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Varietal diallel analysis in fennel (*Foeniculum vulgare* Mill.)

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Abstract
The extent of heterosis, components of heterosis and combining ability effects were estimated in seven genetically diverse parents of fennel crossed in half diallel fashion. The analysis of variance revealed significant differences among entries, parents and their F_1s for most of the characters studied. The parents *vs* crosses interaction was found significant and the contribution of heterosis ($h_{ii'}$) component from analysis of variance was more than 75% for most of the characters. The specific ($s_{ii'}$) component accounted for more than 50% to heterosis sum of squares for most characters indicating the importance of heterosis in the genetic inheritance of the traits. Crosses RF-143 x RF-178, RF-101 x GF-11 and RF-178 x GF-12 had high mean values and high $s_{ii'}$ values for all yield related traits. Crosses PF-35 x GF-11, RF-101 x RF-143, GF-11 x GF-12, RF-143 x Rajendra Saurabh and RF-101 x RF-178 had significant specific effects. Varieties RF-178 and GF-12 merit attention as parents based on *per se* performance, variety effects (v_i) and varietal heterotic effects (h_i).

Keywords: heterosis, specific combining ability, Fennel, *Foeniculum vugare* Mill

Introduction
Fennel is a major seed spices having high potential as cash crop.It is used as food and is also in cosmetic and medical industries. Fennel essential oil posses' valuable antioxidant, antibacterial, anticancer and antifungal. Fennel is an allogamous crop with cross pollination to an extent of 82.2% to 94.40% (Ramanujam *et al.* 1964) [4]. Genetic improvement in fennel has not been exploited fully. The yield potential of fennel (*Foeniculum vulgare* Mill.) can be increased by use of hybrids and composites. However, very little work has been done in this direction due to reasons like absence of superior compatible inbreds and absence of male sterile lines. The present study is therefore, an attempt to increase the genetic base of the existing varieties by attempting varietal diallel. Varietal diallel mating design is a type of mating system in which a fixed set of parents are crossed in all possible combinations in an allogamous population. Gardner & Eberhart (1966) [6] proposed varietal diallel and gave a statistical genetic model which serves as a guide to plant breeders in the design and analysis of their experiments, concerning a fixed set of random mating varieties.

Material and Methods
The experiment was carried out using seven genetically diverse varieties crossed in half-diallel fashion and the resultant 21 hybrids along with seven parents were evaluated in RBD with three replications at Instructional Farm, Junagadh Agricultural University, Junagadh. The observations were recorded for twelve quantitative characters from ten randomly selected plants except for days to 50% flowering and days to maturity which were recorded on whole plot basis. The data was analyzed according to Gardner and Eberhart (1966) [6], Analysis II.

Result and Discussion
The analysis of variance revealed that mean sum of squares for entries, parents and their F_1s were significant for all the characters studied except for number of umbellets per umbel, indicating the existence of variability among entries, parents as well as their hybrids, which is a pre-requisite for commencement of any crop improvement programme. Significant parents *vs* crosses interaction indicated the presence of heterosis for the characters (Table 1).

Table 1: Analysis of variance for various characters [Gardner and Eberhart (1966), Analysis II] for estimation of components of heterosis

Source of variation	Df	Mean squares					
		Days to 50% flowering	Days to maturity	Plant height upto umbel (cm)	Total plant height (cm)	No. of branches per plant	No. of umbels per plant
Entries	27	4.64**	7.99**	219.49**	152.47**	1.99**	140.87**
Varieties (v_i)	6	3.46*	7.43**	99.44*	35.49*	1.04*	75.43*
Heterosis (h_{ii})	21	4.97**	8.14**	253.79**	185.90**	2.26**	159.57**
Average ($\bar{h}$)	1	6.11*	28.19**	412.99**	91.09**	13.97**	412.64**
Variety (h_i)	6	8.98**	9.01**	334.05**	325.97**	2.76**	198.36**
Specific ($s_{ii'}$)	14	3.18*	6.34**	208.03**	132.64**	1.21**	124.87**
Error	54	1.43	1.14	39.31	12.10	0.39	32.93

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Source of variation	Df	Mean squares					
		Number of umbellets per umbel	Number of seeds per umbel	1000-seed weight (g)	Seed yield per plant (g)	Biological yield per plant (g)	Harvest index (%)
Entries	27	6.814	10786.48**	1.09**	12.37**	410.53**	8.90**
Varieties (v_i)	6	1.273	2604.94*	1.22 **	8.73**	157.73**	9.87**
Heterosis (h_{ii})	21	8.397	13124.06*	1.06**	13.41**	482.76**	8.63**
Average ($\bar{h}$)	1	9.813	32401.85**	1.44**	20.16**	2134.91**	22.94**
Variety (h_i)	6	6.456	5776.667**	1.24**	15.03**	100.61**	6.12**
Specific ($s_{ii'}$)	14	9.128	14895.96**	0.95**	12.23**	528.53**	8.68**
Error	54	6.363	944.713	0.003	0.98	24.34	1.43

Comparative perusal of the *per se* performance revealed that varieties RF-178, PF-35 and GF-12 were best for seed yield per plant while variety GF-12 and GF-11 for earliness traits. Amongst the crosses, best three for seed yield per plant were RF-143 x RF-178, RF-101 x GF-11 and RF-178 x GF-12 and for earliness traits i.e. days to 50% flowering and days to maturity, the crosses were PF-35 x GF-11, RF-178 x Rajendra Saurabh, RF-178 x GF-11, RF-143 x GF-11, PF-35 x GF-11 and RF-143 x RF-178. The best three variety and crosses for all the characters under study are given (Table 2).

Table 2: Three best varieties and hybrids based on *per se* performance

	Days to 50% flowering	Days to maturity	Plant height upto main umbel (cm)	Total plant height (cm)	Number of branches per plant	Number of umbels per plant
Parents	GF-12	GF-11	RF-101	RF-101	PF-35	PF-35
	GF-11	GF-12	RF-143	RF-143	RF-178	RF-178
	RF-178	RF-143, PF-35	PF-35	RF-178	GF-12	RF-101
Hybrids	PF-35 x GF-11	RF-143 x GF-11	RF-143 x RF-178	RF-143 x RF-178	GF-11 x GF-12	RF-178 x PF-35
	RF-178 x RS	PF-35 x GF-11	PF-35 x RS	RF-178 x GF-11	RF-101 x GF-11	GF-11 x GF-12
	RF-178 x GF-11	RF-143 x RF-178	RF-178 x GF-11	RF-101 x RF-143	RF-143 x RF-178	RF-143 x RF-178

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	No. of umbellets/umbel	No. of seeds/umbel	1000-seed weight (g)	Seed yield/plant(g)	Biological yield/ plant(g)	Harvest index (%)
Parents	GF-12	GF-12	RF-178	RF-178	PF-35	RF-101
	GF-11	GF-11	PF-35	PF-35	RF-178	RF-178
	RF-143	Rajendra Saurabh	RF-143	GF-12	Rajendra Saurabh	GF-12
Hybrids	RF-101 x GF-11	RF-143 x PF-35	RF-143 x GF-12	RF-143 x RF-178	RF-178 x GF-12	RF-101 x RF-143
	RF-143 x GF-12	RF-101 x RF-178	RF-178 x GF-11	RF-101 x GF-11	RF-143 xGF-12	PF-35 x RS
	RF-101 x RF-178	PF-35 x RS	RF-101 x RS	RF-178 x GF-12	RF-101 x GF-11	PF-35 x GF-12

Partitioning of variance into components of heterosis revealed that the variety (v_i) as well as heterosis ($h_{ii'}$) component was highly significant for all the characters except for number of umbellets per umbel, indicating the existence of diversity and the importance of heterosis in the expression of the characters. The proportion of $h_{ii'}$ component in the variance was above 75% indicating the importance of heterosis in the genetic inheritance of the traits. The heterosis ($h_{ii'}$) component was further partitioned into average heterosis ($\bar{h}$), varietal heterosis (h_i) and specific effects ($s_{ii'}$). All of these components were significant for maximum of the characters. Amongst the three components i.e. $\bar{h}$, h_i and $s_{ii'}$, the $s_{ii'}$ component accounted for more than 50% to heterosis sum of squares for most of the characters (Table 3).

Table 3: Percent contribution of average heterosis, varietal heterosis and specific combining ability to heterosis sum of squares

Character	Heterosis SS as % of entry SS	% Heterosis SS accounted for		
		Average	Variety	SCA
Days to 50% flowering	83.42%	5.85%	51.56%	42.58%
Days to maturity	79.32%	16.48%	31.59%	51.92%
Plant height upto umbel (cm)	89.93%	7.75%	37.61%	54.65%
Total plant height (cm)	94.82%	2.33%	50.10%	47.57%
Number of branches per plant	88.36%	29.45%	34.86%	35.69%
Number of umbels per plant	88.10%	12.31%	35.52%	52.17%
Number of umbellets per umbel	95.84%	5.56%	21.97%	72.47%
Number of seeds per umbel	94.63%	11.76%	12.58%	75.67%
1000-seed weight (g)	75.09%	6.51%	33.44%	60.05%
Seed yield per plant (g)	84.32%	7.16%	32.03%	60.80%
Biological per plant (g)	91.46%	21.06%	31.75%	47.19%
Harvest index (%)	75.35%	12.66%	20.27%	67.06%

Estimates of genetic constants showed that only few parents were significant for v_i and h_i effects, while large number of crosses exhibited significant specific heterosis effects ($s_{ii'}$) for almost all the traits. This supports the presence of complex type of inheritance involving additive, dominance and epistatic components. Significant desirable variety effects (v_i)and varietal heterotic effects (h_i) were revealed for all the characters. Parents RF-178, RF-143 and GF12 were found to be superior based on v_i effects and h_i effects for all the traits studied. Specific effects ($s_{ii'}$) revealed that several crosses had significant desirable effects for the characters under study. Majority of these crosses also exhibited good *per se* performance. High heterotic crosses were RF-143 x RF-178, RF-101 x GF-11 and RF-178 x GF-12 as they had high mean values, high $s_{ii'}$ values not only for seed yield per plant but for yield related traits as well (Table 4). The parents and crosses which showed superiority for seed yield per plant were also found superior for number of branches per plant, number of umbels per plant and number of seeds per umbel. Hence, improvement in yield can be expected even when selection is based on these component characters.

Table 4: Varieties and Crosses with significant desirable components of heterosis

Characters	v_i	h_i	$S_{ii'}$
Days to 50 % flowering	-	GF-12	RF-101 x Rajendra Saurabh RF-143 x RF-178
Days to maturity	GF-11	GF-12	PF-35 x GF-11 , RF-101 x RF-143, RF-101 x RF-178, GF-11 x GF-12 RF-143 x Rajendra Saurabh
Plant height upto main umbel (cm)	-	-	RF-101 x RF-143, RF-143 x RF-178, PF-35 x GF-12, PF-35 x Rajendra Saurabh
Total plant height (cm)	RF-101	RF-143 RF-178	RF-101 x RF-143, RF-143 x RF-178, RF-178 x GF-11, PF-35 x GF-12, PF-35 x Rajendra Saurabh
Number of branches per plant	-	RF-178	GF-11 x GF-12
Number of umbels per plant	-	RF-178	RF-143 x RF-178, RF-178 x PF-35 GF-11 x GF-12
Number of umbellets per umbel	-	-	RF-101 x GF-11
Number of seeds per umbel	GF-12	-	RF-101 x RF-178, RF-143 X PF-35 RF-143 x GF-12, PF-35 x Rajendra Saurabh , GF-11 x GF-12
1000-seed weight (g)	RF-178 PF-35	RF-143 RF-178	RF-101 x PF-35, RF-143 x GF-12 RF-101 x Rajendra Saurabh RF-143 x GF-12, RF-178 x GF-12 PF-35 x Rajendra Saurabh
Seed yield per plant (g)	RF-178	RF-143 RF-178	RF-101 x GF-11, RF-101 x Rajendra Saurabh, RF-178 x GF-12 , PF-35 x Rajendra Saurabh , RF-143 x RF-178, RF-178 x GF-11, RF-143 x GF-12
Biological yield per plant (g)	RF-178 PF-35	RF-178	RF-101 x PF-35 , RF-101 x GF-11 RF-143 x PF-35, RF-143 x GF-12 RF-143 x Rajendra Saurabh, RF-178 x PF-35, RF-178 x GF-11, RF-178 x GF-12* GF-11 x GF-12
Harvest index (%)	RF-101	-	RF-101 x RF-143 , RF-101 x Rajendra Saurabh ,PF-35 x Rajendra Saurabh, PF-35 x GF-12

Conclusion

Crosses PF-35 x GF-11, RF-101 x RF-143, GF-11 x GF-12, RF-143 x Rajendra Saurabh and RF-101 x RF-178 had significant specific effects for earliness and considerably fair *per se* performance. Using these crosses, a base population with highly variable gene frequencies could be generated and used for developing composites or identifying superior lines in the segregating generations. Varieties RF-178 and GF-12 merit attention as parents based on *per se* performance, variety effects (v_i) and varietal heterotic effects (h_i). Other varieties worth considering are Rajendra Saurabh and RF-143. These can therefore be included in hybridisation programmes for improvement of production and productivity in fennel.

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