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RESEARCH **P**APER

Genetic variability, divergence, correlation and path analysis in *Foeniculum vulgare* Mill. germplasm

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The importance of fennel is well realized on account of its high remunerative prices, domestic consumption, medicinal value and means to get earn foreign exchange. Despite the economic importance of fennel, disease resistant, locally acceptable and high yielding crop. The present investigation was therefore, carried out to estimate the magnitude and nature of genetic variability in terms of variation, heritability, genetic advance and genetic diversity for different traits like seed yield per plant and yield contributing traits in a set of 50 germplasm with four checks and extent of environmental influence on these traits, form the basis on which a breeder can predict the extent of dependence on phenotypic selection for improvement of traits. The analysis of variance revealed that significant amount of variability was present in germplasm lines for almost all morphological traits studied as days to germination, 50 per cent flowering, king umbel anthesis, number of number of primary branches, number of secondary branches, plant height (cm), diameter of king umbel (cm), number of umbels per plant, number of umbellates per umbel, number of seeds per umbel, at a test-weight (g) and seed yield (g). A wide range of mean for yield and some of its contributing traits indicates good chance for improvement of yield through direct selection or by transferring desired traits. On the basis of mean performance of yield and other yield contributing morphological traits, the germplasm AF-22, AF-63, AF-85, AF-96, AF-128, AF-48, AF-45, AF-62, AF-47, AF-58, AF-80, AF-154, AF-32, AF-44, AF-108, AF-140, AF-134, AF-22, AF-63, AF-85, AF-96, AF-128, AF-48, AF-45, AF-62, F-47, AF-58, AF-80, AF-154, AF-32, AF-44, AF-108, AF-140, AF-134, AF-22, AF-63, AF-85, AF-96, AF-128, AF-48, AF-45, AF-62, AF-47, AF-58, AF-80, AF-154, AF-32, AF-44, AF-108, AF-140, AF-134, were found to be superior. The variability of characters was compared on the basis of co-efficient of variation. The genotypic co-efficient of variation (GCV) and phenotypic co-efficient of variation (PCV) were worked out. Higher GCV (genotypic co-efficient of variation) was recorded for number of umbels per plant (15.7), seed yield (12.4) and number of secondary branches per plant (12.3), it expresses the true genetic potential which indicated the presence of high amount of genetic variability for these characters thus, selection may be more effective for these characters because the response to selection is directly proportional to the component of variability, while, number of seeds per umbellate (11.9), king umbel diameter (10.8) and umbellate per umbel showed moderate to high genotypic co-efficient of variation. Whereas primary branches (9.6), test weight (8.1) showed low magnitude of genotypic co-efficient of variation. Higher PCV was recorded for number of umbels per plant (16.7), king umbel diameter (14.3) and number of secondary branches per plant (14.0), while, seed yield (g) (12.5), number of seeds per umbellate (12.1) and number of umbellates per umbel (11.1) showed moderate to high phenotypic co-efficient of variation. Whereas number of primary branches (10.6), test weight (g) (8.9) showed low magnitude of phenotypic co-efficient of variation.

Key words : Variability, Germplasm, Phenotypic, Heritability, Fennel

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INTRODUCTION

Spices are very important place in the lives of people since Vedic and Bibilical times. They have been considered indispensable in seasoning and test of food, flavouring of beverages, perfumery, cosmetics and medicines. The fragrance of spices prompted explorers like Columbus and Vasco da Gama to undertake hazardous sea journey to discover India "the land of spices". A wide ranges variety of spice are grown in the country of which seed spices is a group. Seed spices include all those annuals whose dried seeds are used as spices and condiments. We considered 10 seed spices crops. Fennel, fenugreek, coriander, cumin, come in major seed spices. Ajowain, dill, nigella, celery, caraway and parsely come under minor seed spices. Fennel (*Foeniculum vulgare* Mill,) belongs to family Apiaceae is a cross pollinated crop. It is a diploid species with chromosome number, 2x = 22 and native of Europe and Mediterranean region (Agarwal *et al.*, 2001). Fennel is a tall, erect, glabrous, glaucous, biennial or perennial herb, with yellow flowers and aromatic seeds. There is normally erect, stout, main stem upto 1.5 meters occasionally to 2 meters with the base 2.0- 3.0 cm diameter. The stem is erect, striate, smooth, shiny and green to blue green, leaves are bright green to blue green alternate, decompounds, leaves sheath 2-15 cm with scabrous margins, forming an open cylinder at the base embracing the stem the inflorescence is a large flats compound umbel upto 20 cm in diameter but usually not more than 16 cm, brome terminally on branches. Flowers are bisexual, actinomorphic and open centripetally. The flowering dynamics and pollination of umbels indicate that inbreeding and hybridization could be successful in genetic improvement. The fruit is a light green to dark brown lens-shaped schizocarp of two mericarps attached to a dividing carpophore, oblong-oval to ellipticl 2-3 mm with long pedicel and short stylopodium. The plant is pleasantly aromatic and each of the parts-leaves, stalks, bulbs and seeds are edible. The root is regarded as a purgative. Fennel fruits are used in diseases like cholera, bile disturbances, nervous disorders, constipation, dysentery and diarrhea and also used for control of diseases attacking chest, lungs, spleen, kidney and in colic pain. In India, the seeds are also used for mastication and chewing either alone or with betel leaves (Girija Lakshman, 1952). The seeds contain about 9.5 per cent protein, 10.0 per cent fat, 42.3 per cent carbohydrates, 18.5 per cent crude fibre and 13.4 minerals. The seeds contain about 0.7 to 6.0 per cent volatile oil depending on the genotypes or botanical types. The main constituents of the fennel oil are anethole and fenchone. The other constituents are methyl chavicol, alpha-pinene, camphene, alpha-phellandrene and dipentene.

Uses:

The volatile oil extracted from seeds is used for scenting soaps and flavouring cakes. Fennel oil and fennel oleoresins are used in pizza sauces, topping, non- alcoholic beverages, liquors, ice creams and in seasoning of processed meats. The volatile oil is used in the manufacture of cordials and enters into the composition of fennel water, which is commonly given to infants as medicine. The volatile oil is primarily beneficial for digestive system and also exhibits vermicidal, antispasmodic and anti- flatulence properties. The leaves of fennel are used for fish sauce and for garnishing. Also, leaves and stalks are used in salads. It is an essential ingredient in Italian sausages, widely used to sprinkle on pizza. Dried fruits, having a pleasing fragrance and aromatic taste, are used as a masticatory. Fennel's seeds, leaves and roots have medicinal properties. It cures appetite loss, gassy colic in children, dysentery, eye strain, throat pain, stomach pain and headache, and improves eye sight. Fennel is rich in vitamin A and contains a fair amount of calcium, phosphorus and potassium. Fennel is cultivated throughout the temperate and subtropical region in the world mainly in the countries like, Romania, Russia, Hungary, Germany, France, Italy, India, Sri Lanka, Malaysia, Japan, Argentina and USA. In India, it is mainly grown in the states of Gujarat and Rajasthan as a cold weather crop and to some extent in U.P., Karnataka, A.P., Punjab, M.P., Bihar, Haryana and J & K. Total area under the crop in India is about 3172468 hectares with production of 580114 tonnes (Source: Spice Board). In Rajasthan, fennel occupies an area of 99610 hectares with an annual production of 142940 tonnes (Source: Spice Board). It is mainly cultivated in the districts of Sirohi, Jodhpur, Nagour, Tonk, Dausa and Pali and to a limited extent in Bharatpur, Kota and Ajmer. Though, the crop has a potential as a cash crop in Rajasthan, limited work has been done as far as its genetic improvement is concerned. The importance of fennel based on its medicinal value and export potential as spices was recognized long back but it remained neglected for long

time from scientific attention for its improvement in its productivity as well as its quality. Despite the importance of the crop, very limited breeding work has been done. The starting point of any systemic breeding programmes is the collection of a large germplasm. The adequacy of the germplasm is determined by the amount of genetic variability present in the germplasm. Information on nature and magnitude of variability for different important characters is necessary to judge the potentiality of the germplasm collection. Furthermore, information on association among different morphological characters and with seed yield is necessary for formation of suitable selection criteria for producing high yielding varieties. The objectives of the proposed research project are : To asses genetic variability in fennel germplasm, to study divergence in fennel germplasm and to asses correlation and path analysis in fennel germplasm.

RESEARCH METHODOLOGY

The present investigation on genetic variability, divergence, correlation and path analysis in *Foeniculum Vulgare* Mill germplasm among different genotype was conducted during *Rabi* season of 2014-2015. The details of materials used, experimental procedure, criteria employed and methodology adopted for evaluation of treatment effect, during the entire course of investigation are described in this chapter.

Experimental materials:

The experimental material for the present investigation consisted of 50 diverse genotypes from geographic and genetic origin, beside it 4 genotypes which are used as checks also included among them. These four checks [AF-1, GF-1, RF-101, and RF-125] are locally used famous high yielding improved varieties, collected from different National, State, Regional levels institutes or agencies. The list of genotypes used in the study has been presented in Table A.

Details of crop sowing:

Field preparation :

The experimental field was prepared by ploughing once with tractor drawn disc followed by two harrowing and planking. As per layout plan, plots were made with provision of irrigation channels and before sowing plot were leveled, so irrigation may be done properly.

Table A : List of germplasm and checks used for the investigation

Sr. No.	Genotypes	Sr. No.	Genotypes	Sr. No.	Genotypes
1.	AF-85	21.	AF-149	41.	AF-59
2.	AF-17	22.	AF-37	42.	AF-95
3.	AF-89	23.	AF-106	43.	AF-140
4.	AF-28	24.	AF-58	44.	AF-45
5.	AF-96	25.	AF-30	45.	AF-47
6.	AF-42	26.	AF-160	46.	AF-94
7.	AF-154	27.	AF-48	47.	AF-32
8.	AF-72	28.	AF-49	48.	AF-116
9.	AF-108	29.	AF-63	49.	AF-137
10.	AF-104	30.	AF-64	50.	AF-152
11.	AF-11	31.	AF-128		
12.	AF-130	32.	AF-9	Checks	
13.	AF-99	33.	AF-87	1	AF-1
14.	AF-82	34.	AF-56	2	RF-125
15.	AF-134	35.	AF-36	3	GF-1
16.	AF-54	36.	AF-57	4	RF-101
17.	AF-22	37.	AF-91		
18.	AF-14	38.	AF-44		
19.	AF-80	39.	AF-138		
20.	AF-13	40.	AF-62		

Fertilizer application:

For good production of fennel about 15 t/ha well decomposed FYM used before 4 weeks of sowing. In addition to this in the soil of normal fertility status 90kg N_2 per ha, 45kg P_2O_5 per ha and 40kg K_2O per ha used. The fennel has responded positively upto 120kg N_2 and 50kgP_2O_5/ ha. Apply 1/3rd N_2 and full dose of P_2O_5 as basal and remaining N_2 at 30 and 60DAS as top dressing.

Irrigation:

Fennel being a long duration crop, therefore, water requirement this crop is higher as compared to other seed spice crops. Ten irrigations were applied during the crop season.

Thinning and weeding:

Thinning was done at 25DAS to maintain plant to plant distance of 25cm. Three to four weeding was done for successful cultivation of fennel.

Plant protection measures:

All necessary plant protection measures were taken to raise a healthy crop.

Harvesting:

Five tagged plants were selected at randomly for recording of the yield and yield related data.

Threshing and winnowing:

Threshing of individual plant was done after recording all plant growth data. Seed weights were weighed and seed was taken for essential oil etc.

Observation to be recorded:

Days to germination:

Numbers of days were counted from the date of sowing to five plant germination. The average was worked out and expressed as number of days.

Duration of complete anthesis :

Numbers of days were counted from the date of initiation of flowering to complete anthesis; randomly selected five plants have appearance of umbel from each line. The average was worked out and expressed as number of days.

Days to 50 per cent flowering:

Numbers of days were counted from the date of sowing to the date when 50 per cent plant from five randomly selected plants. The average days to 50 per cent flowering was worked out and expressed.

Number of primary branches per plant:

The primary branches from five randomly selected plants from each line were counted at harvesting time. The average was computed and expressed as number of primary branches per plant.

Number of secondary branches per plant:

The secondary branches from five randomly selected plants from each line were counted at harvesting time. The average was computed and expressed as number of primary branches per plant.

Plant height (cm):

The height of five randomly selected plants from each line was measured at harvesting time. The plant height was measured from upto main umbel and upto top of the plant. The average was worked out and expressed as plant height in cm.

Diameter of king umbel (cm):

The diameter of main umbel from five randomly selected plants from each line were measured each umbel.

Numbers of umbels per plant:

The umbels of five randomly selected plants from each line at the time of harvesting were counted and average number of umbels per plant was recorded.

Numbers of umbellates per umbel:

The umbellates of five randomly selected plants from each line at the time of harvesting were counted and average number of umbellates per plant was recorded.

Number of seeds per umbellate:

The umbellates of five randomly selected plants from each line at the time of harvesting were counted and average number of seeds per umbellate was recorded.

Test seed weight (g):

A random sample of 1000 seeds was drawn from the produce of five tagged plant to get test weight (g).

Seed yield (five plants) (g):

After threshing and winnowing clean grain obtained from five tagged plant were weighted and the weight was recorded in grams.

Statistical analysis:

Analysis of variance:

To estimate the variation among the germplasm and checks, analysis of variance was carried out as per the procedure suggested by Federer (1956). The skeleton of the ANOVA Table B is given below:

Table B: ANOVA table and expectation of mean squares

Source of variation	Df	MS
Blocks	(b-1)	MSb
Treatments	(e-1)	MSt
Germplasm	(g-1)	MSg
Checks	(c-1)	MSc
Germplasm v/s hecks	1	MS
Error	(b-1) (c-1)	MSe
Total	N-1	

where, b =Number of blocks, e = Number of treatments, g=Number of germplasm, c=Number of checks, MSb=Mean sum of squares due to blocks, MSt = Mean sum of squares due to treatments, MSg = Mean sum of squares due to germplasm, MSc = Mean sum of squares due to checks, MSe = Mean sum of squares due to error. The ANOVA using the above model was done as per the Indostat version 8 augmented block design software.

Mean:

Computation of general mean was done as per the following formula :

$$\text{General mean } (\bar{X}) = \frac{\Sigma X}{N}$$

where, Σx = Sum of all the observations, N = Total number of observations (the number of germplasm evaluated).

Range:

The range of characters represented the lowest and highest means values among the germplasm for a given character.

Standard error of mean:

Computation of standard error of difference between two means was done by the following formula:

$$SEm\pm = \sqrt{\frac{2MSe}{r}}$$

where, r =Number of replications, MSe =Mean square due to error.

Critical difference:

The critical difference (C.D.) at 5 per cent was calculated by the following formulae :

$$\text{Between check varieties} = \sqrt{\left[\frac{2 \times MSe}{b}\right]} \times t$$

$$\text{Between germplasm within a block} = \sqrt{2 \times MSe \times t}$$

$$\text{Between germplasm between block} = \sqrt{\left[\frac{2 \times MSe \times (c+1)}{c}\right]} \times t$$

$$\text{Between block varieties and accessions} = \sqrt{\left[\frac{MSe \times (b+1) \times (c+1)}{b \times c}\right]} \times t$$

where, MSe=Error variance, b=Number of blocks, c=Number of checks, t= t value at 0.05 at error d.f. (c-1) (b-1) = 1.

Co-efficient of variation :

The co-efficient of variation (CV) was calculated by the following formula :

$$\text{Co-efficient of variation } (CV) = \frac{SD}{\bar{X}} \times 100$$

where, SD=Standard deviation of sample, $\bar{X}$ = Mean of sample.

Genetic analysis :

The components of genotypic variance and phenotypic variance are estimated directly by using mean sum of squares. From the components of variance, the genotypic and phenotypic co-efficients of variation, heritability in broad sense and genetic advance expressed as percentage of mean were computed. The formulas were used for various analyses are given below:

Estimation of co-efficient of variation :

Genotypic co-efficient of variation for a given character was estimated using the following formula :

$$GCV\ \% = \frac{\text{Standard deviation of adjusted means}}{\text{Mean of adjusted mens}} \times 100$$

Phenotypic co-efficient of variation for a given character was estimated using the following formula :

$$PCV\ \% = \frac{\text{Standard deviation of unadjusted means}}{\text{Mean of unadjusted means}} \times 100$$

Heritability :

Heritability in broad sense was calculated by the formula given by Hanson *et al.* (1956). Heritability $\left(h^2_{bs}\right)$ inpercentage $= \frac{\sigma^2_g}{\sigma^2_p} \times 100$ where, σ^2_g = Genotypic variance = σ^2_g =(MSt –MSe) / r σ^2_p = Phenotypic variace = $\sigma^2_p = \sigma^2_g + \sigma^2_e$

Expected genetic advance (GA):

The genetic advance (GA) was calculated by the following formula as suggested by Johnson *et al.* (1955): Genetic advance (GA) = $h^2.k.\sigma_p$

While, genetic advance as percentage of mean was obtained by the following formula:

$$GA\ as\ \%\ of\ mean = \frac{GA}{\bar{X}} \times 100$$

where, h^2 = Heritability in broad sense, k = Selection differential (2.06 at 5% selection intensity), σ_p = square

root of phenotypic variance,

$\bar{X}$ = The general mean of the character,

GA= Genetic advance.

Association analysis:

The character associations between different pairs of characters were estimated as per Singh and Chaudhary (1979) by using the formula as given below:

$$r_{xy} = \sqrt{\frac{cov_{xy}}{\sqrt{(var_x . var_y)}}}$$

where, x and y represent two independent variables x and y (characters), For the genotypic correlations (r_g) the adjusted values were used while for the phenotypic correlations (r_p), the r The d.f. for the significance test were number of germplasm-2.

Correlation:

For fifty phenotypic traits, Pearson's co-efficient of correlation was calculated.

Path analysis:

To know the cause and effect relationship between two variables, path co-efficient analysis was carried out according to the procedure described by Dewey and Lu (1959) using estimates of correlation co-efficients. Genotypic correlation co-efficients of eight variables with seed yield were used to estimate the path co-efficient for the direct and indirect effects of various independent characters on yield. The path co-efficients were obtained by solving a set of simultaneous equations as below:

$$r_{1y} = p_{1y} + r_{12} P_{2y} + r_{13} P_{3y} + \ldots\ldots\ldots r_{1i} P_{iy}$$
$$r_{2y} = P_{2y} + r_{12} P_{21} + r_{21} P_{1y} + r_{23} P_{3y} + \ldots\ldots\ldots r_{2i} P_{iy}$$
$$\vdots \quad \vdots \qquad\qquad \vdots \qquad\qquad \vdots$$
$$r_{iy} = P_{iy} + r_{i1} \qquad P_{1y} + r_{i3} \qquad P_{3y} + \ldots\ldots r_{i(i-1)} P_{iy}$$

where,

r_{1y} to r_{iy} = Genotypic correlation co-efficients between causal charcaters, 1 to n and dependent character, yield (y)

r_{i1} to $r_{i(i-1)}$ = Genotypic correlation co-efficients among causal charcaters (independent variables)

P_{1y} + p_{iy} = Direct effect of causal characters, 1to I on character 'Y' (Path co-efficients).

The above equations written in a matrix form are as under:

$$\begin{bmatrix} \text{Matrix A} \\ r_{1y} \\ r_{2y} \\ r_{3y} \\ r_{iy} \end{bmatrix} = \begin{bmatrix} \text{Matrix C} \\ 1 & r_{12} & r_{13}\ldots\ldots\ldots\ldots r_{1i} \\ r_{21} & 1 & r_{23}\ldots\ldots\ldots\ldots r_{2i} \\ r_{31} & r_{32} & 1\ldots\ldots\ldots\ldots r_{3i} \\ \vdots & & \vdots \\ r_{i1} & r_{i2} & r_{i3}\ldots\ldots\ldots\ldots 1 \end{bmatrix} x \begin{bmatrix} \text{Matrix B} \\ P_{1y} \\ P_{2y} \\ P_{3y} \\ P_{iy} \end{bmatrix}$$

With the help of matrix inversion (Goulden, 1962), the following form of inverted 'C' matrix was obtained.

The indirect effects were calculated by taking the products of genotypic correlation co-efficients between corresponding two characters and the path co-efficients (direct effects) connecting the causal effects with yield. The residual effects measure the contribution of the characters which are not considered in the causal scheme and were calculated from the following formula :

$$\text{Residual effects (X)} = (1 - R^2)^{1/2}$$

where, $R^2 = \Sigma P^2_{iy} + 2 \Sigma \Sigma P_{iy} P_{jy} r_{ij}$

RESEARCH FINDINGS AND ANALYSIS

The present investigation was carried out to estimate genetic variability, heritability, genetic advance, genetic diversity, path analysis and association among different morphological characters with seed yield in seventy germplasm lines of *Foeniculum vulgare* Mill with four checks namely, AF-1, GF-1, RF- 101, and RF-125 were evaluated in an Augmented Block Design in five blocks. Path analysis performed to assess the important of character on yield which affect on seed yield directly and indirectly.

Analysis of variance for different characters in fennel:

Analysis of variance was carried out for each character separately and is presented in Table 1. Analysis of variance revealed and found significant differences among block were 50 per cent flowering, umbellate per umbel and seed per umbellate and analysis of variance gave significant differences among entries (germplasm + checks).The mean sum of squares due to entries was found significant for the characters *viz.*, 50 per cent flowering, umbel diameter at five per cent level of significance, while on one per cent level of significance, it also was found significant for the characters namely, number of primary branches, umbel per plant, umbellate per umbel, seed per

umbellate, test weight and seed yield. Analysis of variance revealed also found significant differences among checks. The mean sum of squares due to checks was significant for the characters *viz.*, number of primary branches, number of secondary branches, umbel per plant, umbellate per umbel, seed per umbellate, test weight and seed yield' at one per cent level of significance, while it was non-significant for the days to germination, king umbel anthesis, 50 per cent flowering, umbel diameter and plant height. Mean sum of squares among germplasm was found significant for the characters namely 50 per cent flowering, umbel diameter at five per cent level of significance. At 0.01 per cent number of secondary branches was found significant, while on one per cent level of significance, it was found significant for the characters namely number of primary branches, umbel per plant, umbellate per umbel, seed per umbellate, test weight and seed yield. It was found non- significant for the characters *viz.*, days to germination, king umbel anthesis and plant height. Beside this analysis of variance for checks v/s germplasm the mean sum of squares was found significant for the characters *viz.*, king umbel anthesis, umbellates per umbel and test weight at five per cent level of significance, while on one per cent level of significance, it was significant for the characters namely number of primary branches, number of secondary branches, seed per umbellate and seed yield.

Genetic parameters of variation:

The mean performance, range, heritability (broad sense) genotypic, phenotypic and environmental co-efficients of variation and genetic advance as percentage

Table 1 : Analysis of variation for different characters in fennel germplasm

Source of variation	DF	Days to germination	King umbel anthesis	50% flowering	King umbel diameter	Plant height (cm)	Number of primary branches	Number of secondary branches	Number of umbels per plant	Number of umbellate per umbel	Number of seeds per umbellate	Test weight (g)	Seed yield (5 plant) g
Block (eliminating Check+Germplasm	4	0.05	0.9	288.6**	5.7	23.4	0.3	5.8	18.6	10.8**	3.7***	0.1	12.4
Entries (ignoring Blocks)	53	0.2	3	87*	6.3*	102.2	0.9***	13***	63.3***	14.7***	16.6***	0.4***	431.5***
Checks	3	0.1	0.6	68.2	1.03	33.2	1.3***	28.4***	85***	16.4***	17.8***	0.8***	409.1***
Germplasm	49	0.2	2.8	89.8*	6.7*	108.1	0.8***	10.7**	63.2***	14.7***	16.7***	0.4***	427.2***
Checks vs. Germplasm	1	0.02	18.9*	5.3	2.6	17.03	5.3***	76.1***	5.04	7.9*	7.4***	0.3*	706.2***
Error	12	0.2	2.3	34.3	2.4	88.7	0.1	1.9	5.9	1.4	0.3	0.04	6

*, ** and *** indicate significance of values at P=0.05,0.01 and 0.1, respectively

Table 2 : Mean values of germplasm, their range, genotypic and phenotypic co-efficient of variation, heritability and genetic advance in fennel

Character	Mean	Range	Genotypic co-efficient of variation(GCV)	Phenotypic co-efficient of variation (PCV) (%)	Heritability in broad sense (%)	Genetic advance (%)
Days to germination	10.8	10-11	3.9	4.1	12	1.0
King umbel anthesis	25.8	22-30	2.3	6.3	12	1.8
50% flowering	114.4	102-132	5.7	7.6	55	8.6
King umbel diameter (cm)	16.5	13-27.8	10.8	14.3	57	16.8
Plant height (cm)	180.7	160-201.8	2.1	5.6	14	1.6
Number of primary branches	7.3	6-9.4	9.6	10.6	81	17.8
Number of secondary branches	20.2	11.6-28.4	12.3	14.0	78	22.4
Number of umbels per plant	42.1	28.2-58.4	15.7	16.7	88	30.3
Number of umbellate per umbel	30.2	22.1-37.9	10.4	11.1	87	20.1
Number of seeds per umbellate	29.2	21.2-37	11.9	12.1	98	24.3
Test weight (g)	6.0	4.7-7	8.1	8.9	85	15.6
Seed yield (5 plant) g	146.0	112.5-178.1	12.4	12.5	98	25.3

of mean for different characters are given in Table 2 and 3, respectively.

Days to germination:

The overall mean of days to germination was 10.8 with a wide range of variability for this is 10 to11. The genotypic and phenotypic co-efficients of variation were 3.9 and 4.1 per cent, respectively for this character. The value of heritability in broad sense was recorded 12 per cent which was low. The value of genetic advance expressed as percentage of mean being 1.0 per cent was recorded.

King umbel anthesis:

The overall mean of king umbel anthesis was found 25.8 with a wide range was found 22 to 30. The genotypic and phenotypic co-efficients of variation were recorded 2.3 and 6.3 per cent, respectively. The value of heritability in broad sense was found 12 per cent which was low. The value of genetic advance expressed as percentage of mean being was observed 1.8 per cent.

50 per cent flowering:

The mean of 50 per cent flowering was recorded 114.4 with a wide range of variability were also found 102 to 132. The genotypic and phenotypic co-efficients of variation were recorded 5.7 and 7.6 per cent, respectively for this trait. The value of heritability in broad sense was recorded 55 per cent which was high. The value of genetic advance expressed as percentage of mean being was estimated 8.6 per cent.

King umbel diameter (CM):

The mean of king umbel diameter was found 16.5 with a wide range of variability was 13 to 27.8. The genotypic and phenotypic co-efficients of variation were estimated 10.8 and 14.3 per cent, respectively. The value of heritability in broad sense was recorded 57 per cent which was high. The value of genetic advance expressed as percentage of mean being was also found 16.8 per cent.

Number of primary branches:

The overall mean of number of primary branches was recorded 7.3 with a wide range of variability 6 to

Table 3 : Phenotypic and genotypic correlation co-efficient between different characters in fennel

Characters	Level	King umbel diameter (cm)	Plant height (cm)	Number of primary branches	Number of secondary branches	Number of umbels per plant	Number of umbellate per umbel	Number of seeds per umbellate	Test weight (g)	Seed yield (5 plant) g
50 % flowering	P	0.57***	0.05	-0.05	0.02	-0.38**	-0.35*	-0.36**	-0.19	-0.05
	G	0.09	0.19	-0.03	0.19	-0.08	-0.11	-0.31*	0.01	-0.01
King umbel diameter(cm)	P		0.09	-0.07	0.02	-0.28*	-0.26	-0.16	-0.22	-0.08
	G		0.07	-0.04	0.07	-0.12	0.11	-0.06	-0.23	-0.12
Plant height (cm)	P			-0.14	-0.10	-0.25	-0.25	-0.24	0.03	-0.26
	G			-0.15	-0.04	-0.25	-0.29*	-0.22	0.08	-0.24
Number of primary branches	P				0.48***	0.61***	0.53***	0.55***	0.36**	0.73***
	G				0.53***	0.71***	0.57***	0.61***	0.42**	0.75***
Number of secondary branches	P					0.64***	0.33*	0.59***	0.39**	0.63***
	G					0.66***	0.42**	0.56***	0.38**	0.63***
Number of umbels per plant	P						0.69***	0.76***	0.43**	0.79***
	G						0.64***	0.75***	0.44**	0.87***
Number of umbellates per umbel	P							0.78***	0.41**	0.54***
	G							0.71***	0.39**	0.63***
Number of seeds per umbellate	P								0.42**	0.64***
	G								0.43**	0.70***
Test weight (g)	P									0.49***
	G									0.52***

*,** and *** indicate significance of values at P=0.05, 0.01 and 0.1, respectively

9.4, respectively. The genotypic and phenotypic co-efficients of variation were estimated 9.6 and 10.6 per cent, respectively. The value of heritability in broad sense was found 81 per cent which was high. The value of genetic advance expressed as percentage of mean being recorded 17.8 per cent.

Number of secondary branches:

The mean for number of secondary branches per plant was recorded 20.2 with a wide range of variability 11.6 to 28.4, respectively. The genotypic and phenotypic co-efficients of variation were found 12.3 and 14.0 per cent, respectively. The value of heritability in broad sense was recorded 78 per cent which was moderate to high. The value of genetic advance expressed as percentage of mean being recorded 22.4 per cent which was also high.

Plant height (cm):

The overall mean for plant height upto main umbel was estimated 180.7 with a wide range of variability 160 to 201.8. The genotypic and phenotypic co-efficients of variation were recorded 2.1 and 5.6 per cent, respectively. The value of heritability in broad sense was found 14 per cent which was low. The value of genetic advance expressed as percentage of mean was found 1.6 per cent.

Number of umbels per plant:

The overall mean for number of umbels per plant was recorded 42.1with a wide range of variability 28.2 to 58.4, respectively. The genotypic and phenotypic co-efficients of variation were found 15.7 and16.7 per cent, respectively. The value of heritability in broad sense was estimated 88 per cent which was high. The value of genetic advance expressed as percentage of mean was found 30.3 per cent.

Number of umbellates per umbel:

The mean for number of umbellates per plant was recorded 30.2 with a wide range of variability 22.1 to 37.9, respectively. The genotypic and phenotypic co-efficients of variation were estimated 10.4 and 11.1 per cent, respectively. The value of heritability in broad sense was estimated 87 per cent which was high. The value of genetic advance expressed as percentage of mean was found 20.1 per cent which was high for this character.

Number of seeds per umbellates:

The overall mean for number of seeds per umbellates was found 29.2 with a wide range of variability 21.2 to 37, respectively. The genotypic and phenotypic co-efficients of variation were recorded 11.9 and 12.1 per cent, respectively. The value of heritability in broad sense was estimated 98 per cent which was very high. The value of genetic advance expressed as percentage of mean was found 24.3 per cent for this character.

Test weight (g):

The mean for test weight (g) was estimated 6 with a wide range of variability 4.7 to 7.0, respectively. The genotypic and phenotypic co-efficients of variation were recorded 8.1 and 8.9 per cent, respectively. The value of heritability in broad sense was found 85 per cent which was high. The value of genetic advance expressed as percentage of mean was found 15.6 per cent for these traits.

Seed yield (g):

The overall mean for seed yield was recorded 146 g with a wide range of variability 112.5 (g) to178.1 (g), respectively. The genotypic and phenotypic co-efficients of variation were recorded 12.4 and 12.5 per cent, respectively. The value of heritability in broad sense was observed 98 per cent which was very high. The value of genetic advance expressed as percentage of mean was found 25.3 per cent which was very high.

Correlation:

The values of all possible correlation co-efficients among the characters were calculated at both phenotypic and genotypic levels, which are presented in Table 3. In general, the direction of the correlation did not change for the respective genotypic and phenotypic levels. Even the change in magnitude was also limited. This is expected in Augmented Design. The estimate of phenotypic correlation co-efficient was higher than their respective genotypic correlation co-efficient, which clearly showed that genotypic expression was affected by the environments.

50 per cent flowering :

Character association at phenotypic level for 50 per cent flowering was found significant and positive correlated with king umbel diameter (0.57) while it was also found non-significant but positively correlated with plant height (0.05) and no. of secondary branches (0.02). It had significant and negative correlated with number of

umbels per plant (-0.38), number of umbellate per umbels (-0.36). Association at genotypic level for 50 per cent flowering was found significant and negative correlated with number of seeds per umbellates (-0.31), while it was also found non-significant but positively correlated with king umbel diameter (0.09), plant height (0.19), no of secondary branches (0.19) and test weight (0.01).

Diameter of king umbel (cm):

Character association at phenotypic level for diameter of king umbel was found significant and negative correlated with number of umbels per plant (-0.28), while it was also found non-significant but positively correlated with plant height (0.09) and number of secondary branches (0.02). Association at genotypic level for diameter of king umbel was found non-significant positive correlated with plant height (0.07), number of secondary branches (0.02) and number of umbellate per umbel.

Plant height (cm):

Character association at phenotypic level for plant height (cm) had found non-significant and positive correlation with test weight (0.03). Character association at genotypic level for plant height (cm) had found significant and negative correlation number of umbellates per umbel (0.29), while it was also found non-significant but positively correlated with test weight (0.08).

Number of primary branches:

Character association at phenotypic level for number of primary branches had found significant and positive correlation with number of secondary branches per plant (0.48), number of umbels per plant (0.61), number of umbellate per umbel (0.53), number of seeds per umbellates (0.55), test weight (0.36) and seed yield (g) (0.73). Character association at genotypic level for number of primary branches had found significant and positive correlation with number of secondary branches per plant (0.53), number of umbels per plant (0.71), number of umbellate per umbel (0.57), number of seeds per umbellates (0.61), test weight (0.42) and seed yield (g) (0.75).

Number of secondary branches:

Character association at phenotypic level for number of secondary branches per plant had found significant and positive correlated with number of umbels per plant (0.64), number of umbellate per umbel (0.33), number of seeds per umbellates (0.59), test weight (0.39) and seed yield (g) (0.63). Character association at genotypic level for number of secondary branches per plant had found significant and positive correlation with number of umbels per plant (0.66), number of umbellate per umbel (0.42), number of seeds per umbellates (0.56), test weight (0.38) and seed yield (g) (0.63).

Number of umbels per plant:

Character association at phenotypic level for Number of umbels per plant had recorded significant and positive correlation with number of umbellate per umbel (0.69), number of seeds per umbellates (0.76), test weight (0.43) and seed yield (g) (0.79). Character association at genotypic level for number of umbels per plant had also recorded significant and positive correlated with number of umbellate per umbel (0.64), number of seeds per umbellates (0.75), test weight (0.44) and seed yield (g) (0.87).

Number of umbellates per umbel:

Character association at phenotypic level for number of umbellates per umbel was found significant and positively correlated with number of seeds per umbellates (0.78), test weight (0.41) and seed yield (g) (0.54). Character association at genotypic level for number of umbellates per umbel was found significant and positively correlated with number of seeds per umbellates (0.71), test weight (0.39) and seed yield (g) (0.63).

Number of seeds per umbellates:

Character association at phenotypic level for number of seeds per umbellates had recorded significant and positive correlated with test weight (0.42) and seed yield (g) (0.64). Character association at genotypic level for number of seeds per umbellates had also recorded significant positive correlated with test weight (0.43) and seed yield (g) (0.70).

Test weight (g) :

Character association at phenotypic level for test weight (g) had found significant positive correlated with seed yield (0.49). Character association at genotypic level for test weight (g) was also estimated non- significant but positively correlated with seed yield (0.52).

Path analysis:

Seed yield per plant is the result of direct and indirect

effects of several yield contributing characters. To know the contribution of various characters toward seed yield, the genotypic correlations co-efficients of different traits with seed yield are partitioned into their direct and indirect effects. This provides more precise information for the contribution of important traits towards seed yield. The estimates of direct and indirect effects of various traits on seed yield are presented in Table 4.

Days to 50 per cent flowering:

The genotypic correlation between days to 50 per cent flowering and seed yield was found negative and non-significant (-0.012). The direct effect of days to 50 per cent flowering on seed yield was positive and negligible (0.057). The indirect effects of days to 50 per cent flowering were negligible via, number of secondary branches (0.009) and test weight (0.001). Days to 50 per cent flowering showed negative indirect effect via, king umbel diameter (-0.001), plant height (-0.014), number of primary branches (-0.006), number of umbel per plant (-0.046), number of umbellate per umbel (-0.005) and number of seeds per umbellate (-0.007) were negligible on seed yield.

King umbel diameter :

The genotypic correlation between king umbel diameter and seed yield was found negative and non-significant (-0.117). The direct effect of king umbel diameter on seed yield was negative and negligible (-0.016). The indirect effects of king umbel diameter were negligible via, number of secondary branches (0.003) and umbellate per umbel (0.005). King umbel diameter showed negative indirect effect via, plant height (-0.005), number of primary branches (-0.008), number of umbel per plant (-0.066), number of seeds per umbellate (-0.001) and test weight (-0.034) were negligible on seed yield.

Plant height:

The genotypic correlation between plant height and seed yield was found negative and non-significant (-0.239). The direct effect of plant height on seed yield was negative and negligible (-0.070). The indirect effects of plant height were positive and negligible via, test weight (0.011). The indirect effects of plant height to umbel per plant (-0.137) was negative and low. Plant height showed negative indirect effect via, number of primary branches (-0.033), number of secondary branches (-0.002), number of umbellate per umbel (-0.013), number of seeds per umbellate (-0.005) were negligible on seed yield.

Number of primary branches :

The genotypic correlation between number of primary branches and seed yield was found positive and highly significant (0.753). The direct effect of number of primary branches on seed yield was positive and moderate (0.224). The indirect effects of number of primary branches were high via, umbel per plant (0.396). Number of primary branches showed positive indirect

Table 4: Direct (bold) and indirect effect of characters on seed yield of fennel

Character	50 % flowering	King umbel diameter	Plant height	Number of primary branches	Number of secondary branches	Number of umbel per plant	Number of umbellate per umbel	Number of seeds per umbellate	Test weight (g)	Genotypic correlation with yield
50% flowering	0.057	-0.001	-0.014	-0.006	0.009	-0.046	-0.005	-0.007	0.001	-0.012
King umbel diameter	0.005	-0.016	-0.005	-0.008	0.003	-0.066	0.005	-0.001	-0.034	-0.117
Plant height	0.011	-0.001	-0.070	-0.033	-0.002	-0.137	-0.013	-0.005	0.011	-0.239
Number of primary branches	-0.002	0.001	0.010	0.224	0.025	0.396	0.024	0.013	0.060	0.753***
Number of secondary branches	0.011	-0.001	0.003	0.118	0.049	0.366	0.018	0.012	0.055	0.629***
Number of umbels per plant	-0.005	0.002	0.017	0.160	0.032	0.556	0.028	0.016	0.062	0.868***
Number of umbellate per umbel	-0.006	-0.002	0.021	0.128	0.020	0.357	0.043	0.015	0.056	0.632***
Number of seeds per umbellate	-0.018	0.001	0.015	0.138	0.027	0.419	0.030	0.021	0.061	0.695***
Test weight (g)	0.000	0.004	-0.005	0.094	0.019	0.243	0.017	0.009	0.143	0.523***

Residual effect: 0.428 *** indicate significance of values at P=0.1

effect via, number of secondary branches (0.025), number of umbellate per umbel (0.024), seeds per umbellate (0.013) and test weight (0.060) were negligible on seed yield.

Number of secondary branches:

The genotypic correlation between number of secondary branches and seed yield was found positive and highly significant (0.629). The direct effect of number of secondary branches on seed yield was positive and negligible (0.049). The indirect effects of number of secondary branches were high via, umbel per plant (0.366) where as low via, number of primary branches (0.118). Number of secondary branches showed positive indirect effect via number of umbellate per umbel (0.018), seeds per umbellate (0.012) and test weight (0.055) were negligible on seed yield.

Number of umbels per plant :

The genotypic correlation between number of umbels per plant and seed yield was found positive and highly significant (0.868). The direct effect of number of umbels per plant on seed yield was positive and high (0.556). The indirect effects of number of umbels per plant were high via, umbel per plant (0.366) whereas low via, number of primary branches (0.160).Number of umbels per plant showed positive indirect effect via number of umbellate per umbel (0.018), seeds per umbellate (0.012) and test weight (0.055) were negligible on seed yield.

Number of umbellate per umbel:

The genotypic correlation between number of umbellate per umbel and seed yield was found positive and highly significant (0.632). The direct effect of number of umbellate per umbel on seed yield was positive and negligible (0.043). The indirect effects of number of umbellate per umbel were high via, umbel per plant (0.357) where as low via, number of primary branches (0.128). Numbers of umbellate per umbel showed positive indirect effect via number of seeds per umbellate (0.015) and test weight (0.056) were negligible on seed yield.

Number of seeds per umbellate:

The genotypic correlation between number of seeds per umbellate and seed yield was found positive and highly significant (0.695). The direct effect of number of seeds per umbellate on seed yield was positive and negligible (0.021). The indirect effects of number of umbellate per umbel were high via, umbel per plant (0.419) where as low via, number of primary branches (0.138). Number of seeds per umbellate showed positive indirect effect via, test weight (0.061) was negligible on seed yield.

Test weight:

The genotypic correlation between test weight and seed yield was found positive and highly significant (0.523). The direct effect of test weight on seed yield was positive and low (0.143). The indirect effect of test weight via, umbel per plant (0.243) was positive and moderate.

Heritability (Broad sense) and genetic advance:

In crop improvement, only the genetic component of variation is important since that contributing trait can only be transmitted to the next generation. Heritability indicates the effectiveness which selection of germplasm would be based on phenotypic performance. The heritability estimates along with the genetic advance are more meaningful for the breeders as they help in appreciates the amount of variation present in the breeding material and guides to choose an appropriate method for the improvement of a given character. The breeder is able to appreciate the proportion of variation that is due to genotypic (broad sense heritability) or additive (narrow sense heritability) effects. If heritability of a character is high (> 70%), selection for such a character should be fairly easy. This is because there would be correspondence between genotypic and phenotypic variation due to relatively smaller contribution of environment to the phenotype, but for a character with a low heritability, selection may be considerably difficult or virtually impractical due to masking effect of environment on the genotypic effect. In the present investigation, the estimates of heritability (in broad sense) expressed in percentage was high for the characters *viz.*, number of primary branches per plant, number of number of secondary branches per plant, umbels per plant, umbellate per umbel, test weight. Number of seeds per umbellate and seed yield was very high. The characters namely 50 per cent flowering and king umbel diameter showed moderate to high heritability. Genetic advance as percentage of mean for the characters ranged from 1.0 (days to germination) to 30.3 (number of umbels per plant).

Correlation studies:

Genotypic and phenotypic correlation co-efficients were worked out among different characters including seed yield. The results of present investigation revealed that phenotypic correlation co-efficient was higher than their genotypic correlation co-efficient counterparts in most of the characters (Table 3). This implied that the non-genetic causes affect the values of genotypic correlation because of the influence of the environmental factors. Character association at phenotypic level for test weight (g) had significant positive correlation with king umbel diameter, number of primary branches, number of secondary branches, seed yield, number of seeds per umbellates, number of umbels per plant, while, character association at phenotypic level for diameter of king umbel was significant negative correlated with number of umbels per plant (-0.28), character association at phenotypic level for 50 per cent flowering was non-significant but positively correlated with plant height (0.05) and no. of secondary branches (0.02). It had significant and negative correlation with number of umbels per plant (-0.38), number of umbellate per umbels (-0.36). Character association at genotypic level for number of umbels per plant had significant and positive correlation with number of umbellate per umbel (0.64), number of seeds per umbellates (0.75), test weight (0.44) and seed yield (g) (0.87). The association analysis at both genotypic and phenotypic level revealed that the seed yield was significantly and positively correlated with umbel plant, number of primary, number of secondary branches, number of umbellates per umbel and number of seeds per umbellates. While the correlation of test weight showed positive but non-significant correlation with seed yield.

Path analysis:

In selection programme when fewer variables are considered correlation study can seven the purpose. However, when the number of variables increases the situation becomes complies. For overcoming this complexity, path analysis is valuable in the sense that through this technique it becomes possible to judge relative contribution of various component characters to seed yield in terms of direct and indirect effects. The analysis o correlation co-efficient together with information of path analysis helps considerably in identification of suitable character for proper weight age to be given during selection. In order to achieve a clear cut picture of interrelationship of various component characters with yield, direct and indirect effects at genotypic level were calculated using path co-efficient analysis. From the path analysis (Table 4) it was revealed that number of umbels per plant on seed yield was positive and high (0.556). Days to 50 per cent flowering had negative and non-significant genotypic associated with seed yield. The direct effect of number of primary branches on seed yield was positive and moderate (0.224). Result of path analysis showed that two key variables included umbellate per umbel and primary branches were the main variable accounting for seed yield. The residual effects indicated the degree to which cause factors accounted for variation in the depended factor low residual effects showed that the causal factor explained the dependent variable well.

Conclusion :

The present investigation was conducted at National Research Centre on Seed Spices, Tabiji, Ajmer (Raj.), during *Rabi* 2014-2015. In the present investigation Fifty germplasm lines with four checks were evaluated in Augmented Block Design in five blocks for seed yield and yield contributing traits with a view to assess the degree of genetic variability as to determine selection criteria and to identify the superior germplasm lines in fennel. Analysis of variance, correlation, divergence and path analysis was employed to realize the above objectives. The results obtained have been summarized below:- (i) Analysis of variance revealed that the characters namely king umbel anthesis, number of primary branches, number of secondary branches, number of umbels per plant, number of umbellate per umbel, number of seeds per umbellates, test weight (g) and seed yield (g) showed significant amount of variability among germplasm lines used in investigation, while, non-significant differences were found for the characters *viz.*, days to germination, plant height (cm). (ii) The genotypic and phenotypic co-efficients expressed as percentage were high for the character *viz.*, number of umbels per plant and number of secondary branches, while, moderate to high for the characters *viz.*, number of umbellate per umbel and number of primary branches. They both were low for the characters *viz.*, test weight and 50 per cent flowering. (iii) The estimates of heritability in (broad sense) expressed in percentage was high for the characters *viz.*, number of primary branches per plant, number of number of secondary branches per plant,

umbels per plant, umbellate per umbel, test weight. Number of seeds per umbellate and seed yield was very high, while character *viz.*, 50 per cent flowering and king umbel diameter showed moderate to high heritability and low for characters *viz.*, days to germination, king umbel anthesis and plant height. (iv) The genetic advance expressed as percentage of mean were high for the seed yield, number of seeds per umbellate, number of umbels per plant and umbellates per umbel, while, moderate for test weight, number of primary branches and number of secondary branches. Moderate to low for the characters *viz.*, 50 per cent flowering and king umbel diameter, while, low for plant height. (v) The association analysis at phenotypic level revealed that the seed yield per plant was significantly and positively correlated with king umbel diameter, number of primary branches, number of secondary branches, seed yield, number of seeds per umbellates, number of umbels per plant, while, its association with 50 per cent flowering showed positive but non-significant correlation with plant height and number of secondary branches. (vi) The association analysis at genotypic level revealed that the seed yield per plant was significantly and positively correlated with number of umbellate per umbel, number of seeds per umbellates, test weight and seed yield (g), while, its association with test weight showed positive but non-significant correlation with seed yield. (vii) Path co-efficient analysis revealed that number of umbels per plant on seed yield was positive and high. Days to 50 per cent flowering had negative and non-significant genotypic association with seed yield. The direct effect of number of primary branches on seed yield was positive and moderate. Based upon the present investigation, it can be suggested that for improving seed yield in fennel selection can be based on the traits, plant height and number of seeds per umbellate like as these characters had positive correlation co-efficient and direct effect on seed yield per plant.

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