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Studies on genetic variability parameters and character association in fennel (*Foeniculum vulgare* Mill.) under semiarid conditions of Rajasthan

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Abstract
Seventy-eight genotypes of fennel (*Foeniculum vulgare* Mill.) were evaluated in a randomized block design with three replications at the research farm, S.K.N. College of Agriculture, Jobner (Rajasthan) for seed yield and quality parameters. The analysis of variance revealed significant differences between the entries for all the characters studied indicating the existence of variability among genotypes. The phenotypic coefficient of variation (PCV) was slightly higher than corresponding genotypic coefficient of variation (GCV) for most of the characters except total Soluble sugar content which indicates that environment has little influence on the character's expression. The present study showed higher heritability values (>70% for most of the characters) ranging from 10.0 to 91.6%. High heritability coupled with high genetic gain and coefficient of variability was observed for umbels per plant, seeds per umbel, harvest index, crude fibre content and seed yield per plant, indicating a possible role of additive gene effect for the genotypic variance for these characters. Phenotypic and genotypic correlation coefficient indicated that seed yield per plant showed significant and positive genotypic association with total plant height, branches per plant, umbels per plant, 1000-seed weight, biological yield per plant and harvest index. Hence, the selection based on phenotypic performance for these characters would be beneficial for achieving the desired gain.

Keywords: Fennel, *Foeniculum vulgare* Mill., genetic advance, heritability, variability correlation

Introduction
Fennel (*Foeniculum vulgare* Mill, 2n = 22) is a member of Apiaceae family. It is an allogamous crop where cross-pollination takes place up to 82.2 to 95.40% (Ramanujam *et al*., 1964) [20]. It is native to the Southern Europe. India is known as the 'Land of Spices' and is the largest producer, consumer and exporter of seed spices and their products. Fennel (*Foeniculum vulgare* Mill.) is an important seed spice crop, mainly grown in the states of Gujarat and Rajasthan and to some extent in other states. In India fennel is cultivated covering a total area of about 0.753 lakh ha with annual production of 1.28 lakh tonnes in 2019-2020. (Anonymous 2019) [2]. Based on its medical value and export potential as spices the importance of fennel was recognized long back yet remained neglected for long from scientific attention towards improvement in its productivity as well as quality. With the change in life style, the value-added form of seed spices has become the thrust area. The main constraints for the production of value-added products are lack of sufficient number of improved varieties having high volatile oil, low crude fibre, high soluble sugars and high seed yield.

Information on variability, heritability, genetic advance and correlation of seed yield with different quality and yield attributes is important since these provide basis for improving efficiency of hybridization and handling of segregating populations by selection. Such information on fennel (*Foeniculum vulgare* Mill.), an important seed spice, is very limited. Hence, the present investigation was carried out to study the nature and extent of genetic variability, heritability, genetic advance and correlation for fourteen characters in seventy-eight genotypes of fennel.

Materials and Methods

Seventy-eight genotypes of fennel (*Foeniculum vulgare* Mill.) including sixty-six hybrids resulting from crossing of twelve open pollinated varieties in diallel design excluding reciprocals, along with their twelve parents were evaluated in a randomized block design with three replications during at the research farm, S.K.N. College of Agriculture, Jobner (Rajasthan). Each entry was grown in two rows of 4.0 m in length. The spacing was maintained 45 cm between rows and 20 cm between plants. Observations were recorded on a sample of ten randomly selected plants for plant height upto main umbel, total plant height, branches per plant, umbels per plant, umbellets per umbel, seeds per umbel, biological yield per plant, harvest index, 1000-seed weight and Seed yield per plant.

Ten single plants were randomly tagged before initiation of flowering so as to reduce the biasness in the plant selection in each genotype in each replication for recording the observations on plant height upto main umbel (cm), total plant height (cm), branches per plant, umbels per plant, umbellets per umbel, seeds per umbel, biological yield per plant (g), harvest index (%), 1000-seed weight (g) and Seed yield per plant (g). The data were recorded at the time of maturity after uprooting the plants except days to 50% flowering (which were based on whole plot).

For quality analysis of seeds; volatile oil content was estimated by essential oil distillation assembly (A.O.A.C., 1970) [3], the total soluble sugar content was determined by colorimetric method of Dubois *et al.* (1951) [8] using anthrone reagent while crude fibre content was determined by the method of crude fibre determination (A.O.A.C., 1970) [3] in fat free material.

The means values of different genotypes, for all the characters were subjected to analysis of variance to determine the significance of differences among genotypes as per procedure given by Panse and Sukhatme (1985) [18]. Genotypic and phenotypic coefficient of variation, broad sense heritability and genetic advance were worked out following the methods of Burton & De Vane (1953) [4] and Johnson *et al.* (1955) [10].

Result and Discussion

Fennel a cross pollinated crop, commands respect as an important seed spice crop. In India it is one of the main seed spices crops, and every part of the plant is used for either as medicine or as an aromatic ingredient. It is also being exported and earns foreign exchange for the country. In heavy soils it can be raised as rainfed crop on conserved moisture. The productivity of fennel is low due to non availability of high yielding varieties and their poor stability in performance. A survey of literature indicated that limited work has been done as far as its genetic improvement is concerned and there is lack of adequate genetic variability, lack of information on the genetics of different economically important characters, inadequate knowledge of population dynamics and high degree of genotype x environment interaction (Sharma, 1996) [25].

The present investigation was, therefore, carried out to generate information on gene action involved in the control of yield and its component characters including quality aspects in fennel which will help the breeder in selection of desirable genotypes for population improvement and crossing programme and to suggest suitable breeding methodology for the genetic improvement in various quantitative and quality characters.

The analysis of variance revealed significant differences between the entries for all the characters studied indicating the existence of variability among genotypes (parents and their hybrids)(Table 1), Which is in accordance with the earlier reports by Singh (2000) [26], Dashora (2000) [7], Kumar *et al.* (2017) [12, 13], Patel *et al.* (2018) [19] and Meena *et al.* (2019) [16] in fennel.

The observed general mean for seed yield per plant was 15.2 g. and the mean for seed yield ranged from 10.27 to 21.23 g. Mean days to 50% flowering was 116.5 days, it ranged from 112.7 to 121.0, The general mean for plant height upto main umbel was 75.4 cm and main height ranged from 59.7 cm to 100.1 cm,The observed general mean for total plant height trait was 105.56 cm. the mean ranged from 89.23 to 126.47 cm The observed general mean for number of branches per plant was 7.2 while the mean number of branches ranged from 5.63 to 9.17.The observed general mean for number of umbels per plant was 31.77 while mean ranged from 14.2 to 51.3. The observed general mean for umbellets per umbel was 17.0, while mean ranged from 11.7 to 25.1.The general mean for number of seeds per umbel was 232.1.the mean ranged from 175.9 to 363.3. The general mean for biological yield per plant was 59.3 g. the mean ranged from 45.8 to 75.8 g. The general mean for harvest index was 25.8% while the mean ranged from 15.6 to 37.0%. The general mean for seed weight was 4.77 g per 1000 seed. The mean for this character ranged from 3.63 to 6.59 g. The general mean for volatile oil content was 2.26%. The mean volatile oil content ranged from 1.67to 2.97%. The general mean for crude fibre content was 15.03%. The mean crude fibre content ranged from 9.50 to 21.37%. The general mean for total soluble sugars content was 1.09% the mean for this character ranged from 0.81 to 1.73%. Similar results were reported by Kumawat (2010) [14] and Dashora and Sastry (2011) [6] for number of umbels per plant, Meena *et al.* (2013) [17] and Shaktawat *et al.* (2016) [24] for harvest index.

The phenotypic coefficient of variation (PCV) was slightly higher than corresponding genotypic coefficient of variation (GCV) for most of the characters except total Soluble sugar content which indicates that environment has little influence on the characters expression. The coefficient of variability was higher for total Soluble sugar contentfollowed by umbels per plant, harvest index, crude fibre content and seed yield per plant, while it was lowest for days to 50% flowering. Variability alone is of little importance in determining the heritable portion. A study of genotypic coefficient of variability gives the amount of gain expected from a selection. Similar conclusions were defined by Meena *et al.* (2010) [15], Yogi *et al.* (2014) [29] and Shaktawat *et al.* (2015) [23]. The present study showed higher heritability values ranging from 10.0 to 91.6%. Maximum heritability was observed for umbels per plant (91.60%) followed by seed yield per plant (90.90%), harvest index (87.90%), crude fibre content (87.70%) andbiological yield per plant (87.50%). Similar findings were reported by Yadav *et al.*, (2013) [28], Ghanashyam *et al.* (2015) [9] and Choudhary *et al.* (2017) [5]. Low heritability was observed for total soluble sugar content (10.0%) followed by days to 50% flowering (11.60%). Similar findings were reported by Shaktawat *et al.* (2015) [23] and Patel *et al.* (2018) [19]. In the study the estimates of heritability were observed high (>70%) for most of the characters.

Unless sufficient genetic gain attributable to additive gene action is present, high heritability does not guarantee large gain from selection. In a selection programme where the primary objective is character improvement, a study of genetic gain is more advantageous than heritability studies. Therefore, in the present study genetic gain was maximum for umbels per plant (53.19%) followed by harvest index (34.16%), seed yield per plant (32.81%), crude fibre content (31.74%) and seeds per umbel (26.40%). Similar agreement with earlier reports of Rawat *et al*. (2013) [21], Saxena *et al*. (2016) [22] and Kumar *et al*. (2017) [12, 13]. High heritability coupled with high genetic gain and coefficient of variability was observed for umbels per plant, seeds per umbel, harvest index, crude fibre content and seed yield per plant, indicating a possible role of additive gene effect for the genotypic variance for these characters. Hence, the selection based on phenotypic performance for these characters would be beneficial for achieving the desired gain.

Phenotypic and genotypic correlation coefficient (Table 2), indicated that seed yield per plant showed significant and positive genotypic association with total plant height, branches per plant, umbels per plant, 1000-seed weight, biological yield per plant and harvest index. However, for most of the characters the magnitude of genotypic correlation coefficients was higher with seed yield per plant than that of corresponding phenotypic correlation coefficients. Further days to flowering, volatile oil content and total soluble sugar content were negatively correlated with seed yield per plant. As plant height upto main umbel, umbellets per umbel and crude fibre content showed positive association with seed yield per plant. Selection for improvement of seed yield based on these components would be effective in improving the yield.

The study also indicated that the parents and crosses which showed superiority for seed yield per plant were also found superior for branches per plant, umbels per plant, umbellets per umbel, seeds per umbel, harvest index and 1000-seedweight. Hence, improvement in yield can be expected even if selection is based on these component characters. Earlier, Kathiria (1980) [11], Agnihotri (1997) [1] and Singh (2003) [27] have also reported positive association of these characters with seed yield. Thus, it is suggested that breeder should use these characters while selecting the material for yield improvement.

Path coefficient analysis was carried out at both genotypic and phenotypic levels by taking seed yield per plant as dependent variable and all the remaining characters as independent variables (Table 3). Direct effects at genotypic level were stronger than the phenotypic level. Harvest index followed by biological yield per plant, Umbels per plant, seeds per umbeland 1000-seed weightestablished high positive direct effects on seed yield per plant. These traits were also correlated positively with seed yield. Therefore, direct selection for these characters will be effective in improving seed yield in fennel. The information could be exploited in formulating a sound selection criterion inbreeding programme for genetic improvement to develop high yielding genotypes. Similar results were also reported by Agnihotri *et al.* (1997) [1].

In the era of value-added products, fennel oil has high value in export market and therefore breeding efforts to increase the oil content, total soluble sugars content and reducing crude fibre content will be highly desirable for quality breeding programme.

Table 1: Range, mean, coefficient of variation, heritability and expected genetic advance for seed yield and other characters in fennel.

Characters	Range	Mean	Genotypic coefficient of variation (GCV)	Phenotypic coefficient of variation (PCV)	Heritability % (Broad sense)	Expected genetic advance (as percentage of mean)
Days to 50% flowering	112.67-121.00	116.55	0.89	2.62	11.60	0.63
Plant height upto main umbel (cm)	59.70-100.10	75.43	9.91	10.79	84.40	19.22
Plant height total (cm)	89.23-126.43	105.56	6.47	7.59	72.50	11.35
Branches per plant	5.63-9,17	7.24	11.82	13.35	78.30	21.55
Umbels per plant	14,23-51,30	31.77	26.97	28.17	91.60	53.19
Umbellets per umbel	11.70-25.07	17.03	11.35	13.13	74.70	20.20
Seeds per umbel	175.97-363.27	232.14	13.83	14.92	85.90	26.40
1000-seed weight (g)	3.63-6.29	4.77	7.55	11.90	40.30	9.85
Biological yield per plant (g)	45.83-75.83	59.34	11.95	12.78	87.50	23.04
Volatile oil (%)	1.67-2.97	2.26	11.41	14.15	65.10	19.03
Harvest index (%)	15.65-37.02	25.85	17.69	18.87	87.90	34.16
Crude fibre content (%)	9.50-21.37	15.03	16.44	17.55	87.70	31.74
Total Soluble sugar content (mg/g)	0.81-1.73	1.28	14.84	47.04	10.00	9.66
Seed yield per plant (g)	10.27-21.23	15.18	16.69	17.51	90.90	32.81

Table 2: Phenotypic and genotypic correlation coefficients for seed yield and other characters in fennel.

Character		Days to 50% flowering	Plant height upto main umbel (cm)	Plant height total (cm)	Branches per plant	Umbels per plant	Umbellets per umbel	Seeds per umbel	1000-seed weight (g)	Biological yield per plant	Volatile oil (%)	Harvest index	Crude fibre content	Soluble sugar content	Seed yield per plant
Days to 50% flowering	P	1.000	0.000	-0.053	-0.090	-0.175	0.067	-0.074	-0.063	-0.131	-0.044	-0.049	0.000	0.115	-0.143
	G	1.000	0.006	-0.480**	-0.226*	-0.504**	0.282**	-0.242**	-0.367**	-0.256*	-0.110	-0.263*	0.142	-0.178	-0.452**
Plant height upto main umbel (cm)	P		1.000	0.479**	0.327**	0.103	0.411**	0.088	-0.012	0.126	0.040	0.074	-0.064	-0.157	0.160
	G		1.000	0.607**	0.410**	0.105	0.477**	0.120	-0.039	0.159	0.043	0.072	-0.056	-0.368**	0.177
Plant height total (cm)	P			1.000	0.448**	0.323**	0.284**	0.156	0.092	0.406**	-0.007	0.042	0.022	0.016	0.332**
	G			1.000	0.557**	0.400**	0.394**	0.185	0.127	0.481**	-0.015	0.078	0.031	-0.325**	0.423**
Branches per plant	P				1.000	0.233*	0.275*	0.222*	0.071	0.318**	0.043	-0.013	-0.017	-0.011	0.229*
	G				1.000	0.276**	0.317**	0.292**	0.173	0.364**	0.059	-0.019	-0.017	0.053	0.254*
Umbels per plant	P					1.000	0.102	0.172	0.232*	0.226*	-0.055	0.657**	0.059	-0.038	0.881**
	G					1.000	0.122	0.191	0.367**	0.261*	-0.053	0.732**	0.050	-0.094	0.971**
Umbellets per umbel	P						1.000	0.296**	-0.024	-0.055	0.110	0.173	-0.091	-0.010	0.123
	G						1.000	0.373**	-0.075	-0.055	0.139	0.204	-0.122	0.025	0.146
Seeds per umbel	P							1.000	-0.043	-0.073	-0.018	0.190	0.048	0.099	0.165
	G							1.000	-0.081	-0.081	-0.031	0.220	0.040	0.257*	0.191
1000-seed weight (g)	P								1.000	0.207	0.232*	0.065	-0.279**	0.100	0.222*
	G								1.000	0.365**	0.513**	0.140	-0.406**	0.160	0.408**
Biological yield per plant	P									1.000	0.070	-0.438**	-0.053	-0.003	0.253*
	G									1.000	0.043	-0.415**	-0.041	0.193	0.277**
Volatile oil (%)	P										1.000	-0.059	-0.827**	-0.005	-0.015
	G										1.000	-0.061	-0.092**	0.128	-0.031
Harvest index	P											1.000	0.044	-0.037	0.751**
	G											1.000	0.060	-0.264*	0.753**
Crude fibre content	P												1.000	-0.031	0.014
	G												1.000	-0.016	0.029
Soluble sugar content	P													1.000	-0.046
	G													1.000	-0.161
Seed yield per plant	P														1.000
	G														1.000

Table 3: Direct (Diagonal) and indirect (Non diagonal) effects of different characters on seed yield in fennel on phenotypic and genotypic level.

Character		Plant height upto main umbel (cm)	Plant height total (cm)	Branches per plant	Umbels per plant	Seeds per umbel	1000-seed weight (g)	Biological yield per plant	Harvest Index	Genotypic and phenotypic correlation on seed yield per plant
Plant height upto main umbel (cm)	P	-0.006	-0.007	0.005	0.007	0.001	0.000	0.085	0.074	0.160 P
	G	0.010	-0.003	-0.001	0.026	0.002	0.000	0.0086	0.057	0.177 G
Plant height total (cm)	P	-0.003	-0.014	0.007	0.023	0.002	0.000	0.275	0.042	0.332 P**
	G	0.006	-0.005	-0.002	0.098	0.003	0.002	0.026	0.061	0.423 G
Branches per plant	P	-0.002	-0.006	0.016	0.017	0.000.003	0.000	0.215	-0.013	0.229 P
	G	0.004	-0.003	-0.003	0.068	0.005	0.002	0.196	-0.015	0.254 G
Umbels per plant	P	-0.001	-0.005	0.004	0.071	0.002	0.000	0.153	0.656	0.881 P
	G	0.001	-0.002	-0.001	0.245	0.003	0.005	0.141	0.579	0.971 G
Seeds per umbel	P	0.000	-0.002	0.003	0.012	0.012	0.000	-0.049	0.190	0.165 P
	G	0.001	-0.001	-0.001	0.047	0.016	-0.001	-0.044	0.174	0.191 G
1000-seed weight (g)	P	0.000	-0.001	0.001	0.017	-0.001	0.001	0.140	0.065	0.222 P
	G	0.000	-0.001	-0.001	0.090	-0.001	0.012	0.197	0.111	0.408 G
Biological yield per plant	P	-0.001	-0.006	0.005	0.016	-0.001	0.000	0.676	-0.437	0.253 P
	G	0.002	-0.002	-0.001	0.064	-0.001	0.005	0.540	-0.328	0.277 G
Harvest index	P	0.000	-0.001	0.000	0.047	0.002	0.000	-0.296	0.999	0.751 P
	G	0.001	0.000	0.000	0.180	0.004	0.002	-0.284	0.791	0.753 G

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