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Original Research Paper

Stability analysis of yield, yield attributes and essential oil content in fennel (*Foeniculum vulgare* Mill.) evaluated under a long-term organic production system

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ABSTRACT

Eight varieties of fennel (*Foeniculum vulgare* Mill.) were evaluated under field trial for their stability of yield, yield attributes and essential oil content under the organic production system in six consecutive years from 2016 to 2021. Mean square due to environment + (variety × environment) was significant for all the traits studied indicating the existence of variety × environment interaction. Based on the mean performance, regression coefficient and deviation from regression values, it was found that stability of yield and yield components are imparted in the varieties, GF-12 and AF-1 across the years through the stable performance of characters and like numbers of primary and secondary branches, number of umbels and umbellate and seed yield. However, variety RF-101 for essential oil content can be considered as most suitable, stable and adopted to organic production system compared to other varieties. Correlation analysis revealed highly positive relationship in plant height, number of primary branches, number of umbels and umbellate per plant and seed yield. Based on the findings, fennel growers are apprised to select stable high-yielding fennel varieties for the organic production systems in semi-arid regions of India. Along with their use in hybridization programmes to converge the stability characteristics of seed yield for the development of a stable variety adapted to a wider range of environments under organic production systems.

Keywords : Correlation, essential oil, fennel, organic production system, seed yield, stability

INTRODUCTION

Fennel (*Foeniculum vulgare* Mill.), chromosome number 2n=2x= 22, is one of the most eminent medicinal and aromatic plant belonging to the family Apiaceae (Umbelliferae). Fennel is widely cultivated throughout the temperate and sub-tropical regions (Sheet *et al*., 2020). Gujarat ranks first in the area, production and productivity of fennel. It is used in a wide range of curry powder, curries flavoured soups, such as mulligatawny and shorbas, and is often used with fish. Fennel seeds are also used in pickles, chicken casseroles, salad dressings, fish liver and pork sauces and cucumber, sauerkraut lentils and pickled beef. Powdered fennel goes into biscuits, cakes and cooked apple dishes. The volatile oil in Indian fennel seed ranged from 0.7-1.2% (Saharkhiz and Tarakeme, 2013), and 4 to 6% in East European fennel seeds. Its seeds are found to be a good source of minerals like Ca, Fe, Mg, K, Na, and Zn as well as Vitamin A, and Niacin and phytate (11.35-13.10 mg/g.).

In recent times, due to awareness of health and food safety concerns, organic farming and natural cultivation practices are gaining momentum. The organic farming practices are compatible with the environment and able to sustain soil microflora, fauna and fertility in the long term. Although organic farming is still a small industry (1%–2% of global food sales), its importance is rapidly growing worldwide. In the domestic as well as the international market, there is a great demand for organic products which shows a greater potential source of income for small producers/ stakeholders. Despite the potential benefits of organic farming in terms of higher soil health and quality of produce, maintenance of high yields is one of the major challenges under organic farming systems (Tilman *et al*., 2002; Patel *et al*., 2014).

Modern cultivars are selected by plant breeders under conventional systems and they may not perform well under organic farming systems where they are grown in a stressed environment without the addition of external inputs that are entirely different to those in which they were selected (Murphy *et al*., 2007; Singh *et at*., 2017). So, there's a need to select varieties for the organic production system which is believed as a stressed environment as crops are not supplied with chemicals for either supplying nutrients or to protect the crop from pests and diseases. Very limited scientific information is available regarding the evaluation of different varieties under organic production system, especially in seed spices for yield and quality attributes especially genetic studies on the performance of a diverse variety of fennel grown under the organic system are lacking. In recent times, improved released fennel varieties AF-1, RF-101, CO-01, Rajendra Saurabha, GF-12, RF-281, RF-125 and GF-02 are cultivated widely under different arid and semi-arid regions for high yields and quality, therefore, these varieties were chosen to investigate their performance and stability for growth and yield under an organic production system.

MATERIALS AND METHODS

A field experiment under AI-NPOE project was carried out at ICAR-National Research Centre on Seed Spices, Tabiji, Ajmer, Rajasthan for six consecutive years from 2016 to 2021 to identify suitable and stable fennel varieties for the organic production system. Eight released varieties *viz*., AF-1, RF-101, CO-01, Rajendra Saurabha, GF-12, RF-281, RF-125 and GF-02 of fennel were tested under an organic production management system for growth, yield and quality attributes. The experiment was laid out in a randomized block design with three replications in a plot size of 12 m^2. Soil of the experimental site was sandy loam in nature and the experimental block was maintained as per the organic production requirements since 2011. Soil fertility status of an experimental site shows organic carbon (0.26%), available nitrogen (130.4 kg ha^{-1}), available phosphorus (12.06 kg ha^{-1}) and available potassium (359.07 kg ha^{-1}). The recommended dose of nutrients for fennel is 100:50:30 kg ha^{-1} and manures were applied on a nitrogen equivalent basis through organic sources (50% by FYM, 25% by vermicompost and 25% by castor cake). Nitrogen content of farmyard manure, vermicompost and castor cake is 0.50, 1.0 and 5.0%, respectively.

Every year seeds were sown during the second week of October by maintaining the row-to-row spacing of 50 cm. Fennel seeds were sown at the rate of 10 kg ha^{-1} after treating seeds with *Trichoderma virdae*, phosphate solubilising bacteria and *Azotobacter* at the rate of 10 g kg^{-1}. Irrigation and intercultural operations were followed as per recommended package of practice. The biometrical observations were recorded for ten different characters *viz*., initiation of flowering, days to 50% flowering, plant height at harvest, number of primary branches, number of secondary branches, number of umbels per plant, number of umbellate per umbel, seed yield and essential oil per cent in a seed. Observations on days to 50% flowering and days to maturity were recorded on a plot basis, whereas, data on the rest of the characters were recorded on five randomly selected plants in all three replications. For extraction of essential oil, a thirty-gram fresh seed sample in three replications was drawn from each treatment and used for essential oil extraction by hydro-distillation for 7 hrs using a Clevenger apparatus.

In the present study, stability analysis was carried out using pooled data of six *rabi* seasons over six years following the model proposed by Eberhart and Russell (1966). The model was used to find out G × E interaction and both linear (bi) and non-linear (S^2di) components of G × E interaction were considered for the indication of the performance of the individual variety. A different year of study was considered as different environment. The linear regression coefficient (bi) was considered as a measure of responsiveness and deviation from regression (S^2di) as a measure of stability. According to the model, stable variety has regression coefficient (bi) equal to unity (bi=1.0) and deviation from regression does not significantly differ from zero (S^2di=0). In general bi=1 implies average stability, bi>1 (1.01-1.30) implies below average stability and bi<1 (0.81-0.99) implies above average stability of a varieties. The desirability of a variety is judged based on stability criteria together with the mean value of the character. Stability analysis carried out using online OPSTAT (Sheron *et al*., 1998). Correlations were calculated on a genotypes mean basis, according to Pearson's test using SAS 9.3 software.

RESULTS AND DISCUSSION

Analysis of variance (ANOVA) for the stability of different traits was analysed in selected varieties across six years (Table 1). Results of ANOVA revealed that

Table 1 : Analysis of variance for stability performance for seed yield, its components and essential oil content in fennel

Source	DF	Plant height at harvest (cm)	Days to anthesis	Days to 50% flowering	No. of primary branches	No. of secondary branches	No. of umbels/ plant	No.of umbellate/ plant	Yield (q/ha)
Variety	7	1,961.08**	52.05**	50.42**	116.43**	241.80**	564.96**	224.13**	87.91**
Environment	6	25,644.04**	1,546.61**	953.02**	67.98	108.96	1,015.50	943.18**	2,065.10**
Var. x Env	42	1,223.23**	53.50**	82.94**	20.79**	42.92**	89.15**	69.96**	52.03**
Env.+ Var. x Env.	48	26,867.26**	1,600.16**	1,035.97**	88.78**	151.88**	1,104.6**	1,013.10**	2,117.20**
Env. (Linear)	1	25,644.04**	1,546.66**	953.02**	67.98**	108.96	1,015.5**	943.18**	2,065.10**
Env. X Var. (Linear)	7	240.03**	1.808**	4.43*	16.07**	8.11*	52.36**	56.56**	10.821*
Pooled Deviation	40	983.195**	51.69**	78.51**	4.72*	34.80	36.78**	13.40*	41.20*
Pooled Error	98	6,124.55	190.58	217.50	57.68	158.50	917.2	342.14	473.71

DF- degree of freedom, * significant at p- 0.05, Var-variety, Env-Environment

the mean squares due to varieties were highly significant for all the traits *viz*., plant height at harvest, days to initiation of flowering, number of primary branches, number of secondary branches, number of umbels/plant, number of umbellate/plant, seed yield and essential oil content. It indicates that selected varieties were divergent and possess significant genetic variation for traits studied. The mean squares due to environments and interaction of variety with the environment (G x E) and environment + (variety x environment), were found highly significant for all the selected traits indicating the selected environments (years) were random and differ in climatic conditions. The partitioning of variance into components likes environments, environments (linear), variety x environment (linear) and pooled deviation (non-linear) showed that mean squares due to environment (linear) were also found significant. The significant mean squares value confirmed that the environments (years) were random and distinct, and they employed influence on the expression of a trait having significant mean squares and this variation could be attributed to have arisen due to the linear response of the expression of the variety to the environment. The significant value of mean squares for all the attributes studied revealed that the behaviour of the variety could be predicted for environments (years) more precisely for most of the traits and the G x E interaction was the result of the linear function of the environmental factors. The non-linear component arising due to heterogeneity, measured as mean squares due to pooled deviation, these significant mean squares revealed the presence of a non-linear response of the variety to the changing environments (stability performance). The significant mean squares for the pooled deviation confirmed the contribution of the non-linear component to the total G x E interaction. The variety differed in the stability of these traits making its prediction more difficult. Similar kind of results was earlier reported by Sastry *et al*. (1989), Verma and Solanki (2015), Lal (2014), Sawargaonkar & Sahu (2018) and Mangat (1986) where fennel genotypes and varieties were evaluated under a traditional production system. The results based on the stability parameters are discussed character-wise based on the model proposed by Eberhart and Russell (1966). According to Eberhart and Russell model, genotypes are grouped based on their variance of the regression deviation (either equal or not to zero). A genotype with variance in regression deviation equal to zero is highly predictable, whilst a genotype with regression deviation more than zero has less predictable response (Scapim *et al*., 2010). A correlation coefficient was estimated according to Johnson *et al*. (1955) using SAS 9.3 software and only significant correlation discussed.

Initiation of flowering (days) averaged 87.85 across the study years, while, the mean values ranged from 85.91 to 89.00 (Table 2). In GF-12, flowering took place early, whereas, CO-01 experienced late flowering over the course of the study's years. Out of the eight varieties, AF-1 depicted regression coefficient that was unity and did not significantly deviate from the regression line, indicating good stability and favourable all environmental conditions (years) for this trait. Rajendra Saurabha, RF-125 and RF-125 had high mean values and regression coefficient that was above than unity implies above average stability. In contrast, CO-01, RF-101, and GF-02 had high mean values and regression coefficient that was less than one, indicating above average stability that was suitable for an unfavourable or poor environment (organic production system) for this trait.

The average plant height (cm) years was recorded 169.21, and the mean values ranged from 163.92 to 180.61. GF-12 had the tallest plants, whereas (RF-281) 163.92 had the shortest plants. Only three of the eight varieties, AF-1 and GF-12 had high mean, regression coefficient above unity and non-significant departures from the regression line, indicating that these two varieties have below average stability for plant height.

The average days to 50% flowering ranged from 94.76 to 97.86 against an average of 96.80 days. The earliest 50% flowering was recorded in variety (GF-12), while the late variety was Rajendra Saurabha. The variety *viz*., AF-1 and CO-01, has showed above average stability as they had higher mean, regression coefficient of more than one and non-significant deviation from regression line, hence, this variety was considered as suitable for a favourable environment for this trait and has below average stability for this trait.

The mean value for numbers of primary branches varied from 7.07 to 11.10 as against the average of 8.54 across the years under study. The maximum number of primary branches was recorded in variety GF-12 while the lowest was in CO-01. Variety GF-12 and AF-1 has high mean value with regression coefficient above unity and non-significant deviation from regression line considered as stable variety. However, variety AF-1 has high mean value with regression coefficient below unity and non-significant deviation from regression has above average stability. The findings suggested that these varieties are well adapted to suitable for poor and favourable environmental conditions respectively for this trait. RF-125 was specially adapted to the favourable environment for this trait as it had a regression coefficient above unity and a high mean with a small non-significant deviation from regression.

The average numbers of secondary branches varied from 15.45 to 21.21 as against the average of 17.82 across the years under study. The maximum numbers of secondary branches were recorded in variety GF-12 while, the lowest was in variety RF-101. Variety RF-281 has a high mean value with regression coefficient above unity and non-significant deviation from regression line considered as below average stable variety for the trait. Variety AF-1 and GF-12 have high mean values with regression coefficient below unity and non-significant deviation from regression explaining its suitability in poor (unfavourable) environment.

Across the study years, the average numbers of umbels per plants were varied from 28.95 to 37.92, with a mean value of 31.92 (Table 3). GF-12 had the highest numbers of umbels per plants, whereas CO-01 had the lowest ones during the course of the study's years. Rajendra Saurabha and RF-281varieties demonstrated regression coefficient that was unity and non-significant deviations from the regression line, indicating average stability. In contrast, AF-1, GF-12 and GF-125 had high mean values and regression coefficient that was higher than one, indicating below average stability that was suitable for an unfavourable or poor environment (organic production system) for this trait.

The average number of umbellate per plant varied from 22.21 to 28.49, whereas, across the study years, it averaged 25.22. The variety RF-281 recorded lowest number of umbellate per plant, while variety GF-12 had the highest number of umbellate per plant. Variety GF-12, AF-1, RF-125 and GF-02 had high mean

Table 2 : Stability parameters of growth, flowering and number of branches attributes in fennel

Variety	Day to initiation of flowering			Plant height (cm)			Days to 50% flowering			No. of primary branches			No. of secondary branches		
	Xi	bi	S²di	Xi	bi	S²di	Xi	bi	S²di	Xi	bi	S²di	Xi	bi	S²di
AF-1	87.91	1.00	2.60	177.58	1.01	-8.56	96.33	1.05	6.18	10.68	0.93	-0.17	20.71	0.88	-0.39
RF-101	88.29	0.98	0.92	164.89	0.96	-20.19	96.57	1.06	0.53	7.54	0.34	-0.09	15.45	0.60	-0.40
CO-01	89.00	0.97	0.82	167.21	0.81	-9.12	97.71	1.08	-0.29	7.07	0.41	0.04	15.84	0.74	1.66
Rajendra Saurabha	88.76	1.02	-0.11	166.89	0.94	-11.60	97.86	0.93	-0.15	7.25	0.98	-0.09	16.27	1.26	-0.02
GF-12	85.91	0.96	0.12	180.61	1.02	7.61	94.76	1.07	0.13	11.10	1.02	-0.13	21.21	0.84	-0.53
RF-281	87.57	1.07	0.08	163.92	1.16	29.01	96.95	0.91	0.05	7.81	0.91	-0.13	18.28	1.01	-0.27
RF-125	88.43	1.01	0.88	164.42	1.08	22.78	97.67	0.99	1.02	8.70	1.48	-0.09	18.44	1.21	1.02
GF-02	86.91	0.97	-0.18	168.14	1.03	20.07	96.57	0.92	2.32	8.14	1.93	0.02	16.33	1.47	1.57
	Pooled Mean: 87.85			Pooled Mean: 169.21			Pooled Mean: 96.80			Pooled Mean:8.54			Pooled Mean: 17.82		
	SE(mean): 0.46			SE(mean): 2.02			SE(mean): 0.57			SE(mean): 0.14			SE(mean): 0.38		
	SE (b):0.082			SE (b):0.088			SE (b):0.128			SE (b):0.118			SE (b): 0.253		

Xi- mean, bi-regression coefficient and S²di-deviation from the regression

values and regression coefficient that was higher than one indicating below average stability suitable in unfavourable/poor environment (organic production system) for this trait.

The average seed yield (q/ha) across the study's years was 25.75 which was ranged from 23.95 to 27.82. Variety RF-101 had the lowest seed yield per hectare, whereas, variety GF-12 had the highest. For seed yield, the regression coefficient (bi) varied from -0.88 to 1.10. This wide variation in regression coefficients suggests that different varieties have responded differently over the course of six years and in the context of an organic production system. A regression coefficient for GF-12 is unity, so GF-12 would be adaptable to all environments. Similar results was also reported in the genotypes RF-101, FNL-72 and FNL-71 had above average mean, seed yield, regression coefficient of bi=1 but non-significant deviation from regression line ($S^2di=0$). Hence, indicating its specific adaptability under good agronomic management practices (Sawargaonkar *et al*., 2018). For AF-1, it is less than unity and hence, it is adaptable across poor environments. This demonstrates its particular adaptability for yield component traits under good agronomic management. The higher seed yield per hectare that was observed for RF-125 and GF-02 and are attributed to the regression coefficient value being less than unity and the non-significant deviation from regression that explains its suitability in a harsh environment with above-average stability. Rajendra Saurabha and RF-281, regression coefficient value is more than unity that depicts above average stability, hence it performs well in favourable environments. Lal (2008) and Verma & Solanki (2015) also reported above average stability of fennel genotypes RF-205 for seed yield. Gangopadhyay *et al*. (2012) also reported similar results trait in stability analysis for seed yield of fenugreek genotypes.

The range of seed essential oil content (%) was estimated from 1.14-1.25 as against the average of 1.197 obtained across the years under study. The maximum essential oil content was recorded in variety AF-1, while, the minimum was in variety GF-02. The variety AF-1 and RF-101 had recorded higher essential oil content above average value and regression coefficient value is near unity with non-significant deviation from regression indicates that the variety is more responsive for input rich conditions.

Table 3 : Stability parameters of umbel and umbellate/plant and yield contributing traits in fennel

Variety	No. of umbels/plant			No. of umbellate/plant			Seed yield (q/ha)			Essential oil content (%)		
	Xi	bi	S^2di	Xi	bi	S^2di	Xi	bi	S^2di	Xi	bi	S^2di
AF-1	36.13	1.15	-2.18	27.86	1.16	-1.12	27.51	0.98	-1.20	1.25	1.081	0.001
RF-101	29.14	0.63	-2.71	22.21	0.80	-0.91	23.95	0.99	0.64	1.24	1.071	-0.001
Co-01	28.95	0.63	-2.22	24.10	0.56	-0.86	24.50	1.08	-0.81	1.20	0.610	0.000
Rajendra Saurabha	29.69	1.00	-2.67	24.81	0.73	-1.05	25.27	1.10	-0.82	1.21	0.810	0.001
GF-12	37.92	1.11	-1.72	28.49	1.11	-1.00	27.82	1.00	-1.16	1.19	0.730	-0.000
RF-281	31.26	0.99	-3.09	23.30	1.26	-0.34	25.75	1.02	-1.20	1.18	0.691	0.001
RF-125	32.50	1.21	-2.48	25.51	1.20	-0.39	25.43	0.88	-0.22	1.17	0.642	-0.000
GF-02	29.75	1.25	-0.49	25.51	1.19	-0.97	25.74	0.91	0.15	1.14	1.050	-0.000
	Pooled Mean: 31.92 SE(mean): 0.39 SE (b): 0.085			Pooled Mean: 25.22 SE(mean): 0.24 SE (b): 0.053			Pooled Mean: 25.75 SE(mean): 0.41 SE (b):0.063			Pooled Mean: 1.197 SE(mean): 0.98 SE (b): 0.184		

Xi- mean, bi-regression coefficient and S^2di-deviation from the regression

Table 4 : Correlation analysis among seed yield, its components and essential oil content in fennel

Characteristics	Day to initiation of flowering	Plant height (cm)	Days to 50% flowering	No. of primary branches	No. of secondary branches	No. of umbels/ plant	No. of umbellate/ plant	Seed yield (q/ha)	Essential oil content (%)
Day to initiation of flowering	1.000	-0.619	0.891*	-0.672	-0.593	-0.634	-0.567	-0.701	0.360
Plant height (cm)		1.000	-0.783	0.891*	0.780	0.863*	0.887*	0.866*	0.264
Days to 50% flowering			1.000	-0.782	-0.647	-0.735	-0.577	-0.690	-0.066
Number of primary branches				1.000	0.937**	0.977**	0.889**	0.919**	0.159
Number of secondary branches					1.000	0.979**	0.828**	0.932**	0.110
Number of umbels/plant						1.000	0.869**	0.927**	0.166
Number of umbellate/plant							1.000	0.916**	-0.024
Seed yield (q/ha)								1.000	0.002
Essential oil content (%)									1.000

*Significant at p-0.05; ** Highly significant at P0.05

Correlation analysis among plant, yield and quality traits

The correlation study (Table 4) determines interrelationships among the studied traits showed that the days to initiation of flowering was found significant relation with days to 50% flowering, plant height showed positive association with number of primary branches, number of umbels per plant, number of umbellate per plant and seed yield. Number of primary branches revealed highly significant positive correlation with number of secondary branches, number of umbels per plant, number of umbellate per plant and seed yield similarly number of secondary branches showed positive correlation with number of umbels per plant, number of umbellate per plant and seed yield. Number of umbels per plant revealed positive highly significant correlation with number of umbellate per plant and seed yield. Similar kind of results were also reported by Dashora and Sastry, (2011), Yogi, (2013) and Abou *et al*. (2013) in fennel.

CONCLUSION

The two varieties GF-12 and AF-1 had high mean performance, non-significant regression coefficient deviation from unity (bi=1) and non-significant deviation from zero ($S^2di=0$) in terms of numbers of umbels and seed yield per hectare and RF-101 had recorded higher essential oil content. Hence, in terms of yield, yield components GF-12 and AF-1 and RF-101 for essential oil content can be considered as the most suitable, average stable over the environments (years) and adopted to organic production system compared to other varieties besides further utilization in stable varietal development programme in fennel.

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