***	2.392

RMSS-Replication Mean Sum of Squares, GMSS-Genotypic mean sum of Square EMSS-Error Mean Sum of Squares.
* Significant at P=0.05, ** Significance at P=0.01, ***Significance at P=0.001

Wider range of variation was found for most of the quantitative characters *viz*., no. of umbels/plant (9.0-93.0), no. of umbellates/ umbel (18.0-105.0), width of primary open umbel (4.10-22.65Genetic variability, heritability and association pattern in carrot cm), % germination (5.0-87.0%), seed germination Index-I (20.82-412.50), seed yield (3.10-50.42 g) and umbel yield/plant (0.34-9.81 gms) Moderate range was also observed for few characters *viz*., no. of leaves below the primary umbel (2.90-13.75), speed of germination (0.62-10.88 %) and1000-seed weight (1.50 to 6.40g). Most of the qualitative characters (recorded as scores) showed a narrow range of variation such as umbel shape (1.17-2.50), umbel type (1.50-2.90), density of flowers in umbels (3.0-7.0), colour of the central flowers (1.00-2.50), size of spine (3.00-6.00), number of spines (3.00-7.00), shuttering (3.00-7.00), type of bracts (1.17-4.58), bolting tendency (3.00-7.00), leaf growth habit (4.20-7.00).

Among the 48 cultivars, highest umbel weight was recorded by UHSBC 31 (9.81 g) followed by UHSBC 42 (9.57 g) and for seed yield, UHSBC 24 (50.41 g) followed by UHSBC 14 (48.5 g). For germination %, UHSBC 25 (87.0%) followed by UHSBC 20 and UHSBC 46 with 83 % germination (data not shown).

Genetic variability for the characters revealed higher variation in terms of both GCV and PCV for characters such as number of umbels/plant, number of umbellates/ umbel, width of primary open umbel (cm), umbel colour when immature, 1000-seed weight (gms), no. of spines, % germination, seed germination index-I, seed germination index-II, % dry weight, root/shoot ratio, speed of germination, seed yield/ plant (gms) and primary umbel yield (gm). Other characters recorded low to moderate GCV and PCV.

The heritability in broad sense was analyzed for all the 27 characters where in, the highest heritability was recorded for bolting tendency (70.70%) followed by umbel weight (61.20%) and no. of umbels per plant (60.60%).

Moderate heritability was observed for most of the characters viz., number of umbellates/ umbel (35.20%), width of primary open umbel (31.80%), umbel type (28.0%), no. of leaves below the primary umbel (34.30%), leaf growth habit (20.80%), seed length (56.20%), seed diameter (51.20 %), 1000 seed weight (58.50%), no. of spines (54.90 %), seed shuttering (35.60 %), % germination (51.10 %), seed germination index-I (35.90%), seed germination index-II (23.88%), speed of germination (51.07%) and seed yield/ plant (29.00%).

Low heritability was recorded for type of bracts on primary open umbel (11.20%), umbel shape (0.30%), umbel colour when immature (18.50%), colour of the central flower of the umbel (15.20%), seed colour (9.20%), size of spine (18.10%), % dry weight (7.80%).

High heritability coupled with high GAM was observed for number of umbels/plant, bolting tendency and umbel weight. Characters such as density of flowers in umbels, no. of umbellates/ umbel, width of primary open umbel, no. of leaves below the primary umbel, 1000 seed weight, no. of spines, seed shuttering, % germination, seed germination index-I and II, speed of germination and seed yield/plant showed moderate heritability but high GAM. Low heritability coupled with low GAM was observed for umbel shape. But for the charters, leaf growth habit showed moderate heritability with low GAM. Similarly, moderate heritability coupled with moderate GAM was observed for type of bracts on primary umbel, seed colour, % dry weight, umbel types, umbel colour when immature, colour of the central flower of the umbel, size of spine, % dry weight and root/ shoot ratio.

Further, Pearson's correlation coefficient analysis was done using SPSS (Ver. 16.0) to understand the association pattern among the seeds, umbel characters and germination parameters of carrot. Among the seed characters, seed length showed strong positive significant correlation with seed diameter (0.721), 1000-seed weight (0.569) and size of spine (0.440). Similarly, between seed

Table 3. Mean, range, genetic variability (GCV, PCV) and heritability components (h^2 broad sense, GA and GAM at 5 %) for 27 characters among 48 open pollinated cultivars of carrot

S. No.	Characters	Mean ± SEd	Range		GCV	PCV	h^2	GA	GAM (5 %)
			Min	Max					
X1	Density of flowers in umbels	5.49 ± 0.14	3.0	7.0	15.474	20.573	0.566	1.317	23.98
X2	Number of umbels/plant	25.66 ± 2.04	9.0	93.0	47.814	61.442	0.606	19.672	76.65
X3	Number of umbellates/umbel	57.50 ± 2.37	18.00	105.00	20.599	34.719	0.352	14.476	25.18
X4	Width of primary open umbel (cm)	8.62 ± 0.47	4.10	22.65	26.361	46.724	0.318	2.642	30.64
X5	Type of bracts on primary umbel (score)	1.96 ± 0.08	1.17	4.58	12.481	37.23	0.112	0.169	8.62
X6	Umbel shape	1.92 ± 0.04	1.17	2.50	1.103	19.01	0.003	0.0025	0.13
X7	Umbel type (primary)	2.05 ± 0.04	1.50	2.90	7.882	14.90	0.28	0.176	8.59
X8	Umbel colour when immature	1.88 ± 0.14	1. 00	5.50	28.71	66.81	0.185	0.477	25.43
X9	Colour of the central flower of the umbel	1.38 ± 0.059	1.00	2.50	15.18	38.89	0.152	0.169	12.21
X10	No of leaves below the primary umbel	7.20 ± 0.28	2.90	13.75	19.165	32.75	0.343	1.662	23.11
X11	Leaf growth habit (attitude)	5.84 ± 0.12	4.20	7.00	8.199	17.97	0.208	0.451	7.71
X12	Bolting tendency	6.75 ± 0.13	3.00	7.00	11.637	13.84	0.707	1.36	20.16
X13	Seed colour	1.92 ± 0.13	1.00	6.00	19.377	64.00	0.092	0.233	12.09
X14	Seed length (cm)	0.57 ± 0.01	0.36	0.71	11.35	15.13	0.562	0.099	17.52
X15	Seed diameter(cm)	0.18 ±0.003	0.13	0.24	9.40	13.14	0.512	0.0251	13.86
X16	1000- seed weight (gms)	3.64 ±0.02	1.50	6.40	25.10	32.82	0.585	0.144	39.53
X17	Size of spine	4.31 ±0.13	3.00	6.00	11.97	28.19	0.181	0.451	10.48
X18	No. Of spines	5.563 ±0.21	3.00	7.00	22.24	29.99	0.549	1.89	33.97
X19	Seed Shuttering	5.13 ±0.17	3.00	7.00	16.547	27.75	0.356	1.04	20.33
X20	% Seed Germination	51.78 ±2.66	5.00	87.00	29.299	40.99	0.511	22.334	43.13
X21	Seed germination index-i	226.70 ± 13.77	20.82	412.50	30.583	51.06	0.359	85.534	37.73
X22	Seed germination index-ii	0.70 ±0.09	0.07	3.51	54.834	78.90	0.239	0.3878	55.20
X23	% Dry wt	0.17 ±0.02	0.03	0.55	25.69	91.79	0.078	0.0244	14.81
X24	Root/shoot ratio	1.47 ±0.10	0.56	5.14	27.22	61.68	0.195	0.363	24.75
X25	Speed of germination	6.47 ±0.33	0.62	10.88	29.299	40.99	0.511	2.791	43.13
X26	Seed yield/ plant (gms)	26.23 ±1.69	3.10	50.42	29.943	55.62	0.290	8.711	33.21
X27	Primary umbel yield (gm)	5.24 ±0.32	0.34	9.81	37.04	47.36	0.612	3.13	59.65

GCV – Genotypic coefficient of variation, PCV-Phenotypic coefficient of variation, h^2–heritability in broad sense, GA-Genetic advance, GAM-Genetic advance as percent mean at 5 % level of probability, SEd: Standard Error Difference

diameter and 1000 seed weight (0.469), seed length and bolting tendency (0.382), significant positive correlation was recorded. However, strong negative correlation was observed between size of spine and no. of spines (-0.624).

Among the umbel characters, significant positive correlation was obtained for density of flowers in umbel with number of umbellates/umbel (0.340), width of primary open umbel (0.440), umbel colour when immature (0.318) and umbel weight (0.527). Similarly, there was significant negative correlation for density of flowers in umbels with number of umbels/plant (-0.471), umbel type (-0.328) and seed length (-0.493).

Within the components of germination, strong positive correlation was recorded between % germination and seed germination index-II (0.713); and seed germination index-I and seed germination index-II (0.505).

In general, across different parameters, umbel yield was positively correlated with density of flowers in umbel (0.527), number of umbellates/umbel (0.339), width of primary umbel (0.383), umbel colour when immature (0.268), colour of the central flower of the umbel (0.361), bolting tendency (0.399) and seed yield per plant (0.398). Bolting tendency (0.353), umbel colour when immature (0.388) and seed germination index- I (0.327) were positively correlated with seed yield per plant. But the number of umbels/plant (0.325), type of bracts on primary open umbel (0.281), umbel shape (0.395), seed length (0.237) and seed shuttering (0.304) were negatively correlated with primary umbel yield.

Discussion

Being a seed propagated biennial vegetable root crop, seed and umbel characters in the reproductive phase of carrot life cycle are equally important as they ultimately decide the root quality, productivity and uniformity of the subsequent vegetative phase. Hence, understanding the characters related to flowering and seed in terms of genetic variability components, heritability components and association pattern provides useful information to

Table 4. Pearson's correlation partitioned into positive and negative correlation values among 27 characters of OPVs of carrot

Sl. No	Characters	Positive significant correlation	Negative significant correlation
X1	Density of flowers in umbels	X3 (0.34***), X4(0.44***), X8(0.318**), X9(0.291**), X10 (0.224*), X12(0.251*), X27(0.527***)	X2(-O.471***), X6 (-0.259*), X7(-0.328**), X14(-0.493***), X16(-0.262*)
X2	Number of umbels/plant	X6(0.307**), X14(0.382***), X15(0.239*), X21 (0.256*)	X4(-0.231*), X27(-0.325*)
X3	Number of umbellates/umbel	X27(0.399**)	X7(-0.263**)
X4	Width of primary open umbel (cm)	X5(0.318**), X12(0.251*), X18(0.261*), X27(O.383**)	-
X5	Type of bracts on primary umbel (score)	-	X17(-0.258*), X24(-0.227*), X27(-0.281**)
X6	Umbel shape	X7(0.241*), X15(0.215), X19(0.219*), X20(0.309**), X21(0.296**), X25(0.309**)	X9-0.494***), X27(-0.395***)
X7	Umbel type (primary)	-	X9(-0.277*), X11(-0.323***)
X8	Umbel colour when immature	X12(0.218*), X13(0.269*), X26(0.388***), X27(0.268*), X17(0.233*)	X15(-0.233*), X24(-0.237*)
X9	Colour of the central flower of the umbel	X27(0.361***)	X14(-0.221*), X21(-0.283*)
X10	No of leaves below the primary umbel	X23(0.377***)	X13(-0.290**), X19 (-0.256*)
X11	Leaf growth habit (attitude)	X16(0.26*)	X18(-0.229*), X22(-0.247*), X23(-0.419***)
X12	Bolting tendency	X18(0.326**), X26(0.353***), X27(0.399***)	X14 (-0.370)
X13	Seed colour	X19(0.218*), X22(0.219*)	-
X14	Seed length (cm)	X15(0.421***), X16(0.569***), X17(0.440***)	X18-(-0.288**), X20(-0.281**), X25(-0.281**), X27(-0.237*)
X15	Seed diameter(cm)	X16(0.469***)	-
X16	1000- seed weight (gms)	-	-
X17	Size of spine	-	X18(-0.624***), X19(-0.341**), X20-(-0.237*), X23(-0.248), X24(-0.250*), X25(-0.237*)
X18	No. Of spines	X22(0.238*), X23(0.247*)	
X19	Seed Shuttering		X27(-0.304**)
X20	% Seed Germination	X21(0.713***)	
X21	Seed germination index-I	X22(0.505***), X25(0.713***), X26(0.327**)	X24(-0.352***)
X22	Seed germination index-II	X23(0.367***)	X24(-0.242*)
X23	% Dry wt	-	-
X24	Root/shoot ratio	-	-
X25	Speed of germination	-	-
X26	Seed yield/ plant (gms)	X27(0.398***)	-
X27	Primary umbel yield (gm)	-	-

* Significant at P=0.05, ** Significance at P=0.01, ***Significance at P=0.001, - no significant correlation

breeders and seed scientists. Based on such knowledge, selection of superior hybrids of carrots with high seed yielding trait as well as prediction of the root quality in the early phases of its growth becomes easy Seed characters such as germination %, total seed yield, 1000-seed weight are important characters for successful vegetative plant stand and has direct influence on cost- benefit ratio to the growers. As these characters are highly influenced by environment and quantitative in nature, hence, study of correlation with the easily recordable qualitative characters coupled with high heritability helps in efficient indirect selection of superior carrot cultivars.

Analysis of variance revealed significant variation across the cultivars for twenty characters indicating the existence of variation among the cultivars for these characters. For seven qualitative characters, there was no significant variation among the cultivars due to narrow range of variation (only 3-4 types in each of these characters as measured with the help of standard descriptors as given in table1). Though there was non-significant variation for these characters, but these parameters were also included for statistical analysis with an interest to study the nature of their association with important productivity traits as they were easily observable and easy for selection in the large segregating population.

Conversion of qualitative data in to numerical data in biometrical genetics is a very old practice as it will be very helpful to quantitatively estimate the variation there by selection of complex polygenic traits may be simplified for selection.

The mean and standard error were calculated for each character across the cultivars both for quantitative and qualitative traits. We observed very interesting variation among the qualitative characters while scoring based on the descriptors. For example, for density of flowers in the umbels, the average density was 5.5 *i.e.* intermediate density of flowers, with the range from3.0 to 7.0 (low to high). For the type of bracts, the mean value explained the relatively unbranched type of bracts (1.96) with the range from relatively branched to comparatively broad ultimate segments

(1.17 to 4.58) and based on the frequency distribution, relatively unbranched type of bracts were more prevalent in the cultivars studied (data not shown).

Mean value and frequency distribution revealed prevalence of flat shaped umbels compared to convex (cup) or concave shaped. Nagarajan and Pandita (2001) reported that, flat type have direct influence on seed and root yield than cone and cup shaped umbels. In contrast, in our study, flat type were more predominant but the umbel shape had a negative association with umbel yield may be due to the presence of other two types of umbels.

Similarly, with respect to type of the umbel, mean value indicated whitish umbels across the cultivars, but the range varied from white to purplish indicating the good amount of variation for the umbel colour when immature and this character which had a positive association with umbel weight as well as seed yield in the present study.

Colour of the central flower ranged from white to purple but the average score observed for this character was 1.38 *i.e.* of red central floret and the most predominant was white colour as revealed by frequency distribution.

Exceptionally high number of umbels/plant (93) and very high umbellates/umbel (105) were observed.. In contrast, low numbers 18.0 and 4.0 for these two characters respectively were also observed in the indicating the extent of variation in carrot naturally. UHSBC 77 recorded highest number of umbels whereas, UHSBC 64 showed highest number of umbellates/umbel. The umbel shape in both of these cultivars was flat to concave and UHSBC 77 showed lowest primary umbel weight (1.96g) but higher seed yield (39.67 g) and UHSBC 64 showed lower umbel weight of 16.67 g but higher umbel weight (5.87 g). Hence, the number of umbellates/umbel increases the primary umbel weight but as the number of umbels/plant increases overall weight of the umbel/plant decreases as the plant has to divert the resources to lower ordered umbel there by reducing its efficiency to accumulate more sink.

Bolting tendency for most of the cultivars was high as shown by the mean value (6.75) and the frequency distribution, although the range for bolting tendency observed for the cultivars was low to high but many cultivars showed very high tendency for bolting indicating their least requirement for vernalization. Since, low to very low bolting tendency is required for proper root development, hence, the cultivars with low bolting tendency need to be identified.

Good amount of variation was also observed for seed colour. Although in the descriptors, only 2 colors (Brownish and grayish) were available, we observed a range of variation in seed colour from dark brown to red. Predominant colour was grayish as shown by mean value near to 2.0 (*i.e.*1.92).

The genetic variability and heritability components were analyzed to know the extent of genetic variation which is heritable to the next generation as it is of great interest to a breeder in developing superior cultivars. Although genetic variability components for most of the characters showed a higher PCV among the cultivars, but as depicted by their moderate heritability and low to moderate GCV, these traits are supposed to be highly influenced by environment.

Although few of these characters showed low to moderate genetic variability coupled with low to moderate heritability except few characters (bolting tendency), but they could be reliable morphological markers for fingerprinting of released varieties, hybrid purity testing and also for effective selection in the large segregating population.

Among the 27 characters, only three characters, bolting tendency, number of umbels per plant and umbel weight showed high heritability, but later two with higher variability components (GCV and PCV) with moderate to high GAM and bolting tendency showed moderate genetic variability with moderate GAM, hence selection based on these two characters would be rewarding to achieve higher productivity as they have a direct influence on seed yield of carrot as revealed by their correlation with seed and umbel yield.

Among the umbel characters, high genetic variability and heritability coupled with genetic advance were observed for number of umbels per plant and umbel weight indicating that these could be the best characters for effective selection indicating additive gene action. Moderate heritability coupled with moderate GAM was observed despite their high genetic variability (GCV and PCV) among the umbel characters such as density of flowers in umbel and number of umbellates/ umbel.

For seed related characters, 1000-seed weight and number of spines showed moderate heritability components (h^2 and GAM) and high genetic variability hence considered as reliable characters for selection. Among the germination studies, percent germination, seed germination index-I and speed of germination showed high GCV, PCV with moderate heritability and GAM and hence less influenced by environment than other traits. Among the plant morphological characters, except bolting tendency, other three traits (type of bracts, no. of leaves below the primary umbel ad leaf growth habit) were highly influenced by environment as shown by their low to moderate GCV, heritability and GAM with higher PCV, hence, one cannot depend on these characters for selecting superior cultivars although they are easily observable characters.

Correlation analysis for all the 27 characters revealed that, carrot seed yield is highly associated with umbel weight, density of flowers in umbel, number of umbellates/umbel, width of primary open umbel, colour of the central floret of umbel, bolting tendency. Umbel weight is negatively influenced by number of umbels/plant, seed length and seed shuttering. Many carrot researchers have the opinion that, the seed yield and root quality as well as germination % and seedling vigor may be reduced as the order of the umbels increases (Gray, 1983; Thakur *et al*., 2015). Hence, during flowering, only higher order umbels have to be maintained to improve the umbel weight, seed quality, % germination and ultimately the carrot root quality and productivity. Seed yield per plant interestingly showed positive association with umbel colour, bolting tendency and seed germination index-I. Higher order umbels possess superior quality and vigorous seeds (Thakur *et al*., 2015; Nascimento *et al*., 2012; Carvalho and Nakagawa, 1983; Pereira *et al*., 2008). The frequency of green colour umbel was high among the 48 cultivars and positive association with the seed yield of this character was probably due to better photosynthetic efficiency of umbels because of more chlorophyll content as exhibited by green colour. Highest seed yield was recorded by UHSBC 24 (50.41) & UHSCBC 14 (48.5). Both of these cultivars showed intermediate flowers in the umbels, moderate number of umbels/plant (27.33 and 38.20 umbels respectively) with moderate umbellates/umbel (53.33 & 64.2 respectively) with flat umbel shape, compound type of umbel, with an umbel weight of 0.57 & 6.06g respectively. Adgham *et al*. (1995) found positive correlation between seed yield and number of umbels/plant.

For germination %, only five cultivars showed above 80% germination (UHSBC20, UHSBC25, UHSBC31, UHSBC46 and UHSBC65). However few cultivars with >60 % germination were also obtained. Higher umbel order had positive influence on better germination % (Amjad and Anjum 2001)

Since, the germination percentage is generally low in carrot, the speed of germination may range from 8-21 days after sowing in the field conditions. In tropical conditions, higher soil temperature and relative humidity greatly affects the speed of germination as well as germination %. The Indian Minimum Seed Certification Standards for germination in carrot is above 60% up to two years of storage (Thakur *et al*., 2015) and the germination % of carrot seeds even reduces to zero after two years of storage (Andrade *et al* ., 1995). These two characters are very important for the seed industries for profitable seeds production. Hence selection of cultivars for higher % germination and early germination are very important for the successful plant stand in the subsequent vegetative phase cycle of carrot which ultimately decides, the uniform harvesting date of carrot root with uniform sized roots. In the present study, both speed of germination and germination showed strong positive correlation as only one germination count was recorded after eight days of sowing. Germination % and speed of germination were negatively influenced by size of spine and seed length; hence lesser spine and small seeded types would be more preferable for better seed germination.

The carrot root quality, productivity and the uniformity with respect to shape, size and colour (internal and external) are the most important breeding objectives of carrot and these are highly influenced by genotype and climatic and many associated characters in both the phases of carrot life cycle. Present study has thrown a light on how the various seed, umbel and germination parameters affect seed yield of carrots. Studies on influence of these characters on economic part of carrot (root) are necessary for effective phenotypic selection. The seeds obtained in the present study are being evaluated for root morphological, biochemical and functional molecular markers and would be discussed elsewhere.

Carrot, like onion and other biennial crops has two life cycles *i.e.* reproductive and vegetative phases and root is an economic part for consumption. The quality and productivity of root depends on the morphological, biochemical characters as well as environmental conditions in both phases. Annual types of carrot cultivars are also available depending on the adaptability to warmer climates and vernalization requirement. Identification of simple morphological and/or molecular markers for annual types without any adverse affect on root quality would be more rewarding for harvesting root (economic part) as well as seeds (propagating material) in a single generation.

In the present study, we identified important characters such as density of flowers in umbels, number of umbellates/umbel, umbel shape and bolting tendency had e strong associations with seed and umbel yield. Higher heritability was recorded for bolting tendency, number of umbels/plant and umbel weight. For % germination, umbel shape and seed germination index-I had positive influence but interestingly, the seed length and size of spines have a negative influence on this important character. Hence, breeders may consider these characters to improve the reproductive potential of carrot for root quality and productivity in subsequent generations. The present investigation is especially informative for seed scientists and breeders for selection of highly productive carrot seeds with higher germination % based on the knowledge of association with simple morphological characters. By further studying the influence of these seed and umbel characters on the root quality, we can predict the performance of the vegetative phase of carrot in the previous cycle itself.

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