Stability Analysis in Ajwain
(*Trachyspermum ammi* L.)

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Monika Meena

Thesis

Master of Science in Agriculture

(Plant Breeding & Genetics)

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DEPARTMENT OF PLANT BREEDING AND GENETICS

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This is to certify that the thesis entitled **"Stability Analysis in Ajwain (*Trachyspermum ammi* L.)"** submitted for the degree of **Master of Science in Agriculture** in the subject of **Plant Breeding and Genetics,** embodies bonafide research work carried out by **Miss Monika Meena** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on / /2015.

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Stability Analysis in Ajwain (*Trachyspermum ammi* L.)

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ABSTRACT

Twenty eight genotypes of Ajwain (*Trachyspermum ammi.* L) was planted under two locations in four environments during late *kharif* 2013-14 and 2014-15 at Udaipur and ARS, Pratapgarh.

Observations were recorded for eleven yield contributing characters. Variability parameters, correlations and path analysis were computed over pooled basis. Stability parameters were analyzed using the model (Eberhart and Russell, 1966).

Superior genotypes UA-7, UA-32 and UA-48 were identified on the basis of their consistent *per se* performance in each environment and over pooled basis for seed yield and its component traits. UA-32, UA-48 and UA-191 exhibited high oil content while UA-32 displayed superiority for seed yield as well as oil content characters. Large genetic advance as percentage of mean coupled with high GCV and heritability were recorded for oil content, number of umbels per plants and seed yield per plant over pooled basis suggesting that selection for these traits would be effective for seed yield in Ajwain.

Association studies revealed that seed yield per plant was positively correlated at genotypic and phenotypic level with biological yield per plant and Test weight.

path analysis studies indicated that oil content contributed to seed yield directly with positive effect.

A joint regression analysis of variance based over four environments indicated that genotypes differed significantly for almost all the characters except days to 50 per cent flowering and days to 75 per cent maturity. The mean squares due to E + (G x E) were significant for almost of the characters except days to 50 per cent flowering, days to 75 per cent maturity and plant height.

Superior genotypes were identified with respect to their phenotypic stability for different environmental conditions. Genotypes namely UA-7, UA-32 and UA-48

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displayed high *per se* performance, above average response and stability for seed yield per plant and its components. For oil content genotypes UA-32, UA-48 and UA-191 had high *per se* performance under high management practices. Thus aforesaid these Ajwain genotypes appeared the most promising.

To conclude the present study conducted in four environments at two locations in two years based over various estimates viz. variability parameters, correlations, path analysis and stability parameters. Ajwain genotypes UA-7, UA-32 and UA-48 appeared to be the most promising for seed yield as they were not only stable but also had high *per se* performance for umbelets per umbel, seeds per umbelet, biological yield per plant Test weight and seed yield per plant. Among these, UA-32, UA-48 and UA-191 also possessed high oil content. The results so obtained were critically discussed to give an impetus to Ajwain breeding programme. Thus, stability of seed yield per plant in UA-7, UA-32 and UA-48 genotypes were imparted by the stability of its component characters like like umbelets per umbel, seeds per umbelets, biological yield per plant, seed yield per plant, Test weight and oil content.

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1. INTRODUCTION

Ajwain (*Trachyspermum ammi* L. Sprague; 2n=18), belongs to the family Apiaceae, a highly valued medicinally important seed spices. It is native of Egypt and is cultivated in Iraq, Iran, Afghanistan and India. It is also known as Bishop's weed and Carum in English and cultivated mainly for its seed, herb and volatile oil. It has medicinal value specially for curing indigestion, stomach pain and elements concerning digestive system. It is also used in cholera, diarrhea, gastric and urinary trouble. Seed contains volatile oil (2-4 %) that is yellow brownish in colour used in many *Ayurvedic* medicines and industries.

In India, it is grown in Gujarat, Rajasthan, Madhya Pradesh, Bihar, Punjab, Tamil Nadu, West Bengal, Andhra Pradesh and Uttar Pradesh. In India, 19000 m t of Ajwain was produced from 27000 ha area with the productivity of 703.70 kg/ha (Department of Agricultural Cooperation & Statistics, 2014). In Rajasthan, it is cultivated in Chittorgarh, Udaipur, Jhalawar, Pratapgarh, Baran, Rajsamand, Bhilwara and Kota districts covering an area of 12620 ha with the production and productivity of 9220 m t and 730.58 kg/ha, respectively (National Horticultural Board, 2014).

Ajwain is an annual herbaceous plant. The plant is profusely branched having height of 60-90 cm, erect with soft hair. It has feather like leaves, 2-3 pinnately divided, and linear segments. Flower is terminal compound umbel. The minute grayish white fruits are oval in nature. The flowers are protandrous and cross pollination occurs through insects (Malhotra and Vijay, 2004).

Though the crop has the domestic, medicinal as well as commercial value, it has altogether been neglected as far as proper genetic improvement is concerned As a result, local type genotypes having low yield potential and susceptible to diseases are still occupying the major area resulting in low production. The productivity of spice crops particularly Ajwain is so far below the desired levels for meeting out the global demand. Intensive breeding efforts will have to be made for the development of high yielding genotypes of Ajwain to keep India's monopoly in international market.

There is ample scope to increase the productivity of Ajwain through genetic improvement. However, little emphasis has been given to the crop improvement aspect in Ajwain. Yield is complex polygenic trait depending on number of characters

influenced by the genotype x environment interaction. The genetic improvement primarily depends upon the nature and magnitude of variability in plant characters, overall genetic diversity among the genotypes and association among the traits. Further, with the help of path analysis, correlation is partioned into direct and indirect effects which measures the relative importance of each causal factor.

The development of cultivars or varieties, which can be adapted to a wide range of diversified environments, is the ultimate goal of plant breeders in a crop improvement programme. The adaptability of a variety over diverse environments is usually tested by the degree of its interaction with different environments under which it is planted. A variety or genotype is considered to be more adaptive or stable one if it has a high mean yield but a low degree of fluctuation in yielding ability when grown over diverse environments.

The genotype x environment interaction was studied by different researchers (Lal (2008), Tomer *et al.* (2004), Basu *et al.* (2009), Kole *et al.* (2005) in various crops but such type of studies are still lacking in seed spice crops particularly in Ajwain. Further, the parameters for measuring phenotypic stability gives very important information that should be available for the crops like Ajwain for the yield improvement .

The present study was undertaken to develop stable genotype using *elite* Ajwain genotypes at morphological level so as to select the suitable material for further utilization in breeding programme with the following objectives:

- To estimate various variability parameters for seed yield and its component traits over four environments.
- To estimate Path analysis for seed yield, its components & oil content.
- To estimate stability parameters for seed yield and its component traits, over four environments.

2. REVIEW OF LITERATURE

The genetic improvement of any crop can be achieved by breeding of high yielding varieties with improved quality. A detailed knowledge of nature and

magnitude of genetic variability, its heritable portion in economic traits information regarding inter-relationship among the component characters, and direct/indirect contribution of important characters towards yield are the prime reguisite of any efficient breeding programme. Studies on genotype x environment interaction lead to successful evalution of stable genotypes which could be used in breeding programme. Thus present investigation was conducted to estimate variability parameters, correlation, path coefficient analysis and stability parameters for yield, its components as well as essential oil content in Ajwain (*Trachyspermum ammi* L.).

Since there is limited research work carried out so far on Ajwain, as a result only few reviews on the crop are available. However, review on same topic on other related seed spices has been attempted under following heads.

2.1 Variability Parameters

2.2 Correlation and path Analysis

2.3 Stability Parameters.

2.1 Variability Parameters:

A detailed study of the extent of variability for grain yield and its contributing characters is prime requisite for an efficient breeding programme. The magnitude of variability may be measured by genetic variance into three components (a) additive genetic variance, (b) dominance components, and (c) epistatic component. Accordingly additive genetic variance can be exploited for genetic advance through selection. Grain yield as well as oil content are complex characters being governed by different kinds of gene actions and are highly influenced by the environment. Environment plays an important role in expression of genotype and the genetic factors are inferred from phenotypic observation. Hence, the observed variability can be divided into heritable and non-heritable variations. Information about these genetic parameters can be obtained through the parameters like genotype coefficient of variation (GCV), heritability (broad sense) and genetic gain. This would help the breeder in developing and formulating selection programme for genetic improvement of crop plants.

Dhayal *et al.* (1999) studied variability in nine genotypes of cumin (*Cuminum cyminum*) indicated higher estimates of genotypic coefficient of variance, phenotypic coefficient of variance, heritability and genetic advance for plant height, number of

umbels per plant, number of seeds per umbel, test weight, seed yield per 10 plants on normal soil and number of seeds per umbel and test weight on saline soil, thereby suggesting the probable role of additive gene effects on character expression.

Tripahti *et al.* (2000) evaluated forty genotypes of coriander to estimate phenotypic and genotypic coefficient of variations (PVC, GVC), heritability, genetic advance (GA) and correlation coefficients for 10 metric traits. High estimates of PVC, GVC, heritability and GA indicated substantial genetic variability and scope for selection for days to maturity, secondary branches per plant, days to flowering and 1000-seed weight. Low estimates of variability for number of umbelates per umbel, primary branches per plant and plant height indicating less suitability for selection.

Singh *et al.* (2001) evaluated 10 cumin genotypes under saline conditions for genetic variability parameters. Results indicated high estimates of genotypic and phenotypic coefficients of variation, heritability and genetic advance suggesting thereby these traits would be more effective for yield improvement through selection.

Krishnamoorthy and Madalageri (2002) observed a wide range of variability in various growth and yield contributing characters in Ajwain. High heritability coupled with high genetic advance was observed for seeds per umbel, essential oil yield per hectare, umbels per plant, total dry weight, essential oil content and number of tertiary branches.

Megeji and Korla (2002) evaluated thirty genotypes of coriander in a field experiment and revealed that the genotypes differ significantly from each other. Genotypic and phenotypic coefficients of variation were high for leaf yield, seed vigour and seed yield. Heritability was highest for 1000-seed weight, followed by germination percentage and seed vigour. Leaf yield, 1000-seed weight, germination percentage and seed vigour recorded high genetic advance.

Singh and Mittal (2002) studied the genetic variability, heritability and genetic advance of different yield-contributing characteristics in 34 diverse collections of fennel and revealed that higher magnitudes of phenotypic and genotypic coefficient of variability, higher estimates of heritability coupled with higher genetic advance as percentage of mean was noticed in the number of primary branches per plant, number of secondary branches per plant, number of umbels per plant, 100-seed weight and seed yield per plant.

Shukla *et al*. (2003) evaluated thirty fennel genotypes for seed yield and five other major traits for genetic variation and heritability and revealed that high estimate of phenotypic and genotypic coefficient of variation observed for all the traits except for plant height and number of branches per plant. Heritability values were high for all characters. Genetic advance was high for seed yield, Stover yield, umbel/plant and umbelate/umbel, indicating the presence of additive gene effect.

Rajput and Singh (2003) conducted a field experiment on coriander using 20 genetically diverse genotypes and reported genetic variability for 7 different morphological traits it was revealed that the traits seed yield, umbels per plant, seeds per umbel and plant height exhibited high estimates of all the variability parameters suggesting the probable role of additive gene effects for character expression.

Agrawal *et al.* (2006) studied on cumin reported the higher range of variability for volatile oil yield and seed yield followed by ratio of oxygenated: hydrocarbon compounds, 1000-seed weight and volatile oil content. The study also indicated the quantitative nature of genetic control for volatile oil yield and seed yield.

Singh *et al.* (2006) conducted an experiment on coriander and reported significant variability for plant height, number of primary branches per plant, number of secondary branches per plant, days to 50% flowering, days to maturity, number of umbels per plant, number of umbellets per umbel, number of grains per umbellet, 1000-grain weight, essential oil content, harvest index and grain per plant in *Coriandrum sativum*. The heritability estimate was high for number of secondary branches per plant, days to 50 per cent flowering, days to maturity, number of umbels per plant, 1000-grain weight, essential oil content and harvest index and low for number of umbellets per umbel and number of grains per umbellet.

Singh and Prasad (2006) evaluated thirty-five genotypes of *Coriandrum sativum* and reveled that ample genetic variability existed for plant height, number of primary branches per plant, number of secondary branches per plant, days to 50% flowering, days to maturity, number of umbels per plant, number of umbellets per umbel, number of grains per umbellet, 1000-grain weight, essential oil content and harvest index in the material under study.

Singh and Jadeja (2006) studied genetic variability for 12 agro-morphological and 4 biochemical parameters in 25 genotypes of cumin (*Cuminum cyminum*) study

revealed that grain yield per plant, number of branches per plant, number of umbels per plant, number of grains per umbel, biological yield per plant, harvest index and test weight were characterized by significant variability, and moderate heritability and genetic advance. Among the biochemical parameters, the essential oil content showed high variability. Thus, these traits may be considered for selection to enhance the yield and quality of cumin.

Singh *et al.* (2006) studied genetic variation for seed yield and yield components in 360 lines of coriander and revealed that the characters seed yield (22.82%), number of umbels per plant (28.65%), and number of seeds per umbel (21-63%) exhibited high estimates of genetic variability where as number of days to 50% flowering (12.39%) and number of umbellate per umbel (13.30%) exhibited low estimates of genetic variability. Similarly the traits umbels per plant and seed per umbel also possess high estimates of heritability and genetic advance.

Singh *et al.* (2008) studied the extent of variability and heritability for seed yield and its component characters using 70 germplasm lines of coriander and reveled that a wide range of variability was noticed and correlation coefficients of seed yield and its component characters in a set of 70 germplasm lines of coriander grown on sodic soil. A wide range of variability was noticed for plant height, branches/plant, umbels/plant, seeds/umbel and seed yield. Ten genotypes were identified more promising for sodic soil yielding above 30 g seed/plant. The high heritability coupled with high genetic advance and coefficient of variability was recorded for plant height, inter-nodal distance, seed yield/plant, test weight and umbels/plant.

Singh and Choudhary (2008) studied the degree of genetic variability, heritability and genetic advance for seed yield per plant in ajowain (*Trachyspermum ammi* L.) The analysis of variance revealed significant differences among the genotypes for all the characters. The estimates of heritability (broad sense) were high for plant height, umbels per plant, harvest index and seed yield per plant whereas, it was moderate for days to 50% flowering, branches per plant, umbellate per umbel, seeds per umbel and 1000-seed weight. The genotypic coefficient of variation and genetic advance expressed as percentage of mean were high for harvest index and seed yield per plant and moderate to low for umbels per plant, seeds per umbel, branches per plant, plant height, days to 50% flowering, umbellate per umbel and 1000-seed weight, respectively.

Meena *et al.* (2010) studied the variability parameters using 13 diverse varieties of fennel (*Foeniculum vulgare* Mill.) for yield and yield attributes. Study showed highly significant difference among varieties for all the characters. High genotypic and phenotypic variances were observed for umbel/plant, umbellate/umbel and seed yield/plant. The highest genotypic coefficient of variation was observed for yield/plot (18.23), followed by umbel/plant (15.10), umbellate/umbel (9.19) and test weight (6.92). High genetic advances as percentage of mean was recorded for seed yield/plot, umbel/plant, umbellate/umbel, test weight, number of branches/plant, angle of primary branches, seed/umbel and plant height suggesting that phenotypic selection for these traits would be effective.

Dashora and Sastry (2011) evaluated 45 genotypes of fennel for 10 quantitative characters to study genetic variability and heritability. The traits seed yield per plant and biological yield per plant showed highest genotypic coefficient of variation and phenotypic coefficient of variation. High heritability coupled with high genetic advance as per cent of mean was observed for seeds per umbel and biological yield per plant indicating the importance of additive gene effects for these traits.

Dalkani *et al.* (2012) assessed the genetic diversity in ten populations of iranian ajwain based on agronomical and morphological characteristics. The study demonstrated that populations of ajwain from Iran displayed considerable diversity of agronomical and morphological characteristics that were useful in germplasm management and for utilization in improvement programmes.

Meena *et al.* (2013) reported high heritability coupled with high genetic gain and coefficient of variability for umbels per plant, seeds per umbel, harvest index, crude fiber content and seed yield per plant, indicating a possible role of additive gene effect for the genotypic variance for these characters.

Jain *et al.* (2013) estimated high PCV along with GCV as well as broad sense heritability, genetic advance and genetic advance as percentage of mean for pods on main axis and seed yield per plant in fenugreek. Total number of pods per plant showed high heritability with moderate genetic advance. Moderate to high estimates of heritability and genetic advance were recorded for primary and secondary branches per plant and test weight.

Pathak *et al*. (2014) evaluated genetic variability among forty genotypes of fenugreek. High genetic advance with high heritability were observed for seed yield followed by pods per plant, primary branches per plant, seeds per pod, protein content, secondary branches per plant, days to 50 per cent flowering and 100-seed weight .

Meena *et al*. (2014) determined high genotypic and phenotypic coefficients of variances for seed yield in coriander. High heritability coupled with high genetic advance as percentage of mean was observed for test weight, plant height and seed per umbel indicating the important of additive gene effects for these traits.

Ghanshyam *et al*. (2015) analysed the genetic variability, heritability among twenty eight germplasm for ten characters in ajwain. Analysis of variance revealed significant differences among the germplasm lines for secondary branches plant per, umbels plant per, umbellate per umbel, seed yield plant per, harvest index and oil content. The estimates of GCV and PCV indicated the existence of fairly high degree of variability for seed yield, oil content, umbels plant per and harvest index.

Sharma *et al.* (2015) analyzed the genetic variability and heritability among fifty genotypes in fennel. The PCV was higher than corresponding GCV for most of the characters. High genetic advance as percent of mean was recorded for seed yield, plant height, umbellate per umbel, secondary branches, umbel per plant, 1000-seed weight, primary branches and seeds per umbellate.

2.2 Correlation and Path Analysis:

Dash *et al.* (2000) studied on association analysis for 15 genotypes of fenugreek. The plants were sown in West Bengal, India during the winter season of 1998-99. Pod per plant, grains per pod, straw yield, biological yield and harvest index showed significantly positive correlation with grain yield per plant at both genotypic and phenotypic level. Path coefficient analysis indicated direct positive effect of straw yield, test weight, grown per pod and pod per plant with grain yield per plant.

Srivastava *et al.* (2000) studied the path coefficient analysis in 40 genotypes of coriander to determine the direct and indirect effects on seed yield of plant height, number of primary branches, number of secondary branches, days to flowering, days to maturity, number of umbels, number of umbellate per umbel, number of seed per plant and 1000-seed weight. About 70% of the characters had positive direct effect on seed

yield. Days to flowering had highest direct effect on seed yield followed by days to maturity and number of umbels per plant. Plant height, number of primary branches and number of seeds per umbel had weak direct effect on seed yield.

Gurbuz (2001) study correlation and path analysis among yield components in 25 winter resistant lines of coriander. The highest correlations were found between single plant yield and single plant weight, branch number and number of branches with seeds. Path analysis indicated the highest direct and positive effect of single plant weight on single plant yield. Plant height had the highest negative effect on single plant yield.

Krishnamoorthy and Madalageri (2002) evaluated fifteen genotypes of ajowan and revealed that the oil yield per hectare was positively correlated with days to flowering, days to harvest, number of umbels per plant, and essential oil content. The thymol content in essential oil was positively correlated with days to flowering, days to harvest, essential oil content of seeds and essential oil yield. Path analysis indicated the direct influence of days to harvest plant, height and essential oil content on thymol content and these traits also had indirect effect via days to flowering and plant height. Essential oil yield and 1000-seed weight through days to harvest and total dry matter influenced indirectly on thymol content.

Garg *et al.* (2003) studied correlation and path analysis of 30 genotypes of fennel (*Foeniculum vulgare*) results indicated that there was a significant genotypic association of seed yield with plant height and stover yield. The stover yield had a positive direct correlation with seed yield followed by number of branches per plant. Plant height exhibited significant positive genotypic associations with all the traits, which suggests that plant height is mainly responsible for the increase of each trait, ultimately contributing to the enhancement of seed yield. The plant height, number of branches per plant and stover yield was important components to build an ideal plant type to increase seed yield.

Jain *et al.* (2003) in an experimental study reported that seed yield was positively and significantly correlated with all the traits studied except number of days to 50% flowering. Total plant height was positively associated with number of umbels per plant, height up to the base of the main umbel, number of branches per plant, number of umbellets per umbel, number of seeds per umbel, and 1000-seed weight.

Path analysis revealed that total plant height had the greatest positive direct effect on seed yield, followed by number of umbels per plant and 1000-seed weight. The number of days to 50% flowering had significant negative correlation with seed yield.

Davila *et al.* (2004) evaluated 4 genotypes of vegetable coriander under 5 environments with an objective to generate models of prediction of flowering using regression, correlation and path analysis. The results showed that the methodologies utilized had capacity to generate models with a high predictive value for each environment of production. The models derived from the variables leaf area at 24 days after sowing or DAS (LA24), dry weight at 38 DAS (DW38), relative rate of leaf area at 24 DAS (RRLA24), relative rate of leaf growth at 52 DAS (RRLFG53) and duration of leaf area at 38 DAS (DLA38) successfully estimated the days to flowering in coriander.

Vijayalatha and Chezhiyan (2004) studied correlation and path analysis in ninety genotypes of coriander (C. sativum) for 8 traits related to yield and quality. The traits such as plant height, number of primary branches, number of umbels, number of umbellets and essential oil exhibited positive and significant association at phenotypic and genotypic levels with yield. The positive direct effect of essential oil and number of umbellets was the highest on yield. This indicated that the yield in coriander was influenced by these traits and therefore selection should be exercised based on these traits.

Agrawal *et al.* (2006) reported that seed yield exhibited significant positive association with oil yield as resulted from study conducted on cumin. It is also summarized that seed yield came out as the major attribute for the progenies of higher oil yield in cumin.

Singh *et al.* (2006) conducted an experiment on coriander and reported that the grain yield per plant had positive and significant correlation with plant height, number of primary branches per plant, number of secondary branches per plant, number of umbels per plant, number of umbellate per umbel, number of grains per umbellate and harvest index. Path co-efficient analysis revealed that number of secondary branches per plant, harvest index, days to maturity and number of umbellate per umbel were the most important characters for selection of high yielding genotypes, as they had high direct positive effects as well as positive association with grain yield per plant.

Singh *et al.* (2006) studied correlation and path analysis in 360 lines of coriander for seed yield and its component traits. The study revealed that the number of umbel per plant and number of branches per plant were the most important traits associated with seed yield as these traits had positive direct effects on seed yield.

Singh and Prasad (2006) evaluated thirty-five genotypes of *Coriandrum sativum* and revealed that the grain yield per plant was positively and significantly associated with plant height, number of primary branches per plant, number of secondary branches per plant, number of umbels per plant, number of umbellate per umbel, number of grains per umbellate, essential oil content and harvest index. Maximum direct contribution to grain yield per plant was made by harvest index followed by primary branches per plant, days to maturity, number of secondary branches per plant, essential oil content, and number of umbellate per umbel and 1000-grain weight. Harvest index showed high indirect effect via primary branches per plant. Primary branches per plant made a high indirect contribution via harvest index.

Lal (2007) in a path analysis study in fennel revealed that the diameter of main stem and oil content made the heighest amount of direct and indirect contribution to t-anethole content, therefore seed yield and oil content could serve as better selection criteria to improve t-anethole content.

Panesar and Jadeja (2008) in a study in cumin reported that harvest index was the most important character for increasing the yield, as it exhibited significantly positive association at the genotypic and phenotypic levels. Other traits such as plant height, umbels per plant and biological yield per plant showed significant positive correlations with grain yield at the phenotypic level. Path analysis revealed that biological yield per plant exhibited the highest positive direct effect on grain yield, followed by test weight and plant height with overall positive genotypic correlation. Therefore, selection for these traits would be easy and bring about improvement in cumin.

Singh *et al.* (2008) studied character association and path analysis for seed yield and its component characters using 70 germplasm lines of coriander and revealed that the branches per plant, leaves per plant, umbels per plant and seeds per umbel exhibited positively significant genotypic correlation among themselves and all were positively and significantly associated with seed yield/plant. A positive significant correlation

with seed yield/plant and its main components - seeds/umbel and umbels/plant were also noticed. Considering the direct and indirect selection parameters of major contributors a plant ideotype has been discussed to enhance seed yield on one hand and leafy vegetable on the other.

Dalkani *et al.* (2011) evaluated 10 population of Ajwain to investigate the association among seed yield and its component traits and their direct and indirect effects on seed yield. It was revealed that positive and significant correlation existed between single plant yield and most of the traits studied while negative significant correlation existed between single plant yield and ripening period studied. A sequential path analysis was used to order the various variables based on their maximum direct effect and minimal co linearity. Based on sequential path analysis, plant height and number of umbels can be used as selection criteria for improving seed yield in Ajwain breeding programs.

Dashora and Sastry (2011) evaluated 45 genotypes of fennel for 10 quantitative characters to study character association and path analysis for seed yield and its component traits it was revealed that the umbellate per umbel (0.43**), seeds per umbel (0.46**), biological yield per plant (0.84**) and harvest index (0.45**) exhibited positive and significant correlation with the seed yield. Path coefficient analysis revealed that seeds per umbel had highest direct effect on seed yield followed by test weight and biological yield per plant. Therefore, greater emphasis should be given on these characters while selecting for higher yield and related traits.

Palanikumar *et al.* (2012)) in a study on coriander reported that the results of the path coefficient analysis, plant height, number of branches, number of leaves, fresh weight of leaves, weight of stem and weight of root exerted the maximum positive direct effect on yield of biomass.

2.3 Stability Parameters:

The phenotypic response for a change in environment may not be the same for all the genotype. Thus interplay in the effect of genetic and environmental factors on development is called genotype-environment interaction. The genotype-environmental interaction signifies that the relative performance of various genotype is affected by environment. The performance of all the genotype may not be influced by the environment to some extent. A specific change in environment may have a

greater effect on some genotype than the others. The magnitude of the genotype-environment interaction can be estimated by growing the experimental material over a number of years, location, controlled condition, growth condition and different cultural practices.

The phenotypic stability may be defined as the ability of a genotype to produce a narrow range of phenotype in different environments. Phenotypically stable varieties are desirable for commercial production of crop plants. In a breeding programme, it is also important to screen and identify the phenotypically stable genotypes which could perform more or less uniformaly under environmental conditions. Stability studies are not only important in finding out the most stable genotype for varied environmental condition but are also equally useful in screening the different genotypes for their comparative performance under a particular set of environment.

Importance of genotype-environment interaction recognized since the breeding programme were started. However, efforts to provide a suitable measure of genotype-environment interaction or of stability of genotypes started after 1950 when Lewis suggested a simple measure of phenotype stability which he termed as stability factor (S.F.) and was expressed as ratio of mean performance of genotype in high yielding environment to its mean performance in low yielding environment. However, a better way of ascertaining phenotypic stability was given by finlay and Wilkinson (1963). They considered linear regression slope as a measure of stability.

Eberhart and Russell(1966) emphasized the need of considering both the linear (bi) as well as non-linear (s^2di). Components of genotype environment interaction in judging the stability of a genotype.

Breese (1969), Paroda and Hayes (1971) avocated that linear regression could simply be regarded as a measure of response of a particular genotype, whereas the deviation around the regression line is considered as a measure of stability, genotype with the lowest deviation being the most stable. According to Eberhart and Russell (1966) on ideal variety is one which has a high mean yield (μi), unit regression coefficient (bi=1) and least deviation from regression (S^2di=0). The mathematical model and stability parameters used by Eberhart and Russell(1966) are discuss in detail in material and methods. A limited number of reports are available on

estimation of stability parameters in Ajwain. Hence the stability analysis in other spice crops have been included for comparison, the important studies are described here :-

Ali *et al.* (1999) evaluted 20 genotypes of coriander, grown from 1990-91 through 1992-93, were evaluated for their stability parameters with respect to their seed yield and its components. Genotype x environment interactions were observed for all the characters, except seed yield per plant and harvest index. The pooled deviations (non-linear component) were significant for all the characters, except for plant height, indicating that the prediction of these characters, except plant height, would be difficult. Genotypes G-5365, UD-1, UD-20 and Panipat local, with good yield potential, average plant height and medium maturity, were found stable and desirable for most of the characters indicating seed yield per plant.

Kaya *et al*. (2000) Investigated the effect of sowing date on the productivity (yield) of Coriander using four different sowing dates. Plant height, number of branches per plant, number of umbels per plant, biological yield and yield decreased with later sowing dates. The effect of sowing date was significante on 1000-seed weight and essential oil content.

Rao and prabhakaran, (2000) gave some useful interrelationships among common stability parameters across environments which and useful from a computational part of view. The theoretical basis of the observed similarity in the behaviour of some of these parameters is explained in the highest of the relationships.

Singh and Shah (2003) evaluated 20 coriander genotype for their stability with respect to their seed yield, its contributing traits and oil content. The genotype x environment interaction was significant found for days to flowering, plant height, 1000 seed weight, harvest index and oil content. Both linear and non linear interaction were significant for plant height, 1000 seed weight, harvest index and oil content, whereas for seed yield only linear component was significant.

Tomer *et al.* (2004) evaluated stability of 8 elite of coriander (*Coriandrum sativum*) during 1999-2001. The mean square due to genotype (G) and environment (E)+G x E were significant when tested against pooled error, indicating that there were changes in the relative ranking of different genotypes over environment. Highly significant mean square due to environment (linear) indicated that the yield

differences were influenced to a great extent under different environments. The regression coefficient value of these genotypes were close to unity and significant high value of deviation from regression indicated their average response but their cultivation might be more fruitful in favourable environment.

Kole (2005) 14 genotype of fenugreek were grown in four different environments during winter season for three consecutive years. The genotype x environment interaction was significant found for pods per plant, seeds pod and test weight. Genotype x environment interaction were highly significant for all the characters. Both linear and non-linear component of genotype x environment interactions were highly significant, non-linear component being predominant for seed pod and seed yield per plant. While linear component was predominant for test weight. However linear and non-linear both component were equally important for pods per plant.

Lal (2008) Evaluated 37 genotype of fennal for the eight economic traits in the three years (1999–2000, 2000–2001, and 2001–2002). Genotypes × environments (years) interactions (G × Y) were significant for some important characters (seed yield, oil content, and t-anethole content), indicating that the genotypes had divergent linear response to environmental changes. While significant pooled deviation suggested that the deviation from linear regression also contributes substantially to the differences in stability of genotypes. Both linear and non-linear components contributed significantly to the differences in the stability of genotypes.

Basu *et al.* (2009) Studies that genotype x environment interactions have an impact on seed and forage yield of fenugreek. When plants are grown under the short growing season. Two studies were conducted: one with up to 83 accessions grown under rain-fed and irrigated conditions for two years and the other had five selected genotypes grown under seven environments scattered five years. In the first study significant ($P < 0.01$) location and year effects were observed for forage yield and 1000 seed weight respectively, while for seed yield effect of year, genotype, year X location and year X genotype were significant ($P < 0.01$). In the second study significant ($P < 0.01$) genotype, environment and their interaction effects were observed for forage and seed yield. These studies indicate that improvement through phenotypic selection for forage and seed yield is possible.

Gangopadhayay *et al.* (2011) evaluated 55 fenugreek genotypes including four check varieties. The analysis of data indicated highly significant differences among the genotypes and environments for all the traits. The variance due to genotype and environments were highly significant for all the traits. Highly significant deviation for plant height, number of primary branches per plant, pods per plant, and seed yield per hectare and highly significant G × E (Linear) interaction for plant height, pods per plant, and seed yield per hectare indicated the preponderance of non-linear components of G × E interaction.

Kole and Saha (2013) evaluated 30 genotypes of fenugreek were grown in six (E1 to E6) environments during the winter seasons for three consecutive years from 2002 to 2003 and 2004 to 2005. created by changing the date of sowing, spacing, fertilizer dose and other crop management practices at the Agriculture Farm of Institute of Agriculture, Visva-Bharati, West Bengal. Analysis of correlations revealed that significant and positive genotypic and phenotypic correlations of pod number, husk weight, stem weight and harvest index with seed yield did not change with the change in environmental conditions. Majority of the characters (except days to flowering and test weight) had significant and positive correlation with seed yield in all the environments except in E3.

Verma *et al.* (2014) Evaluated 15 coriander genotypes including three checks during *rabi* 2007–08 to 2009–10. The G × E interaction showed non-significant differential response of the genotypes to the changing environments. Highly significant pooled deviation for all the characters except days to 50 percent flowering, days to maturity and number of umbels per plant and highly significant G × E (Linear) interaction for number of secondary branches and days to maturity indicated the preponderance of non-linear components of G × E interaction.

3. MATERIAL AND METHODS

The investigation entitled **"Stability Analysis in Ajwain (*Trachyspermum ammi*)"** was conducted in 4 environments including 2 location and 2 years. The locations were Rajasthan college of Agriculture, Udaipur and Agriculture Research Station, Pratapgarh. Whereas the experiment was conducted for two year that is 2013-14 and 2014-2015 at both the locations.

3.1 Experimental Material

Large material of Ajwain was collected from different sources/places and evaluated. Single superior plants were multiplied and tested. Out of 120 genotypes 25 elite genotypes were used for further evaluation along with three genotypes Gujarat Ajwain-1, Pratap Ajwain-1 and Local check used as checks (Table 3.1).

3.2 Experimental Design

. These genotypes were evaluated under four different environments during late *kharif*, 2013-14 at Udaipur and Pratapgarh and during late *kharif*, 2014-15 at Udaipur and Pratapgarh. These genotypes were laid out in Randomized Block Design with three replications. Each genotype was sown in four row plot of 3.0 m row length. Row to row and plant to plant distance was maintained as 30 cm and 10 cm at each location, respectively. All the recommended agronomical practices and plant protection measures were adopted to raise a healthy crop to attain maturity. Fertilizers were applied @ 20 kg N: 20 kg P_2O_5 at the time of sowing as basal dose while 20 kg N/ha was top-dressed in two split doses in thirty and sixty days respectively. Crop was irrigated 6 times during the crop season. First irrigation was given immediately after sowing and there after irrigation was given at an interval of 20-25 days. The geographic details and adaphic characteristics of both locations (environments) are given below.

Geographic details of experimental sites:

Environment	**Location**	**Agroclimatic Zone**	**Elevation (m) a m s l**	**Latitude**	**Longitude**	**Season**
E1	Udaipur	IV A	582	24°-35'N	74°-42'E	Late Kharif, 2013-14
E2	Pratapgarh	IV B	483	24°-10'N	74°-78'E	Late Kharif, 2013-14

E3	Udaipur	IV A	582	24^0-35'N	74°-42'E	Late Kharif, 2014-15
E4	Pratapgarh	IV B	483	24°-10'N	74°-78'E	Late Kharif, 2014-15

Physico-chemical cherecteristics of the soil of experimental sites

particulars of soil characters	**Rajasthan Collage of Agriculture, Udaipur (E_1, E_3)**	**Agricultural Research Station, Pratapgarh (E_2, E_4)**
1. Mechanical		
Course sand (%)		
Fine sand (%)		
Silt (%)	10.48	22.0
Clay (%)		
Textural class	27.05	40.20
	29.98	17.20
	27.55	10.60
	Coarse clay loam	Fine loamy
2. Physical		
Bulk density (g/cc)		
UA-rticle density (g/cc)		
Porosity (%)	1.52	1.62
Field caUA-city (%)		

PWP (%)	2.65	2.63
	21.39	28.20
	25.73	22.80
	12.53	10.60
3. Chemical		
Organic carbon (%)	0.58	0.54
Total nitrogen (%)	0.09	0.07
Available P (kg/ha)	81.00	24.60
Available K (kg/ha)	836.00	325.00
EC ds/m (at 25°C)	1.96	0.28
pH	7.60	7.50

Table 3.1: Twenty eight diverse ajwain (*Trachyspermum ammi* L.) accession.

S. N.	Name of Genotypes	Origin	State
1.	UA-7	Udaipur	Rajasthan
2.	UA-28	Chittorgarh	Rajasthan
3.	UA-29	Chittorgarh	Rajasthan
4.	UA-30	Chittorgarh	Rajasthan
5.	UA-32	Chittorgarh	Rajasthan
6.	UA-41	Chittorgarh	Rajasthan
7.	UA-48	Chittorgarh	Rajasthan
8.	UA-53	Chittorgarh	Rajasthan
9.	UA-63	Pratapgarh	Rajasthan
10.	UA-66	Pratapgarh	Rajasthan
11.	UA-70	Bhilwara	Rajasthan
12.	UA-71	Bhilwara	Rajasthan
13.	UA-83	Chittorgarh	Rajasthan
14.	UA-87	Chittorgarh	Rajasthan
15.	UA-90	Chittorgarh	Rajasthan
16.	UA-113	Chittorgarh	Rajasthan
17.	UA-125	Chittorgarh	Rajasthan
18.	UA-127	Neemauch	M.P.
19.	UA-131	Neemauch	M.P.
20.	UA-141	Neemauch	M.P.
21.	UA-149	Radhapur	Gujarat
22.	UA-168	Banaskantha	Gujarat
23.	UA-169	Banaskantha	Gujarat
24.	UA-175	Banaskantha	Gujarat

25.	UA-191	Banaskantha	Gujarat
26.	Gujarat Ajwain-1	Banaskantha	Gujarat
27.	Pratap Ajwain-1	Banaskantha	Gujarat
28.	Local check	Banaskantha	Gujarat

3.3 OBSERVATIONS TO BE RECORDED:

The observations were recorded on ten randomly selected plants of each genotype in each replication for each environment and average value were used for the statistical analysis. The detailed procedure of data recording observations on 11 characters is given below:

1. **Days to 50% flowering:** The days taken from sowing date to the anthesis of main umbels of 50 per cent plant in a plot were recorded to represent days to 50 per cent flowering.
2. **Days to 75% maturity:** Numbers of days were counted from date of sowing to the date when 75 per cent plants attained complete physiological maturity.
3. **Plant height (cm):** Height of the plant were measured in cm from the ground level to the top of the plant at the time of maturity.
4. **Number of primary branches per plant:** Number of branches coming out of main stem were counted from ten plants at the time of harvesting and mean value was counted from each plot.
5. **Number of umbels per plant:** Total number of fully matured umbels on ten plants were counted and averaged to be obtain umbels per plant.
6. **Number of umbelets per umbel**: Number of seed bearing umbelets in main umbel from tagged plants were counted in the individual plant and mean value was recorded
7. **Number of seeds per umbelets:** Ten umbelets were randomly selected from the ten sampled plant and the seeds were counted per umbelets and average was taken.

8. **Biological yield per plant (g):** The total biomass was estimated by weighing whole plant (excluding roots) at maturity.

9. **Seed yield per plant (g):** Seed was obtained from the ten randomly selected plants, weighted and averaged is calculated seed yield per plant.

10. **Test weight (g):** Bulked the seeds of ten randomly selected plants and divided the seed in three samples, counted the 1000 seeds from each sample and average weight was work out.

11. **Oil content (%):** The random sample of 5 g seeds was drawn from bulk harvest of ten randomly selected plants in each replication and oil content of seed were determined by the Soxhlet's Method and average oil content was work out in percentage. (Detailed procedure is given in appendix II)

3.4 Statistical Methodology

The data recorded for all aforesaid quantitative and quality characters were analysed to get plot means. A brief outline of different statistical calculations studied is mentioned below:

(i) Analysis of variance

To test the variation among the genotypes under each location analysis of variance was carried-out as per standard methodology in individual as well as pooled over four environments. Skelton ANOVA is given below:

Skeleton ANOVA is given as under

Source	d.f.	S.S.	MSS	Expected MSS
Replication	(r – 1)	A	a^1	$\sigma^2e + g\sigma^2r$
Genotype	(g – 1)	B	b^1	$\sigma^2e + r\sigma^2g$
Error	(r – 1)(g – 1)	C	c^1	σ^2e
Total	(r.g – 1)	–	–	–

ANOVA based on the data pooled over environments

Source	d.f.	S.S.	M.S.	Expected M.S.
Environments	(s-1)	SS_1	M_1	$\sigma^2 + r\sigma^2_{GE} + glr\sigma^2_E$

Rep./Env.	s(r-1)	SS_2	M2	$\sigma^2 + g\sigma^2_R$
Genotype	(g-1)	SS_3	M3	$\sigma^2 + r\sigma^2_{GE} + rs\sigma^2_G$
G x E	(g-1)(s-1)	SS_{27}	M_{27}	$\sigma^2 + r\sigma^2_{GE}$
Pooles error	s(g-1)(r-1)	SS	M	σ^2

Where

r = number of replications

g = number of genotypes

a^1 = Mean sum square due to replication

b^1 = Mean sum square due to genotype

c^1 = Mean sum square due to error

Standard error for differences between genotype means was calculated as:

$$SE\,(diff.) = \frac{\sqrt{2\,EMS}}{r}$$

Where,

EMS = Error mean sum of square for the experiment, and

r = number of replication

Coefficient of variation was calculated as:

$$\mathrm{CV} = \frac{\sqrt{2\,\mathrm{EMS}}}{\overline{\mathrm{X}}} \times 100$$

Where, CV = coefficient of variation, and

$\overline{X}$ = population mean

(ii) Estimation of variability parameters

(a) Genetic variability: It is the variance contributed by genetic causes or the genetic occurrence of difference among the individuals due to their genetic makeup. It was calculated by using formula given by panse and Sukhatme (1979).

$$Vg = \frac{MSV - VE}{r} = \frac{bl - cl}{r}$$

Where, V_g = Genotypic variance

MSV = Mean sum of square for genotypes

Ve = Error variance, and

r = Number of replication

(b) **Phenotypic variability:** It is the sum of variances contributed by genetic causes and environmental factors and was computed as :

$$V_{ph} = V_g + VE$$

where, V_{ph} = Phenotypic variance
V_g = Genotypic variance and
V_e = Error variance

(c) **Genotypic coefficient of variation (GCV):** The magnitude of genetic variation existing in a character was estimated by the formula given by the Burton (1952):

$$GCV = \frac{\sqrt{Vg}}{\overline{X}} \times 100$$

Where, V_g = Genotypic variance, and
$\overline{X}$ = Population mean of the character

(d) **Phenotypic coefficient of variation (PCV):** The magnitude of phenotypic variation existing in a character was estimated by using the following formula (Singh and Choudhary, 1985):

$$PCV = \frac{\sqrt{Vph}}{\overline{X}} \times 100$$

Where, V_{ph} = Genotypic variance, and
$\overline{X}$ = Population mean of the character

(e) **Heritability:** It is the proportion of total variability which is heritable in nature. It was estimated in broad sense [Burton and De Vane (1953) and Johnson *et al.* (1955)]:

$$H = \frac{Vg}{Vph} \times 100$$

Where, H = Heritability in broad sense
Vg = Genotypic variance, and
V_{ph} = Phenotypic variance

(f) **Genetic gain:** It is the percentage of expected genetic advance based on the mean of a compound. It was computed using following formula suggested by Johnson *et al.* (1955):

Genetic gain (genetic advance as percentage of mean)

$$\text{G.G.} = \frac{GA}{\overline{X}} \times 100$$

Where, GA = Genetic advance

Genetic advance is the shift in a population towards superior side under some selection pressure. It was measured by the following formula suggested by Lush (1949) and Johnson *et al.* (1955) at 5 per cent selection pressure using the constant K as 2.06 given by Allard (1960).

$$GA = K \frac{\overline{X}}{\bar{i}} \frac{Vg}{Vph} \frac{\overline{X}}{\bar{i}} \sqrt{Vph}$$

Where,	Vg	=	Genotypic variance,
	Vph	=	Phenotypic variance,
	K	=	Selection differential at 5 per cent and
	$\overline{X}$	=	Population mean of the character under study

iii Correlation coefficients

Genotypic and phenotypic correlation coefficients of seed yield with its contributing characters namely days to 50 per cent flowering, days to 75 per cent maturity, plant height, primary branches per plant, umbels per plant, umbelates per umbel, seeds per umbelets, biological yield per plant, test weight and oil content. The genotypic and phenotypic variance and covariance values were calculated by using in the formula suggested by Fisher (1954) and Al Jibouri *et al.* (1958). These genotypic and phenotypic covariances were worked-out between pairs of characters with the analysis techniques as used for variance calculation. Mean product expectations of covariance analysis are analogues of the mean square expectation of the analysis of variance.

(a) Genotype correlation coefficient

$$r_{xy}(g) = \frac{Cov.xy(g)}{\sqrt{Vx(g).Vy(g)}}$$

(b) **Phenotypic correlation coefficient**

$$r_{xy}(ph) = \frac{Cov.xy(ph)}{\sqrt{Vx(ph).Vy(ph)}}$$

Where,

$r_{xy}(g)$	=	Genotypic correlation between x and y traits
$r_{xy}(ph)$	=	Phenotypic correlation between x and y traits
Cov. $_{xy}$ (g)	=	Genotypic covariance for x and y traits
Cov. $_{xy}$ (ph)	=	Phenotypic covariance for x and y traits
$V_x(g)$	=	Genotypic variance for x traits
$V_y(g)$	=	Genotypic variance for y traits
V_x (ph)	=	Phenotypic variance for x traits
V_y (ph)	=	Phenotypic variance for y traits

The significance of correlation was tested by formula:

$$t = \frac{r}{\sqrt{1-r^2}}.\sqrt{n-2}$$

Where,

r	=	Correlation coefficient
t	=	Test of significance, and
n	=	Total no. of observations

The calculated value of 't' (cal.) were tested against the tabulated values of 't' with (n-2) d.f. at 0.1 and 0.5 level of significance.

(iv) path coefficient analysis:

path coefficient can be defined as the ratio of the standard deviation of the effect due to given cause to the total standard deviation of the effect i.e., if y is the effect and x is the cause, the path coefficient for the path from cause x_1 to the effect y_1 is $\sigma x_1/\sigma y_1$.

The principles and techniques suggested by Wright (1921) and Dewey and Lu (1959) to assess direct and indirect effects are followed using genotypic correlation. The path coefficients were determined for seed yield by using eight variables were

days to plant height, primary branches per plant, umbels per plant, umbelates per umbel, seeds per umbelet, biological yield per plant, test weight and oil content and path coefficient calculated at genotypic and phenotypic level over pooled basis.

Eleven simultaneous equations generated were presented in matrix from and solved as per procedure given below

$$
\begin{array}{lll}
R_{1\,Y} & r_{1\,1}\, r_{1\,2} \ldots\ldots\ldots\ldots\ldots r_{1\,10} & P_{1\,Y} \\
R_{1\,Y} & r_{1\,1}\, r_{2\,2} \ldots\ldots\ldots\ldots\ldots r_{2\,10} & P_{2\,Y} \\
. & \ldots\ldots & \ldots \\
. & \ldots\ldots & \ldots \\
. & \ldots\ldots\ldots & \ldots\ldots \\
R_{10\,Y} & r_{10\,1}\, r_{10\,2} \ldots\ldots\ldots\ldots\ldots r_{10\,10} & P_{10\,Y}
\end{array}
$$

or

$$A = B.C.$$

Value of C vectors were obtained as $C = B^{-1}.A$

Where B^{-1} is the inverse of mutual correlation matrix of character. The inversion matrix was carried out by pivotal condensation method.

The residual effect was computed from the following algebraic relationship:

$$1 = R^2 + r_1 Y P_1 Y + r_2 Y P_2 Y + r_3 Y P_3 Y + r_4 Y P_4 Y + r_5 Y P_5 Y + r_6 Y P_6 Y + r_7 Y P_7 Y + r_8 Y P_8 Y + r_9 Y P_9 Y + r_{10} Y P_{10} Y$$

$$R = \sqrt{1 - (r_1 Y P_1 Y + r_2 Y P_2 Y + r_3 Y P_3 Y + r_4 Y P_4 Y + r_5 Y P_5 Y + r_6 Y P_6 Y + r_7 Y P_7 Y + r_8 Y P_8 Y + r_9 Y P_9 Y + r_{10} Y P_{10} Y}$$

Where, R = Residual effect

v. Stability parameters:

In the present study the data obtained for 11 characters for 4 environments were analyzed to estimate the stability parameters following the model of Eberhart and Russell (1966).

According to this model a genotype is said to be stable with unit regression coefficient ($b \approx 1.0$) and the deviation from regression not significantly different from

zero ($s^2d=0$) with high mean value. Eberhart and Russell used the following model to study the stability of varieties under different environments (Singh and Choudhary, 1979).

The statistical model of the analysis was as follows:

$$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij}$$

Where,

Y_{ij}= Mean performance of ith genotype in j^{th} environment

μ_i = Mean of ith genotype over all the environments

β_i = The regression coefficient of ith genotype on the environmental index which measures the response of this genotype to varing environments.

δ_{ij} = The deviation from regression of the ith genotype at the jth environment.

I_j = The environmental index which is defined as the deviation of all the varieties at a given location from the overall mean, and it can be obtained as the mean of all the varieties at the jth environment minus the grand mean.

$$I_j = \frac{\sum_i Y_{ij}}{n} - \frac{\sum_i \sum_j Y_{ij}}{V\,n}$$

With

$$\sum_j Ij = 0$$

Where,

$\sum_i Y_{ij}$ = Total of all the varieties at j^{th} environment

$\sum_i \sum_j Y_{ij}$ = Grand total

V = Number of varieties

n = Number of environments, and

δ_{ij} = The deviation from regression of the ith variety at the jth environment

The two parameters of stability were computed as follows:

(a) Regression coefficient (b_i):

The regression coefficient is the regression of the performance of each genotype under different environments on the environmental means over all the genotypes. It was estimated as follows:

$$b_i = \frac{\sum_{j=1}^{l} Y_{ij} \times I_j}{\sum_{j=1}^{l} I_j^2}$$

b_i = Regression coefficient of ith genotype

$\sum_i Y_{ij}$ = Sum of products of replication mean of ith genotype in the varing environment with corresponding environmental index. (i.e. $\sum Y_{ij} \times I_j = |X| \, |I_j|$, and

$\sum_j I^2 j$ = Sum of square of environmental index

(b) Mean square deviation (s2d) from mean regression:

This parameters of stability was estimated as follows:

$$S_{di}^2 = \left(\frac{\sum_{j=1}^{l} \hat{\delta}_{ij}^2}{n-2} \right) - \frac{S_e^2}{r}$$

Where,

S^2_e = Estimate of pooled error mean square and

$$\sum_j^l \hat{\delta}_{ij}^2 = \left(\sum_{j=1}^{i} Y_{ij}^2 - \frac{Y_i^2}{l} \right) - \frac{\left(\sum_{j=1}^{i} Y_{ij}^2 . I_j \right)^2}{\sum_{j=1}^{i} I_j^2}$$

$\delta^2 e$ = The estimate of pooled error.

$\sum_j Y^2_{ij}$ = Sum of square of replication mean values of ith genotype over all the environment

n = Number of environments

This model provides the mean of partitioning the genotype x environment interaction of each genotype into components.

(i) The variation due to response of a genotype to a varing environmental index (sum of square due to regression), and

(ii) The unexplainable deviation from the regression on the environmental index

(c) Pooled analysis of variance:

The appropriate pooled analysis of variance is given in Table 3.2. In this analysis, the sum of square due to location and genotype x location are partitioned into location (linear) genotype x location (linear) and deviation from regression (i.e. pooled deviation).

The significance of the above estimates were tested as follows (Singh and Choudhary, 1985).

a) The significance of the difference among genotype means i.e.

$$H_0 = \mu_1 = \mu_2 = \ldots\ldots\ldots\ldots\ldots\ldots = \mu_v$$

It can be tested by the appropriate 'F' test

$$F = MS1/MS2$$

b) To test, that the genotypes do not differ their regression on environmental index

$$Ho = b1 = b2 = \ldots\ldots\ldots\ldots\ldots = bv$$

$$\text{Pooled error} = \frac{(n_i + 1)(\text{M.S.error } E_i) + \ldots + (n_i - 1)(\text{M.S.error} E_j)}{(n_1 - 1) + (n_2 + 1) + \ldots + (n_j - 1)}$$

Where, $(n_i - 1)$ = d.f. of error in environment i

$(n_j - 1)$ = d.f. of error in environment j

M.S. error Ej = M.S. due to error for j^{th} location.

It can be tested by appropriate 'F' test.

$$F = MS3/MS4$$

c) An appropriate test of the deviation from regression for each genotype was tested by

$$F = [(\sum_j \delta^2_{ij})/n-1)]/\text{pooled error}$$

d) To test that the individual regression coefficient (bi) do not differ from unity (ostle, Bernerd, and Richard W. Mensing, 1975) i.e.,

$Ho = bo = 1$

It can be tested by appropriate ‘t’ test as:

$t = bi – bo/SE$ of b with (n-2)d.f.

Where,

n = number of location

Assuming homogeneity between all individual regression coefficient SE of b in place of SE of b is used to test the significance of b where b is overall regression coefficient considering all the genotypes together

Table 3.2: Analysis of variance for estimating stability parameters (Eberhart and Russell, 1966)

Source	d.f.	SS	MS
Genotypes	(v -1)	$1/n \sum_i Y_i^2 - C.F.$	MS_1
Environments	(n -1)	$1/v \sum_i Y_i^2 - C.F.$	
Genotypes x Environments	(v -1) (n – 1)	$1/v \sum_i \sum_j Y_{ij}^2 - (\sum Y_i^2/n)(\sum Y_i^2/v) + C.F.$	MS_2
Environment + (Genotypes x environment)	V (n – 1)	$\sum\sum Y_i^2 - (\sum Y_i^2/n) - (\sum Y_i^2/n)$	
Environment (linear)	1	$1/v (\sum_i Y_j \sum I_j)^2 / \sum_j I^2_j$	
Genotype x Environment (Linear)	(v-1)	$\sum_i (\sum_j Y_{ij} I_j)^2 / \sum_j I^2_j$ – Env. Linear S.S.	MS_3
Pooled deviation	v (n-2)	$\sum_i \sum_j \delta_{ij}^2$	MS_4
Pooled deviation due to genotype	(n – 2)	$\sum_j Y_{ij} - (Y_i)^2/n - (\sum_j Y_{ij} I_j)^2_j / \sum I_j^2 - \sum \delta_{ij}^2$	
Pooled error	n (r-1) (v-1)		

4. RESULTS AND DISCUSSION

In the present study, entitled **"Stability analysis in Ajwain (*Trachyspermum ammi.* L.)",** an attempt was made to estimate various genetical parameters, association among various characters, direct and indirect effect of various characters on seed yield and stability analysis in Ajwain. This would not only help in framing an effective breeding programme but also result in making certain improvement in the yield levels and quality of Ajwain. Further this would lead to successful evaluation of phenotypically stable and superior varieties which could be used for commercial production.

The results obtained in the present study are presented and discussed under the following heads.

4.1. *Per se* performance

4.2. Pooled Analysis of variance over the environments

4.3. Variability parameters

4.4. Correlation coefficients

4.5. path coefficient analysis

4.6. Stability parameter

4.1 *Per se* performance

The overall mean performance of all the genotypes with respect to individual characters is presented in Appendix II. The character wise description is being given as under.

(i) Days to 50 per cent flowering

A perusal of the data presented in Appendix II showed that the mean days to 50 per cent flowering was 76.43 days. The genotypes UA-53 (74.5) and UA-41 (75.25 days) followed by UA-127, UA-168, UA-71, UA-90, UA-48, UA-131 and UA-175 (75.83 days) exhibited lower days to 50% flowering. The means of days to 50 per cent flowering of genotypes ranged from (74.5 days) to (78.83 days).

(ii) Days to 75 per cent maturity

The overall mean recorded for days to 75 per cent maturity was 165.22 days. The minimum days to 75 per cent maturity were recorded in Local check (162.33 days) followed by genotypes UA-113 (162.43 days), GA-1 (163.49 days) and UA-1 (163.84 days). The mean of days 75 per cent to maturity of genotypes ranged from (162.33 days) to (168.01 days).

(iii) Plant height

The perusal of data showed that genotype UA-70 (92.67 cm) and UA-28 (93 cm) both had minimum plant height whereas the UA-32 (103.92 cm) had maximum plant height. Overall mean recorded for the trait was 97.35 cm. The genotypes UA-90 (94.67 cm) and UA-30 (95.08 cm), UA-125 (95.17 cm), UA-63 (95.92cm),UA-53 (96.17 cm), UA-7 (96.33 cm) and UA-41 (96.92 cm), and most of the genotypes exhibited lower height than the check GA-1 (98.25 cm).

(iv) Number of primary branches per plant

The perusal of data showed that the average number of primary branches per plant for the experiment was observed 10.65. The genotypes UA-30, UA-149, UA-169 and a local check had maximum number of primary branches per plant (11.67), whereas, minimum number of primary branches per plant emerged in UA-7, UA-29, UA-71 and UA-83 (9.67).

(v) Number of umbels per plant

Maximum number of umbels per plant was recorded in check GA-1 (146.30) followed by check UA-1 (141.08) and genotype UA-32 (139.33), UA-149 (136.08). The genotype UA-29 had minimum number of umbels per plant (93.50). The average number of umbels per plant for the experiment was observed 118.17.

(vi) Number of umbeletes per umbel

Maximum number of umbelets per umbel were recorded in genotype UA-191 (11.75) followed by UA-168 (11.58), UA-87 (11.33), UA-32 (11.17) whereas, minimum number of umbeletes produced in UA-41 (8.92). The overall general mean for character umbeletes per umbel was recorded 10.53.

(vii) Number of Seed per umbelet

The general mean value for number of seeds per umbelets were 20.73. The check GA-1 exhibited maximum number of seeds per umbelet (22.92) followed by check UA-1 (22.54) while both UA-191 (22.5) and UA-41 (22.5) produced same number of seeds per umbelet. Whereas, minimum number of seeds per umbelet was observed in UA-66 (14.91).

(viii) Biological yield per plant (g)

The check UA-1 had maximum Biological Yield (29.10g) followed by genotype UA-66 (28.07g) and local check (27.96g) whereas, minimum biological yield recorded in genotype UA-169 (22.92g). The general mean value of this trait was 26.29g.

(ix) Seed yield per plant (g)

The seed yield per plant ranged from 9.78g to 11.02g indicating significant variability among genotypes and eleven genotypes had higher seed yield than general mean (11.14 g).The genotype UA-66 had maximum seed yield per plant (12.07 g) followed by UA-63 (11.95 g) and UA-7 (11.81 g) whereas, minimum seed yield was recorded in UA-169 (8.26 g)

(x) Test weight (g)

The general mean value for Test weight was 1.13g. The genotype UA-66 had maximum 1000 seed weight 1.22g while, genotype UA-29, UA-48, UA-83 had similar 1000 seed weight (1.19g) whereas, minimum 1000 seed weight was recorded in UA-125 (1.02g).

(xi) Oil content (%)

The maximum oil content was recorded in the genotype UA-32 (4.42 %) followed by UA-191 (4.17 %) and UA-70 (4.08 %). The genotype UA-149 had lowest oil content (2.42 %).The general mean value of this trait was 3.45 %.

Mean performance of the best Ajwain genotypes at both location as well as their consistent and high *per se* performance in all the four environments and over pooled basis for eleven characters are given Table 4.1

4.2 Pooled analysis of variance over the environments:

Analysis of variance was done for all the eleven characters studied and their mean square values are presented in Table 4.2. The replication mean sum of squares was significant for number of primary branches per plant, number of umbels per plant, number of umbeletes per umbel, number of seeds per umbelet, biological yield per plant, seed yield per plant and test weight and oil content while mean sum of squares due to genotypes was highly significant for the characters *viz.*, plant height, number of primary branches per plant, number of umbels per plant, number of umbeletes per umbel, number of seeds per umbelet, biological yield per plant, seed yield per plant, test weight and oil content. The overall analysis of ANOVA indicated the presence of ample genetic variability available in the experimental material under study that can be further exploited for Ajwain improvement.

As revealed from analysis of variance the genotype do not differ significantly from each other for the characters days to 50 per cent flowering, days to 75 per cent maturity. Therefore these characters were not included for further explanation under result and discussion

4.3 Variability parameters

The genetic variability present in the population is a prerequisite for progress of any breeding programme. Assessment of genetic variability in the base population is the first step in any breeding programme. It provides not only basis for selection but also provide some valuable information regarding selection of diverse parents to be used in hybridization programme. Since environment has a great impact on many quantitative characters, it becomes essential to measure error by analysis of variance. The observed variability may be grouped under heritable and non-heritable components with the help of suitable parameters like genotypes coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability, genetic advance as percent of mean (genetic gain) so as to give basis for selection to breeders. The genetic variability along with heritability gives a reliable picture of the genetic advance to be expected for selections while the heritability, coupled with genetic advance aids in predicting the valuable conclusion for effective selection based on phenotypic performance. In any crop improvement programme, existence of variability and selection of genotypes with

due selection pressure on yield component characters is of prime importance. The variability parameters certainly determine the extent and quality of variability.

In the present study, an attempt was made to work out the magnitude of variability both at phenotypic and genotypic level for different characters by estimating variance and corresponding coefficient of variation. The estimates of various variability parameters viz., GCV, PCV, heritability and genetic advance as percent of mean are given in Table 4.5**.**

4.3.1 Phenotypic coefficient of variation

Magnitude of genotypic variability is measured in terms of phenotypic coefficient of variance (PCV). It provides a direct comparison of variability between different traits.

The highest phenotypic coefficient of variation was observed for oil content (17.36 %) followed by number of umbels per plant (14.83 %) and seeds per umbelet (11.42 %) whereas biological yield per plant (8.39 %) and test weight (7.49 %) had low phenotypic coefficient of variation over pooled basis.

In general, estimates of phenotypic coefficient of variation (PCV) was slightly higher than their corresponding genotypic coefficient of variation (GCV) for all the characters indicating the role of environment in the expression of the characters. Low difference between GCV and PCV indicated that variability was primarily of genotypic in nature.

4.3.2 Genotypic coefficient of variation

The existence of high magnitude of genetic variability was evident through high values of genotypic coefficient of variation for majority of the characters. The highest genotypic coefficient of variation was observed for oil content (15.35 %) followed by number of umbels per plant (9.11 %) and seeds per umbelet (9.01 %) over pooled basis, indicating the presence of genetic variability for the traits. The characters *viz.*, number of umbeletes per umbel (4.66 %) and test weight (5.11 %) exhibited lower genotypic coefficient of variation in over pooled basis.

These findings of the experiment are also supported by the similar trends of result by Dhayal *et al.*(1999) in cumin, Singh and Choudhary (2008), Dalkani

et al. (2012), Singh and Mittal (2002) in fennel and Rajput and Singh (2003) in coriander, Ghanshyam *et al.*(2015) in ajwain.

4.3.3 Heritability

Heritability represents the proportion of total variation transmitted to the progenies. Hence, characters having higher value of GCV coupled with greater heritability can be improved through selection. In the present investigation the heritability was estimated in broad sense. The results indicated that the heritability was high for most of the characters studied.

In the present study high estimates of heritability were observed for oil content (78.20 %), number of seeds per umbelet (62.25 %), test weight (46.54 %) seed yield per plant (41.37 %) over pooled basis, indicate a close agreement between genotype and phenotype for the expression of these characters under prevailing environmental condition. These trends of results indicate less influence of the environment in the expression of these traits. Such traits are more suited to selection for crop improvement. These findings of the experiment are also supported by the similar trends of result by Meena *et al*. (2014) in coriander, Dashora and Sastry (2011) in fennal, Singh and Choudhary (2008), Krishnamoorthy and Madalageri (2002) in ajwain, Singh and Mittal (2002) in fennel and Singh *et al.* (2006) in coriander.

4.3.4 Genetic advance as percent of mean (Genetic Gain)

Genetic advance as per cent of mean is expressed as genetic gain. The highest genetic gain was observed for oil content (27.97 %) followed by seeds per umbelets (14.64 %) and number of umbels per plant (11.52 %). The magnitude of genetic gain was medium for seed yield per plant (8.69) over pooled basis. Very low estimates of genetic gain was recorded in plant height (2.84 %).

Johnson *et al.* (1955) reported that the character having higher quantum of genetic variability along with the high heritability and greater genetic gain can be easily improved through selection. panse (1957) also suggested that the characters which have high heritability with high genetic gain are expected to have greater proportion of additive gene effects.

In present investigation, characters like oil content, number of umbels per plant, seeds per umbelets and biological yield per plant showed higher estimates

of genetic parameters over pooled environments basis thereby indicating that selection can be practiced efficiently for these characters.

Burton (1952) suggested that GCV along with heritability estimates would give a better idea about the efficiency of selection and such characters would be more valuable in the selection programme. Heritable variation can be found out with greater accuracy when heritability is calculated in conjunction with genetic advance studies. In the present investigation, the characters like oil content, number of umbels per plant, seeds per umbelets, and seed yield per plant expressed high GCV along with higher values of heritability (more than 65%) suggesting that these characters could be utilized for selection programme with a fair degree of success.

It is also observed that the characters like oil content, number of umbels per plant, seeds per umbelet, biological yield per plant and seed yield per plant exhibited high GCV also possesses high genetic gain indicating preponderance of additive gene effect for these characters. The characters like number of primary branches per plant and number of umbeletes per umbel though exhibited moderate heritability but possessed low estimates of genetic gain might be because of low variability existing for these characters in the material taken for study.

4.4 Correlation Coefficient :

The knowledge of genetic correlation for seed yield, its components and various quality characters become very important when the breeder is confronted with problems of combining high yield potential with desirable agronomic and quality parameters. Association studies would provide reliable information on nature, extent and direction of selection.

Genotypic and phenotypic correlation coefficient of different characters with seed yield, and among themselves was estimated in the present study for each location using variance techniques.

Table 4.6 clearly indicated that, in general, a close agreement existed between genotypic and phenotypic correlation for at least nine characters over pooled environments. It was further noticed that almost all characters exhibited slightly higher genotypic correlation in comparison to their corresponding phenotypic correlation in all the sets of experiments. This revealed that the

environmental factors affected both variables taken at a time at random indicating lack of correlation at environmental level.

In the present study as obvious from Table 4.6, seed yield per plant showed significant positive genotypic and phenotypic correlated with biological yield per plant and test weight in over the environment. Seeds per umbelet showed positive phenotypic correlation with number of umbels per plant..

Similar trends of results were supported by Dalkani *et al.* (2011) in ajwain, In coriander, positive correlation for most of the traits with seed yield per plant, has been reported (Singh *et al.* 2006 and Singh & Prasad 2006).

Variable results were observed with respect with correlations between different characters in all the four environments and over pooled basis [Table 4.6]. Number of umbels per plant and number of seeds per umbelet, showed genotypic correlation with each other in over pooled environments. Plant height showed phenotypic correlation with Days to 75 per cent maturity over pooled environments.

Seed yield per plant showed significant and negative association with seeds per umbelets, and test weight over pooled environments at genotypic level.

On the basis of association studies, it could be concluded that seed yield per plant in Ajwain was correlated with biological yield, test weight, number of primary branches per plant and oil content over pooled environments. Most of these characters were also correlated. Hence simultaneous selection for all these would result in the genetic improvement of seed yield in Ajwain.

4.5 Path Coefficient Analysis :

Information obtained from correlation studies does not provide a clear picture of contribution of each component characters. At the same time as more variables are included in association studies, the direct associations become complex and important. Under such situations path coefficient analysis has been useful in partitioning direct and indirect causes of correlation and allows a detailed examination of specific forces acting to produce a given correlation. path analysis at the same time also measures the relative importance of each causal factor. Hence this study provides a realistic basis for allocation of weightage to each attribute in deciding a suitable criterion for genetic improvement.

path coefficient was computed for seed yield using genotypic correlation only for four environments at two location in two years (Table 4.7). The characters analyzed for this study were plant height, number of primary branches per plant, number of umbels per plant, number of umbelets per umbel, number of seeds per umbelet, biological yield per plant, test weight and oil content.

As observed from correlation study, biological yield per plant, test weight, number of primary branches per plant and oil content were associated with seed yield at genotypic levels over pooled environments.

However, Table 4.7 reveals direct and indirect contribution of component characters on seed yield per plant. Maximum direct effects on seed yield was recorded by biological yield per plant followed by number of primary branches, plant height, number of umbelets per umbel over pooled environments. These characters showed positive genotypic correlations and high direct effects because of their indirect contribution through one another and also through biological yield per plant, test weight, number of umbels per plant, seeds per umbelet and number of primary branches over pooled environments.

Test weight also showed positive indirect effect with biological yield per plant. Seeds per umbelet showed positive indirect effect with test weight and plant height.

Characters like plant height, number of umbelets per umbel, seeds per umbelet showed negative indirect effect with oil content over pooled environments. Negative effects of number of primary branches were on account of indirect contribution to majority of characters towards negative direction and its insignificant association with seed yield.

Further, on the basis of variability parameters, correlations and path analysis number of seeds per umbelet, biological yield per plant, oil content, test weight turned out to be the most important contributing characters for enhancing yield in Ajwain as they showed high to moderate GCV as well as high heritability at all the environments. Hence due emphasis should be given to these characters.

Residual effect

The residual effect on seed yield per plant was 0.17 indicated that 99.83 per cent of variability was governed by above said characters and 0.17 per cent variability was due to environment effect.

It revealed from the path analysis for seed yield that biological yield per plant (1.61) exhibited maximum positive direct effect on seed yield. Higher positive indirect effect of test weight on seed yield exhibited via biological yield per plant and seeds per umbelet via test weight was 1.47 and 0.40 respectively.

Higher negative direct effect of number of umbels per plant (-0.56) on seed yield and plant height show negative indirect effect on seeds per umbelet *via* biological yield per plant.

However as revealed from the Table 4.7, the characters like biological yield per plant, test weight, seeds per umbelet can be selected for further crop improvement in Ajwain.

4.6 Stability parameters :

Phenotypically, stable varieties are usually sought for commercial production of crop plants. In breeding programme also it is necessary to screen and identify phenotypically stable genotypes. Stability of a genotype refers to its performance with respect to changing environmental factors over time with given environments. Several workers have emphasized the importance of evaluating the materials under more than one environment to get information on the relative magnitude of components of variance. The interaction between genotypes and environment gives rise to an additional variance component of the total phenotypic variance. The different source of variation including the genotypes-environment interaction variance are of great practical importance to the plant breeder for deciding the appropriate testing and selection procedure for planning an efficient breeding programme.

The component of genotype x environment interaction are linked with genetic variance and exhibit an upward bias in the estimation of genetic variance and heritability when evaluated only in one environment, which leads to discrepancies between expected and realized response to selection (Allard and Bradshaw, 1964). Further the contribution of micro-environment in the final expression of a genotype is usually very small. Moreover, owning to the

unpredictable and uncontrollable nature of the micro environment its interaction with genotype can't be properly and precisely assessed. Thus it is only the macro environment and its interaction with the genotype that can be isolated and studied (Prabhakaran and Jain, 1992).

Twenty eight genotypes of Ajwain were evaluated for their stability performance in four environments at two locations for 11 characters using the Eberhart and Russell (1966) assumption.

As evident from Table 4.8 mean squares due to genotypes were significant for all the characters except days to 50 per cent flowering and days 75 per cent to maturity, reveals from the analysis of variance that the genotypes do not differ significantly from each other for days to 50 per cent flowering and days 75 per cent to maturity. Therefore, these characters were not included for further explanation under result.

G x E interaction variance were significant for all the characters except days to 50 per cent flowering, days to 75 per cent maturity and plant height, revealing that genotype responded differentially by planting them at different environments. Significant G x E interaction of different characters were also reported by Ali *et al.* (1999), Verma *et al.* (2014), Singh and Shah (2003) in coriander, Kole (2005) in fenugreek, Lal (2008) in fennal.

The pooled analysis of variance (Table 4.8) also exhibited significant linear as well as non-linear components of G x E for almost all the characters. This indicated that genotypes differed considerably with respect to their stability and the prediction of their performance over locations would be difficult.

The prediction of performance with regards to different environment was made on the basis of assumption laid by Eberhart and Russell (1966) considering both linear (b) and non-linear (S^2d) components of G x E interaction in judging stability of genotypes. Accordingly, an ideal adaptable genotype would be one having high mean value, $b \approx 1$ and $S^2d = 0$. However, other measures of stability have also been used by various scientists. Earlier, Finlay and Wilkinson (1966) used simple linear regression as a quantitative measure of stability. Later Breese (1969), Samual *et al.* (1970) and paroda and Hayes (1971) emphasized that 'b' could simply be regarded as a measure of response of a particular genotype

whereas S^2d is the most suitable measure of stability. This approach has been followed in the present study.

For plant height one Ajwain genotype UA-131 showed significant deviation and were highly stable. Plant height ranged from 92.67 cm (UA- 70) to 103.92 cm (UA-32) with a population mean of 97.35 cm (Appendix II). UA-131, UA-87, UA-191 and Pratap Ajwain-1 showed b > 1 highly stable. Ali *et al.*(1999), Singh and Shah (2003) in coriander, Gangopadhayay *et al.* (2011) in fenugreek also identified stable varieties for different environmental conditions.

Fourteen genotypes had greater branches per plant than the population mean 10.25 with UA-30 with the maximum. Four genotypes showed significant S^2d values and were thus stable (Table 4.9). UA-191 was highly responsive to environmental changes (b > 1) with high *per se* performance hence suitable to high fertility conditions. UA-48, UA-53 showed poor response to environmental changes (b < 1) with high *per se* performance.

For number of umbels per plant, eight Ajwain genotypes showed significant S^2d values ranging from 87.048 (UA-125) to 595.395 (UA-149). Both the components of G x E interaction were significant (Table 4.10). UA-169, UA-149 and UA-175 had higher number of umbels per plant with greater responsiveness. Verma *et al.* (2014) in coriander identified stable varieties for different environmental conditions.

Number of umbelets per umbel, four genotypes showed significant S^2d values. UA-7, UA-32 and UA-90 had higher no of umbelets per umbel with greater responsiveness (b>1) and higher *per se* performance.

UA-32, UA-41, UA-48, UA-90, UA-113, UA-125, UA-127 and UA-149 had higher seeds per umbelet with greater responsiveness (b>1) and high *per se* performance while UA-1, GA-1, UA-63, UA-66, UA-71, UA-83, UA-168 and UA-169 showed high *per se* performance with (b<1) responsiveness (Table 4.10).

UA-7, UA-48, UA-63, UA-70 and UA-125, had higher biological yield per plant with greater responsiveness (b>1) and higher *per se* performance while UA-28, UA-32, UA-41, UA-66, UA-83, UA-87, UA-90 and UA-175 showed high *per se* performance with (b<1) responsiveness (Table 4.10).

For seed yield per plant, two Ajwain genotypes showed significant S^2d and twenty one exhibited significant regression coefficient (Table 4.10). Ali et al. (1999) in coriander, Kole (2005) and Gangopadhayay *et al*. (2011) in fenugreek, Lal (2008) in fennal also identified stable varieties for different environmental conditions.

For test weight, fourteen genotypes exhibited significant regression coefficient (Table 4.11). UA-7, UA-32, UA-48, UA-53, UA-63, UA-70 showed high *per se* performance with greater responsiveness (b > 1) and was identified as stable for high management condition while UA-71 high *per se* performance with low responsiveness (b < 1) and was stable, suited for unfavourable/stress environments.

For Oil content, six genotype of Ajwain showed significant S^2d and twelve exhibited significant regression coefficient (Table 4.11). UA-7, UA-29, UA-48, UA-30, UA-32, UA-113, UA-169 GA-1 had higher oil content with greater responsiveness coefficient (b>1) and high *per se* performance while Local check showed high *per se* performance with (b<1) responsiveness. Kaya *et al.* (2000), Singh and Shah (2003) in coriander, Lal (2008) in fennal identified stable varieties for different environmental conditions.

Hence from the present study, it could be concluded that genotypes UA-7, UA-32, UA-48 and UA-113 displayed high *per se* performance, above average response and stability for at least two important characters like umbelets per umbel, seeds per umbelet, seed yield per plant, oil content while UA-63, UA-66, UA-131 and UA-141 displayed high *per se* performance, below average response and stability at least two important characters like seed yield per plant, biological yield per plant, oil content (Table 4.12). It is interesting to note that each genotypes exhibited its superior performance for other important response yield contributing characters besides above which revealed that stability is imparted by its component traits.

Overall conclusion of the present study based on stability parameters which classified the varieties for different situation revealed superiority of UA-7, UA-32, UA-48 for seed yield as well as their important components under varying climatic conditions. While UA-63, UA-66, UA-141 and UA-168 could be

gainfully utilized in Ajwain quality improvement programmes. Therefore, these Ajwain genotypes could be recommended for direct cultivation or could be used in hybridization programme for different management practices.

Table 4.1: Best performing genotypes identified for four environments and pooled over the environments for different characters studied in Ajwain.

Characters	Best Varieties suited to different environments					Varieties/strains showing consistent/ uniform high *per se* performance
	E_1	E_2	E_3	E_4	P	
Days to 50% flowering	UA- 41	UA- 53	UA- 53	UA- 53	UA- 53	UA- 53, UA- 41, UA- 127, UA- 168
Days to 75% maturity	Local check	GA-1	UA- 41	UA- 127	Local check	Local check
Plant height	UA- 131	UA- 32	UA-191	UA- 71	UA-32	UA- 32
Primary Branches per plant	UA- 113	UA-30	UA- 30	UA- 30	UA- 30	UA- 30, UA- 149, UA- 169
Umbels per plant	GA-1	UA-1	GA-1	GA-1	GA-1	GA-1, UA-1, UA- 32
Umbelets per umbel	UA- 191	UA- 191	UA- 87	UA- 169	UA- 191	UA- 191, UA- 168, UA- 87
Seeds per umbelets	GA-1	GA-1	UA-191	GA-1	GA-1	GA-1, UA-1, UA- 191
Biological yield per plant	Local check	UA-1	UA-1	Local check	UA-1	UA-1, UA- 66, LC
Seed yield per plant	UA- 29	UA- 63	UA- 48	UA- 66	UA- 66	UA- 66, UA- 63, UA- 7
Test weight	UA- 29	UA- 7	UA- 7	UA- 7	UA- 7	UA- 66, UA- 29, UA- 7
Oil content	UA- 32	UA- 32	UA- 32	UA- 32	UA- 32	UA- 32, UA- 191, UA- 70

E_1, E_2, E_3, E_4 represent environment at Udaipur, Pratapgarh (2013), and Udaipur, Pratapgarh (2014), respectively.

Table 4.3: Analysis of variance showing mean sum square for different characters studied in Ajwain pooled over the environments

Characters	Environment	Rep/Env	Genotype	G x E	Pool Err
	[3]	[8]	[27]	[81]	[216]
Day to 50% flowering	4.8788	5.1388	9.4498	3.1506	21.61
Days to 75% maturity	188.9133	8.1806	28.3347	3.5018	108.6
Plant height (cm)	22.7433	25.9750	120.8904**	20.7589	35.12
No of primary branches	68.1010**	0.4274	4.4295**	1.2071**	0.3321
No of umbels per plant	396.1201**	35.0570	1819.8630**	429.9441**	71.86
No of umbelets per umbel	73.0160**	0.6406	4.8376**	1.9503**	0.528
Seeds per umbelet	60.6222**	0.8979	43.7769**	1.9273	2.209
Biological yield per plant (g)	13.1267**	4.1223	25.3336**	2.5851	3.159
Seed yield per plant (g)	5.9464**	0.8136	7.6584**	1.2510**	0.5094
Test weight (g)	0.0340**	0.0058	0.0411**	0.0011	0.005193
Oil content (%)	4.8513**	0.0904	3.4952**	0.1346**	0.0498

*, ** significant at 1% and 5% level, respectively

Table 4.5: Coefficient of variation (CV), genotypic coefficient of variation (GCV), Phenotypic coefficient of variation (PCV), heritability (broad sense), genetic advance, genetic gain (genetic advance as percentage of mean) for different characters studied in Ajwain for four environments and over pooled basis

Characters	Env	GCV	PCV	CV	H^2	GA	GG
Plant height (cm)	E1	1.02	6.67	6.59	2.34	0.31	0.32
	E2	0.00	6.58	6.62	-1.09	-0.14	-0.15
	E3	2.63	6.01	5.40	19.17	2.32	2.37
	E4	2.76	6.28	5.64	19.31	2.41	2.50
	Pool	2.97	6.39	6.09	21.57	2.76	2.84
No of primary branches	E1	6.57	9.26	6.52	50.39	0.88	9.61
	E2	5.08	8.13	6.35	39.00	0.64	6.53
	E3	12.36	14.43	7.44	73.41	1.74	21.81
	E4	10.38	12.12	6.26	73.37	1.44	18.32
	Pool	5.98	10.89	6.65	30.10	0.59	6.75
No of umbels per plant	E1	12.58	14.18	6.54	78.70	26.96	22.98
	E2	12.04	13.51	6.12	79.50	25.63	22.12
	E3	12.15	14.30	7.55	72.16	25.21	21.26
	E4	14.81	16.92	8.20	76.55	32.29	26.69
	Pool	9.11	14.83	7.17	37.72	13.62	11.52
No of umbelets per umbel	E1	7.36	9.66	6.25	58.13	1.13	11.57
	E2	7.37	9.90	6.61	55.43	1.15	11.30
	E3	10.78	13.19	7.60	66.81	2.16	18.15
	E4	3.58	7.58	6.68	22.37	0.36	3.49
	Pool	4.66	10.59	6.90	19.36	0.44	4.22
Seeds per umbelet	E1	10.61	12.92	7.37	67.47	3.59	17.95
	E2	9.44	11.89	7.23	63.04	3.09	15.44
	E3	7.98	10.17	6.31	61.53	2.79	12.89
	E4	7.47	10.76	7.73	48.29	2.28	10.70
	Pool	9.01	11.42	7.17	62.25	3.04	14.64
Biological yield per plant (g)	E1	6.32	9.37	6.93	45.41	2.26	8.77
	E2	5.02	8.37	6.69	36.02	1.64	6.21
	E3	4.31	8.23	7.01	27.47	1.24	4.66
	E4	3.97	7.53	6.40	27.80	1.13	4.31
	Pool	5.24	8.39	6.76	38.98	1.77	6.74
Seed yield per plant (g)	E1	11.27	13.07	6.61	74.42	2.15	20.03
	E2	7.22	9.71	6.48	55.39	1.24	11.07
	E3	6.22	8.71	6.10	51.02	1.04	9.16
	E4	6.28	8.99	6.44	48.74	1.02	9.03
	Pool	6.56	10.19	6.41	41.37	0.97	8.69
Test weight (g)	E1	3.89	7.53	6.44	26.74	0.05	4.15
	E2	4.67	7.68	6.09	36.95	0.07	5.84
	E3	3.50	7.45	6.57	22.14	0.04	3.40
	E4	3.55	7.30	6.38	23.59	0.04	3.55
	Pool	5.11	7.49	6.38	46.54	0.08	7.18
Oil content (%)	E1	18.19	19.32	6.53	88.59	1.10	35.26
	E2	14.70	16.05	6.46	83.81	0.95	27.72
	E3	15.52	16.81	6.46	85.23	1.09	29.52
	E4	16.16	17.39	6.42	86.37	1.10	30.95
	Pool	15.35	17.36	6.47	78.20	0.96	27.97

Table 4.8: Analysis of variance for stability parameters for different characters studied in Ajwain for over pooled environments (Eberhart and Russell, 1966)

Characters	Genotype	E+(G x E)	E (L)	G x E (L)	Pool dev.	Pool Err
	[27]	[84]	[1]	[27]	[56]	[216]
Day to 50% flowering	3.1497	1.0708	0.0062	0.7162	1.2608	7.202
Days to 75% maturity	9.4449	3.3746	0.2410	9.0091	0.7139	36.19
Plant height (cm)	40.2966**	6.9433	0.0290	7.4416	6.8265	11.71
No of primary branches	1.4765**	1.1987**	0.0869	3.4522**	0.1321	0.1107
No of umbels per plant	606.6212**	142.9120**	0.5053	252.5202**	92.6082**	23.95
No of umbelets per umbel	1.6125**	1.4961**	0.0931	4.1493**	0.2419	0.176
Seeds per umbelet	14.5924**	1.3412**	0.0773	3.9730**	0.0948	0.7362
Biological yield per plant (g)	8.4446**	0.9872	0.0167	1.7457*	0.6388	1.053
Seed yield per plant (g)	2.5528**	0.4729**	0.0076	0.9847**	0.2345	0.1698
Test weight (g)	0.0137**	0.0008	0.0000	0.0020	0.0002	0.001731
Oil content (%)	1.1651**	0.1010**	0.0062	0.2496**	0.0311**	0.0166

*,** significant at 5% and 1% level, respectively.

Table 4.9: Stability parameters for days to 50% flowering, days to 75%maturity, plant height, branches per plant in Ajwain

Genotype	Day to 50% flowering			Days to 75% maturity			Plant height (cm)			No. of primary branches		
	i	bi	S^2d	i	bi	S^2d	i	bi	S^2d	i	bi	S^2d
UA-7	78.83	-3.62	-6.730	165.92	0.60	-35.956	96.33	0.54	-11.606	9.25	1.41*	-0.046
UA-28	76.00	0.49	-5.565	166.18	0.53	-26.561	93.00	3.22	-1.255	9.41	0.40	-0.040
UA-29	77.33	2.26	-6.209	164.75	0.95*	-35.955	93.50	0.24	-10.242	8.58	-0.05	0.041
UA-30	76.08	1.64	-6.281	167.34	0.66	-36.000	95.08	0.23	-11.575	10.25	0.04	0.260*
UA-32	77.08	-1.11	-2.160	163.92	1.10*	-36.092	103.92	4.79	6.807	9.42	0.31+	-0.077
UA-41	75.25	1.36	-6.547	164.01	2.31*+	-35.767	96.92	-0.04+	-11.666	8.68	0.52	0.021
UA-48	75.75	2.75	-5.363	165.58	1.24*	-35.900	93.83	2.15	-7.979	8.92	-0.06+	-0.074
UA-53	74.50	0.62	-6.738	164.59	1.75**+	-36.124	96.17	-0.75	-9.664	8.67	0.25+	-0.077
UA-63	77.42	2.52	-6.263	166.67	0.68	-35.852	95.92	-4.12	14.872	7.75	0.96**	-0.090
UA-66	76.50	-0.19	-6.148	164.25	1.47*	-35.999	98.67	0.84	-11.433	7.42	0.80*	-0.064
UA-70	77.17	2.25	-6.693	165.75	1.08*	-36.069	92.67	3.09	-3.018	8.08	1.62*	-0.025
UA-71	76.50	4.04	-5.797	166.02	0.68*	-36.057	103.02	-7.35	-7.714	7.84	1.19*	-0.013
UA-83	77.00	2.51	-6.973	166.08	1.61**+	-36.157	98.42	0.93*	-11.690	8.67	1.15*	-0.043
UA-87	76.50	2.57	-5.505	162.57	1.00*	-36.011	93.16	3.24	4.331	8.50	1.76**+	-0.052
UA-90	75.67	1.38	-6.815	165.58	1.11**	-36.166	94.67	-0.96	-8.308	9.08	1.05*	-0.075
UA-113	76.50	-0.74	-3.200	162.43	1.48**++	-36.185	97.58	1.14	-11.421	8.92	1.74*	0.259*
UA-125	77.83	-0.81	-7.090	164.58	0.97**	-36.188	95.17	-0.55	-11.550	7.50	1.69*	0.038
UA-127	75.33	-0.65	-6.907	164.00	1.82	-30.114	97.33	1.56	-10.593	8.68	0.43	0.448**
UA-131	75.75	0.90	-6.788	166.42	0.99*	-35.929	103.46	4.75	44.063**	8.42	1.47*	-0.033
UA-141	76.08	1.37	-6.218	164.91	1.11**	-36.165	99.83	0.86	-11.061	9.25	0.20	-0.005
UA-149	76.42	3.09	-3.867	166.50	0.80*	-36.047	98.25	-0.04+	-11.666	9.00	1.23*	0.050
UA-168	75.34	0.08	-6.648	166.67	1.16**+	-36.192	98.08	0.25	2.638	8.67	1.88*	0.141
UA-169	76.50	0.09	-6.924	166.17	1.54**++	-36.188	100.75	2.51	-11.223	8.33	1.57**+	-0.101
UA-175	75.83	2.50	-4.821	167.50	0.80*	-36.046	96.83	-2.14	-2.191	8.67	1.15*	-0.044
UA-191	77.08	0.00	-5.149	168.01	0.42	-35.815	101.50	4.27	-6.621	8.42	1.94*	0.346*
GA-1	76.50	1.75	-5.525	163.49	0.24	-35.880	98.25	0.85	-11.630	9.08	1.14*	0.037
UA-1	76.83	3.00	-7.036	163.84	0.01++	-36.145	94.39	7.53	-3.551	8.59	1.25**	-0.094
Local check	76.50	-2.05	-6.403	162.33	-0.09+	-35.891	99.08	0.94*	-11.689	8.75	0.97**	-0.091

*, + & ** bi is significantly deviating from 0 and 1 at 5% and 1%, respectively
*, ** S^2d is significant at 5% and 1% respectively

Table 4.10: Stability parameters for umbels per plant, umbelets per umbel, seeds per umbelet, biological yield per plant in Ajwain

Genotype	No of umbels per plant			No of umbelets per umbel			Seeds per umbelet			Biological yield per plant (g)		
	i	Bi	S^2d	i	bi	S^2d	i	bi	S^2d	i	bi	S^2d
UA-7	108.58	-1.81	121.720**	10.84	1.38**	-0.148	18.92	1.71	0.229	27.45	1.03*	-1.037
UA-28	116.42	-3.77	160.294**	10.25	1.28**	-0.152	18.50	0.48	-0.701	26.74	0.59*	-1.045
UA-29	93.50	8.98	241.761**	9.33	0.63	0.764**	20.59	3.50**+	-0.514	27.70	0.65	-0.396
UA-30	116.33	-1.88	47.881	10.42	1.14*	-0.065	20.33	1.15**	-0.712	26.74	0.59	-1.044
UA-32	139.33	-0.00	-18.506	11.17	1.11**	-0.156	21.83	2.27**+	-0.687	26.51	0.79*	-1.041
UA-41	116.67	-1.01+	-21.161	8.92	0.87	0.113	22.50	1.37**	-0.712	26.75	0.79*	-1.041
UA-48	123.91	-2.47	28.740	10.33	1.25*	-0.083	21.00	1.15**	-0.714	27.31	2.30	-0.901
UA-53	116.17	2.18	15.397	10.92	0.79**++	-0.175	18.83	0.48	-0.702	25.50	5.34	0.170
UA-63	106.71	3.86	35.931	11.00	1.31	0.141	21.25	0.37	-0.618	27.46	1.16	-0.767
UA-66	109.50	1.81	-6.632	10.59	0.23	0.347	14.91	0.56*	-0.702	28.07	0.59*	-1.044
UA-70	117.96	3.05	38.323	10.09	-0.04+	-0.137	16.67	2.94**+	-0.639	27.22	1.00*	-1.036
UA-71	104.75	0.30	-22.306	10.42	1.14**	-0.158	18.00	0.69*	-0.701	27.13	0.57	-1.040
UA-83	115.25	-1.16	13.928	10.33	0.27+	-0.162	19.67	1.14*	-0.704	27.46	0.79*	-1.041
UA-87	115.58	1.41	2.390	11.33	1.92*	-0.003	21.17	0.47	-0.696	26.51	0.79*	-1.040
UA-90	104.42	-2.77	21.012	10.83	2.07**++	-0.152	21.50	2.26**+	-0.667	26.70	0.79*	-1.041
UA-113	107.17	-2.69	126.683**	9.92	-0.34	0.500*	21.08	1.47*	-0.611	25.23	3.57	0.918
UA-125	113.08	2.96	87.048*	10.25	1.77*	-0.076	21.08	1.47*	-0.611	23.49	3.69*	-0.726
UA-127	114.25	-1.10+	-22.189	10.67	2.91*+	0.244	21.79	0.08+	-0.706	25.56	1.15	-0.999
UA-131	113.58	0.94	346.987**	10.75	0.79	0.842**	21.71	-0.05++	-0.730	25.46	0.74	-1.025
UA-141	112.67	0.61	-12.486	9.50	1.17*	-0.109	22.00	0.25+	-0.690	25.14	-2.48	0.914
UA-149	136.08	17.26	595.395**	10.59	0.72	0.186	21.84	1.37**	-0.701	25.93	1.46	1.134
UA-168	109.67	0.42	-15.726	11.58	0.93	0.523*	21.17	0.47	-0.696	24.23	0.79*	-1.041
UA-169	122.34	1.36	-5.513	10.75	0.45	-0.067	22.25	0.36	-0.611	22.92	1.83	1.777
UA-175	127.57	2.66	16.727	10.58	0.31+	-0.150	22.34	0.69*	-0.702	24.61	0.79*	-1.041
UA-191	129.33	-2.01	108.931**	11.75	0.92	0.095	22.50	0.72	-0.570	24.61	0.42	-1.044
GA-1	146.30	0.18	45.927	9.92	0.10+	-0.148	22.92	0.01++	-0.723	26.51	-0.95	-0.873
UA-1	141.08	0.15	-8.279	10.83	0.47	0.034	21.50	0.67*+	-0.726	29.10	2.45	3.916**

Local check	130.67	0.55	0.013	10.92	2.46*+	-0.003	22.54	-0.03+	-0.642	27.96	-3.21	-0.160

*, + & ** bi is significantly deviating from 0 and 1 at 5% and 1%, respectively
*, ** S^2d is significant at 5% and 1% respectively

Table 4.11: Stability parameters for seed yield per plant (g), test weight (g), oil content in Ajwain

Genotype	Seed yield per plant (g)			Test weight (g)			Oil content (%)		
	i	Bi	S^2d	i	Bi	S^2d	i	bi	S^2d
UA-7	11.81	0.66**++	-0.170	1.19	1.01	-0.002	3.71	1.44	0.005
UA-28	11.51	0.33+	-0.166	1.16	0.55	-0.002	3.79	0.84*	-0.013
UA-29	11.76	0.26+	-0.165	1.19	0.55	-0.002	3.75	2.49*	0.014
UA-30	11.51	0.33+	-0.166	1.16	0.55	-0.002	3.42	1.42*	-0.011
UA-32	11.41	0.49*+	-0.168	1.16	1.80	-0.002	4.42	1.42*	-0.011
UA-41	11.52	0.49*+	-0.168	1.16	0.84*	-0.002	4.01	2.02	0.049*
UA-48	11.75	1.50**+	-0.168	1.19	2.35	-0.001	2.91	1.82**+	-0.014
UA-53	10.44	7.60*+	0.128	1.14	1.05*	-0.002	3.50	0.81	0.009
UA-63	11.95	0.92	0.130	1.18	1.05*	-0.002	2.46	1.38*	-0.008
UA-66	12.07	0.33+	-0.166	1.22	0.42	-0.002	3.54	0.79	-0.004
UA-70	11.71	0.64*+	-0.169	1.18	1.05*	-0.002	4.08	0.75	0.003
UA-71	11.67	0.35+	-0.167	1.18	0.63*+	-0.002	3.42	0.24	0.132**
UA-83	11.81	0.49*+	-0.168	1.19	0.84*	-0.002	2.58	0.68	0.077**
UA-87	11.41	0.49*+	-0.168	1.14	0.84*	-0.002	3.29	0.70	0.007
UA-90	11.49	0.49*+	-0.168	1.16	0.84*	-0.002	3.58	0.76	0.003
UA-113	10.88	2.01	0.261	1.08	4.31	0.001	3.75	2.34	0.074**
UA-125	9.78	5.11*+	-0.066	1.02	0.68	-0.002	4.00	-0.00	-0.017
UA-127	11.02	0.69	-0.158	1.09	1.27*	-0.002	3.49	0.27	0.071**
UA-131	10.98	0.43	-0.162	1.09	0.89*	-0.002	3.04	-0.05	0.048*
UA-141	10.35	-3.12	2.696**	1.12	0.63*+	-0.002	2.62	0.85*	-0.013
UA-149	10.88	0.72	-0.135	1.08	1.22	-0.001	2.42	1.29*	-0.006
UA-168	10.46	0.49*+	-0.168	1.02	0.82**	-0.002	2.67	0.95*	-0.011
UA-169	8.26	4.44	2.293**	1.06	0.36	-0.002	3.38	1.19**++	-0.017

UA-175	10.62	0.49*+	-0.168	1.04	0.84**	-0.002	3.62	0.73	0.032
UA-191	10.62	0.25+	-0.168	1.03	0.57	-0.001	4.17	0.54*	-0.014
GA-1	11.27	0.33+	-0.166	1.13	0.55	-0.002	3.79	1.23	0.027
UA-1	11.43	0.32+	-0.166	1.15	0.55	-0.002	3.91	0.47	0.005
Local check	11.65	0.48*+	-0.168	1.17	0.84*	-0.002	3.21	0.63*	-0.014

*, + & ** bi is significantly deviating from 0 and 1 at 5% and 1%, respectively
*, ** S^2d is significant at 5% and 1% respectively

Table 4.12: Ajwain varieties/genotypes classified with respect to their adaptability for different environments (Eberhart and Russell, 1966)

Characters	High mean performance above average response (b > 1) and stable suited in favourable environments	High mean performance below average response (b < 1) and stable suited unfavourable/stress environments	High mean performance (b=1) and stable general adoptable in desired environments
Plant height	UA- 131	Local check	_
Primary Branches per plant	UA- 113	UA- 63, UA- 66	_
umbels per plant	UA- 149	UA- 131	_
Umbelets per umbel	UA- 7, UA- 32, UA- 90	_	
Seeds per umbelet	UA- 32, UA- 41, UA- 48, UA- 90, UA- 113, UA- 125, UA- 141	UA- 63, UA- 66, UA- 71	_
Biological yield per plant (g)	UA- 7, UA- 48	UA- 28, UA- 32, UA- 41, UA- 66, UA- 83, UA- 87, UA- 90, UA-175	UA- 70
Seed yield per plant (g)	UA- 48	UA- 168, UA- 175	_

Test weight (g)	UA- 7, UA- 32, UA- 48, UA- 53, UA- 63, UA- 70	UA- 131, UA- 141, UA- 168, UA- 175	_
Oil content	UA- 7, UA- 29,UA- 30, UA- 32, UA- 48, UA- 113,	UA- 141, UA- 168,Local check	

Table 4.6: Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficient among different characters studied in Ajwain for over pooled environments

Character	Day to 50% flowering	Days to75% maturity	Plant height (cm)	No of primary branches	No of umbels per plant	No of umbelets per umbel	Seeds per umbelet	Biological yield (g)	Seed yield (g)	test wt (g)	Oil content (%)
Day to 50% flowering		0.07	0.07	-0.34	0.02	0.14	-0.22	0.25	0.27	0.20	0.22
Days to 75% maturity	0.48*		0.12	0.11	-0.15	0.32	-0.07	-0.27	-0.15	-0.24	-0.26
Plant height (cm)	0.36	0.43*		-0.09	0.25	0.31	0.24	-0.37	-0.33	-0.28	-0.08
No of primary branches	0.13	0.19	0.09		0.32	-0.28	0.36	0.10	0.16	0.08	-0.01
No of umbels per plant	0.10	0.13	0.23	0.17		0.35	0.47*	0.01	-0.17	-0.22	0.22

No of umbelets per umbel	0.12	0.18	0.27	0.14	0.16		0.07	-0.17	-0.13	-0.30	-0.10
Seeds per umbelet	0.23	0.29	0.24	0.25	0.32	0.06		-0.42*	-0.44*	-0.56**	-0.11
Biological yield per plant (g)	0.22	0.12	0.06	0.19	0.06	-0.02	-0.11		0.92**	0.91**	0.02
Seed yield per plant (g)	0.15	0.10	0.02	0.14	-0.00	-0.02	-0.16	0.83**		0.85**	0.01
Test weight (g)	0.26	0.16	0.08	0.23	-0.03	-0.04	-0.21	0.82**	0.72**		-0.02
Oil content (%)	0.14	0.04	0.04	0.13	0.15	-0.04	-0.00	0.20	0.15	0.21	

*, ** significant at 5% and 1% level, repectively

Table 4.7: Path analysis showing direct and indirect effect of Eight characters on seed yield per plant in Ajwain for pooled over the environments

Character	Plant height (cm)	No of primary branches	No of umbels per plant	No of umbelets per umbel	Seeds per umbelet	Biological yield (g)	1000 Seed wt (g)	Oil content (%)	r
Plant height (cm)	0.20	-0.03	-0.14	0.05	-0.02	-0.59	0.20	-0.01	-0.33
No of primary branches	-0.02	0.32	-0.18	-0.05	-0.02	0.16	-0.06	-0.00	0.16
No of umbels per plant	0.05	0.10	-0.56	0.06	-0.03	0.02	0.16	0.03	-0.17

No of umbelets per umbel	0.06	-0.09	-0.20	0.16	-0.00	-0.27	0.21	-0.01	-0.13
Seeds per umbelet	0.05	0.12	-0.26	0.01	-0.07	-0.67	0.40	-0.01	-0.44*
Biological yield per plant (g)	-0.07	0.03	-0.01	-0.03	0.03	1.61	-0.65	0.00	0.92**
Test weight (g)	-0.06	0.03	0.13	-0.05	0.04	1.47	-0.71	-0.00	0.85**
Oil content (%)	-0.02	-0.00	-0.12	-0.02	0.01	0.02	0.01	0.13	0.01

Residual effect = 0.17
*, ** significant at 5% and 1% level, respectively
Diagonal bold values represent the direct contribution of characters on seeds yield
r represent the genotypic correlation coefficient for seed yield in Ajwain

Table 4.2: Analysis of variance showing mean sum of square for different characters studied in Ajwain for four environments

Characters	Replications				Genotypes				Error			
	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
d.f.	(2)	(2)	(2)	(2)	(27)	(27)	(27)	(27)	(54)	(54)	(54)	(54)
Days to 50% flowering	2.22	14.17	0.24	3.91	2.91	5.16	5.39	5.42	21.65	21.4	21.97	21.41
Days to75% maturity	1.31	22.19	4.73	4.47	8.41	9.25	10.48	10.68	105.3	101.8	114.1	113.1
Plant height(cm)	1.66	70.69	13.33	18.20	44.16	40.44	47.57	50.98	41.2	41.79	27.8	29.68
Branches per plant	0.49	0.53	0.13	0.55	1.42**	1.11**	3.25**	2.25**	0.35	0.38	0.35	0.24
Umbels per plant	41.94	87.25	7.10	3.92	711.56**	634.56**	702.49**	1061.06**	58.87	50.24	80.04	98.31
Umbellets per umbel	0.46	0.94	0.79	0.35	1.91**	2.15**	5.73**	0.87*	0.37	0.45	0.81	0.46
Seeds per umbellet	0.97	0.76	1.04	0.80	15.66**	12.79**	10.77**	10.32**	2.16	2.09	1.85	2.71
Biological yield per plant	5.67	5.74	1.84	3.22	11.11**	8.37**	7.48**	6.11**	3.18	3.11	3.50	2.83
Seed yield per plant	1.03	0.70	0.93	0.58	4.91**	2.49**	1.98**	2.02**	0.50	0.52	0.48	0.52
Test weight (g)	0.00	0.00	0.00	0.00	0.01*	0.01**	0.01*	0.01*	0.00	0.00	0.00	0.00
Oil content (%)	0.07	0.10	0.09	0.08	1.01**	0.80**	1.04**	1.03**	0.04	0.04	0.05	0.05

*, ** = significant at 5% and 1%, respectively

( ) values in parenthesis indicates degree of freedom

Table 4.4: Mean and range of different characters studied in Ajwain under four environments and over pooled environments

Character	Environment	Mean	Range
Days to 50% flowering	E1	76.43	75.00 – 78.00
	E2	76.56	74.33 - 78.67
	E3	76.64	74.33 – 79.00
	E4	76.09	74.00 – 80.33
	Pool	76.43	74.50 – 78.83
Days to 75% maturity	E1	166.35	161.67 – 168.67
	E2	166.67	162.67 – 169.00
	E3	164.02	160.67 – 168.00
	E4	163.82	161.33 – 168.37
	Pool	165.22	162.33 – 168.01
Plant height (cm)	E1	97.45	91.67 – 112.83
	E2	97.71	92.00 – 109.67
	E3	97.65	90.33 – 105.33
	E4	96.59	90.00 – 109.08
	pool	97.35	92.67 – 103.92
No of primary branches	E1	9.11	7.67 – 10.33
	E2	9.73	8.33 – 10.67
	E3	7.97	6.33 – 10.67
	E4	7.88	7.00 – 10.00
	Pool	8.67	7.42 – 8.92
No of umbels per plant	E1	117.29	78.67 – 153.55
	E2	115.87	68.34 – 143.67
	E3	118.55	91.33 – 150.33
	E4	120.99	99.33 – 199.33
	Pool	118.17	93.50 – 146.30
No of umbellets per umbel	E1	9.75	8.00 – 11.33
	E2	10.21	8.33 – 12.00
	E3	11.88	9.33 – 14.00
	E4	10.26	9.33 – 11.33
	Pool	10.53	8.92 – 11.75
Seeds per umbellet	E1	19.99	14.33 – 23.00
	E2	20.01	14.67 – 22.83
	E3	21.61	15.33 – 23.67

	E4	21.31	15.33 – 23.33
	Pool	20.73	14.91 – 22.92
Biological yield per plant (g)	E1	25.75	21.22 – 30.17
	E2	26.36	23.80 – 30.14
	E3	26.71	22.89 – 31.22
	E4	26.32	21.90 – 27.98
	Pool	26.29	22.92 – 29.10
Seed yield per plant (g)	E1	10.76	7.00 – 11.67
	E2	11.21	7.50 – 12.67
	E3	11.36	7.93 – 12.03
	E4	11.25	7.72 – 12.03
	Pool	11.14	8.26 – 12.07
Test wt (g)	E1	1.10	1.00 – 1.17
	E2	1.13	1.00 – 1.23
	E3	1.15	1.04 – 1.24
	E4	1.14	1.01 – 1.22
	Pool	1.13	1.02 – 1.22
Oil content (%)	E1	3.13	2.00 – 4.00
	E2	3.42	2.33 – 4.33
	E3	3.69	2.67 – 4.83
	E4	3.55	2.33 – 4.51
	Pool	3.45	2.42 – 4.42

5. SUMMARY AND CONCLUSION

The present investigation entitled **"Stability analysis in Ajwain (*Trachyspermum ammi* L.)"** was undertaken to study the different parameters of variability, heritability, genetic advance, nature and magnitude of correlation, path coefficient and stability analysis for yield and its contributing characters.

The experimental material comprised of 28 genotypes of Ajwain. The material was planted in Randomized Block Design with three replications during late *kharif* 2013-14 at two locations (Udaipur: E_1, and Pratapgarh: E_2) and late *kharif* 2014-15 at same locations (Udaipur: E_3, Pratapgarh: E_4) under irrigated conditions and following uniform and recommended agronomical practices at all the location.

The observations were recorded on ten randomly selected plants for eleven characters *viz.*, days to 50 per cent flowering, days to 75 per cent maturity, plant height, number of primary branches per plant, number of umbels per plant, number of umbeletes per umbel, number of seeds per umbelets, biological yield per plant, Seed yield per plant, Test weight and oil content. The data obtained were subjected to analysis of variance, estimation of different variability parameters, path coefficient analysis and stability parameters.

Variability parameters, correlations and path coefficient were computed pooled over the environments. Stability parameters were analyzed using the model proposed by Eberhart and Russell (1966) over four environments.

Present investigation revealed following important findings:

1. Superior genotypes UA-7, UA-32 and UA-48 were identified on the basis of their consistent *per se* performance in all the environments and over pooled basis for seed yield and its components.
2. Similarly UA- 32, UA- 48 and UA- 70 exhibited high *per se* performance for oil content
3. Genotype UA- 32 displayed superiority for seed yield as well as oil content.

4. Analysis of variance for four environments revealed that mean square due to genotypes were showed differences among the genotypes for plant height, number of primary branches per plant, number of umbels per plants, number of umbelets per umbel, number of seeds per umbelet, biological yield per plant, seed yield per plant, test weight and oil content, indicating considerable amount of variability for all these characters.

5. In present investigation, highest GCV and PCV was obtained for oil content (15.35%), number of umbels per plant (9.11%) and seed yield per plant (9.01%) over pooled basis. Lowest GCV and PCV were found for number of umbelets per umbel (4.66%) and test weight (5.11%) indicating the role of environment in the expression of these characters. In general, magnitude of PCV was higher than the magnitude of GCV.

6. Highest heritability estimates was observed for oil content (78.20%), number of seeds per umbelet 62.25%), test weight (46.54%) and seed yield per plant (41.37%) over pooled basis.

7. Large genetic advance as per cent of mean coupled with high GCV and heritability were recorded for oil content (27.97%), seeds per umbelet (14.64%) and number of umbels per plant (11.52%) over pooled basis, Suggesting that selection for these characters would be effective in genetic improvement of seed yield in Ajwain (*Trachyspermum ammi* L.)

8. Association studies revealed a close agreement between genotypic and phenotypic correlations. The genotypic correlation were slightly higher than their respective phenotypic correlations.

9. A joint regression analysis of variance based over four environments indicated that genotypes differed significantly for almost all the characters except days to 50 per cent flowering and days to 75 per cent maturity.

10. The mean squares due to E + (G x E) were significant for almost all of the characters except days to 50 per cent flowering, days to 75 per cent maturity and plant height.

11. Superior genotypes were identified with respect to their phenotypic stability UA-7, UA-32 and UA-48 displayed high *per se* performance, above average response and stability for seed yield per plant and its

components. It is interesting to note that each genotypes exhibited its superior performance for other important yield contributing characters i.e. umbelets per umbel, seeds per umbelet, biological yield per plant etc. which revealed that stability is imparted by its component traits.

12. UA-63 and UA-66 had high yield, below average response and appeared stable under stress conditions.

13. Fulfilling the assumptions laid by Eberhart and Russell (1966) genotype UA-48 exhibited high mean performance, above average response and stability for their seed yield. This appeared the most promising and could be gainfully utilized.

14. Genotypes UA-32, UA-48 and UA-191 have been considered promising for oil content.

To concluded, the present study was conducted in four environments at two locations in two year based over various estimates viz. variability parameters, correlations, path analysis and stability parameters. Genotypes UA-7, UA-32, UA-48 appeared to be most promising for increasing seed yield levels in Ajwain as they were not only stable but also had high *per se* performance for umbels per plant, seed yield per plant, test weight. Among 28 genotypes, UA-32, UA-48 and UA-191 also possessed high oil content. Thus, stability of seed yield per plant in UA-7, UA-32 and UA-48 were imparted by the stability of its component characters like umbelets per umbel, seeds per umbelet, biological yield per plant, seed yield per plant, test weight and oil content.

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