

**MORPHOMETRIC AND MOLECULAR
CHARACTERIZATION OF AJWAIN (*Trachyspermum
ammi* L.) GENOTYPES UNDER NORTHERN DRY
ZONE OF KARNATAKA**

POOJA S.



**DEPARTMENT OF PLANTATION, SPICES,
MEDICINAL AND AROMATIC CROPS
COLLEGE OF HORTICULTURE, BAGALKOTE– 587 104
UNIVERSITY OF HORTICULTURAL SCIENCES,
BAGALKOTE- 587 104**

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ammi* L.) GENOTYPES UNDER NORTHERN DRY
ZONE OF KARNATAKA**

*Thesis submitted to the
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Plantation, Spices, Medicinal and Aromatic crops

By
POOJA S
UHS19PGD349

**DEPARTMENT OF PLANTATION, SPICES,
MEDICINAL AND AROMATIC CROPS
COLLEGE OF HORTICULTURE, BAGALKOTE
UNIVERSITY OF HORTICULTURAL SCIENCES,
BAGALKOTE- 587 104**

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COLLEGE OF HORTICULTURE, BAGALKOT
DEPARTMENT OF PLANTATION, SPICES, MEDICINAL AND
AROMATIC CROPS

C E R T I F I C A T E

This is to certify that the thesis entitled “**MORPHOMETRIC AND MOLECULAR CHARACTERIZATION OF AJWAIN (*Trachyspermum ammi* L.) GENOTYPES UNDER NORTHERN DRY ZONE OF KARNATAKA**” submitted by **Ms. POOJA S. ID. NO. UHS19PGD349** for the degree of **DOCTOR OF PHILOSOPHY (HORTICULTURE)** in **PLANTATION, SPICES, MEDICINAL AND AROMATIC CROPS** to the University of Horticultural Sciences, Bagalkot is a record of research work carried out by her during the period of her study in this university, under my guidance and supervision and that no part of thesis has been submitted for the award of any other degree, diploma, associateship, fellowship or other similar titles.

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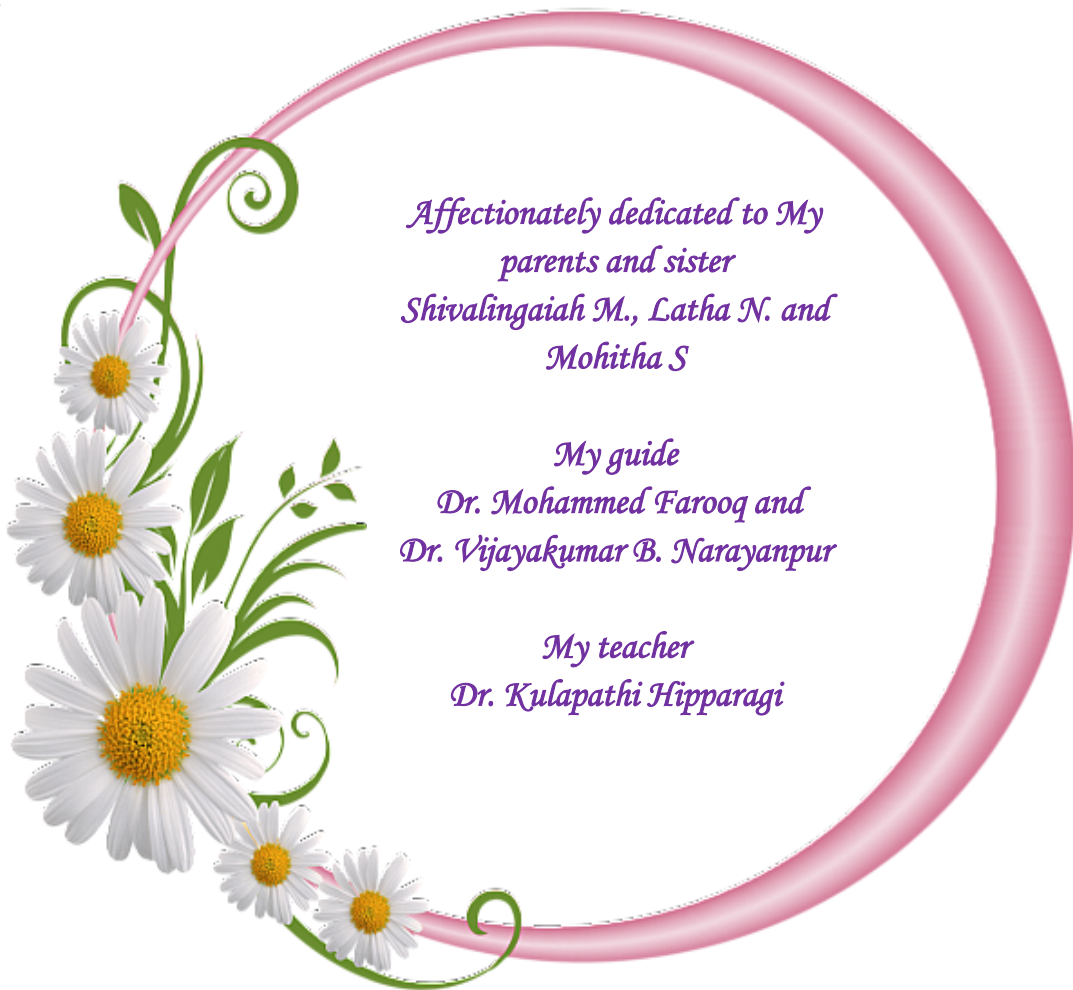
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*Affectionately dedicated to My
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CONTENTS

Sl. No.	Chapter particulars	Page No.
	CERTIFICATE	iii
	ACKNOWLEDGEMENT	iv-v
	LISTS OF TABLES	viii-ix
	LISTS OF FIGURES	x
	LISTS OF PLATES	xi
	LISTS OF APPENDICES	xii
	LISTS OF SYMBOLS AND ABBREVIATIONS	xiii
1	INTRODUCTION	1-5
2	REVIEW OF LITERATURE	6-49
3	MATERIAL AND METHODS	50-68
	3.1 Geographical location of the experimental site	50
	3.2 Climatic conditions of the experimental site	50
	3.3 Soil conditions of the experimental site	50
	3.4 Experimental details	50
	3.5 Cultural practices	53
	3.6 Observations on growth parameters	54
	3.7 Observations on yield parameters	56
	3.8 Observations on quality parameters	57
	3.9 Disease and pest scoring	58
	3.10 Statistical analysis	59
	3.11 Genetic divergence analysis	63
	3.12 Molecular marker profiling	64
4	EXPERIMENTAL RESULTS	69-128
	4.1 Growth parameters	69

	4.2. Yield parameters	81
	4.3. Quality parameters	88
	4.4 Disease and pest scoring	89
	4.5 Analysis of variance	94
	4.6 Genetic, phenotypic, heritability and genetic advance	94
	4.7 Correlation studies	101
	4.8 Path coefficient analysis	109
	4.9 Genetic divergence studies	118
	4.10 Molecular marker profiling	125
5	DISCUSSION	129-152
	5.1 Performance of ajwain cultivars for growth, yield and quality parameters	129
	5.2 Disease and pest scoring	137
	5.3 Analysis of variance	137
	5.4 Genetic variability, heritability and genetic advance	138
	5.5 Correlation analysis	142
	5.6 Path analysis	145
	5.7 Genetic diversity analysis	149
	5.8 Molecular marker profiling	151
6	SUMMARY AND CONCLUSION	153-159
7	REFERENCES	160-179
	APPENDICES	180-182

LIST OF TABLES

Table No.	Title	Page No.
1	List of genotypes and source of collection	52
2	PCR protocol followed for microsatellite primers for different Ajwain	65
3	Microsatellite primers used for analysis of ajwain genotype	67
4	Performance of ajwain genotypes for days to germination	72
5	Plant height at 60 and 90 days in ajwain genotypes	75
6	Plant height at 120 and 150 days in ajwain genotypes	76
7	Number of branches per plant at 60 and 90 days in ajwain genotypes	77
8	Number of branches per plant at 120 and 150 days in ajwain genotypes	78
9	Days to flower initiation (10%) and days to 50 percent flowering in ajwain genotypes	82
10	Number of flowers per umbellates and days to physiological maturity in ajwain genotypes	83
11	Number of umbels per plant and number of umbellates per umbel in ajwain genotypes	84
12	Number of seeds per umbel and seed yield per plant (g) in ajwain genotypes	90
13	Seed yield (g/plot) and (kg/ha) in ajwain genotypes	91
14	Harvest index (%) and test weight (g) in ajwain genotypes	92
15	Essential oil (%) and oleoresin (%) content in ajwain genotypes	93
16	Thymol content (%) in ajwain genotypes	95
17	Reaction of different genotypes of ajwain against stem fly infestation	96
18	Analysis of variance (ANOVA) for the growth, yield and quality parameters in ajwain genotype (Pooled)	97
19	Estimates of genetic parameters for different characters in ajwain genotype (Pooled)	102

20	Genotypic correlation for yield and yield related traits in ajwain genotype (Pooled)	105
21	Phenotypic correlation for yield and yield related traits in ajwain genotype (Pooled)	108
22	Genotypic path for yield and yield related traits in ajwain genotype (Pooled)	112
23	Phenotypic path for yield and yield related traits in ajwain genotype (Pooled)	116
24	Relative per cent contribution of different characters to the total divergence in ajwain genotype (Pooled)	121
25	Categorization of ajwain genotypes into different clusters based on D^2 values (Pooled)	122
26	Inter and Intra (diagonal)- Cluster distance for 14 traits in D^2 analysis (Pooled)	123
27	Cluster mean for 14 traits from D^2 analysis (Pooled)	124
28	Standardized SSR marker amplication data in ajwain genotypes	127
29	Heterozygosity, F-statistics and polymorphism Information Content (PIC) of 10 SSR markers	128

LIST OF FIGURES

Figure No.	Title	B/W Page No.
1	Layout of the experimental site	51-52
2	Thymol content (%) in ajwain genotypes estimated through HPLC	90-91
3	Genotypic path diagram for total seed yield per plant in ajwain genotypes (Pooled)	110-111
4	Phenotypic path diagram for total seed yield per plant in ajwain genotypes (Pooled)	114-115
5	Dendrogram showing the diversity among the 28 genotypes of ajwain (Pooled)	118-119
6	Allelic patterns across populations of 10 SSR markers	126-127
7	Cluster analysis showing the diversity among 28 genotypes of ajwain produced by 25 SSR marker through Darwin software	128-129
8	Plant height in ajwain genotypes at 150 DAS (Pooled)	130-131
9	Number of branches per plant at 150 DAS in ajwain genotypes (Pooled)	130-131
10	Number of umbels per plant in ajwain genotypes (Pooled)	134-135
11	Number of seeds per umbel in ajwain genotypes (Pooled)	134-135
12	Seed yield per plant (g) in ajwain genotypes (Pooled)	134-135
13	Essential oil (%) and oleoresin (%) content in in ajwain genotypes (Pooled)	136-137
14	Thymol content in ajwain genotypes	138-139
15	Reaction of ajwain genotypes against stem fly (<i>Melanagromyza sp.</i>) (Pooled)	138-139

LIST OF PLATES

Plate No.	Title	B/W Page No.
1	General view of the experimental plot	55-56
2	Variability of umbels and umbellates in ajwain genotypes	82-83
3	Variability of seeds among the ajwain genotypes	86-87
4	Variability of essential oil (%) content in ajwain genotypes	88-89
5	Infestation of stem fly (<i>Melanagromyza</i> sp.)	90-91
6	Gel photograph showing different genotypes of ajwain screened by SSR markers	126-127
7	High yielding ajwain genotypes	158-159

LIST OF APPENDICES

Appendix no.	Title	Page No.
I	Meteorological data during the study period recorded at the meteorological observatory of MHREC, UHS, Bagalkot (2020-21)	180
II	Meteorological data during the study period recorded at the meteorological observatory of MHREC, UHS, Bagalkot (2021-22)	181
III	Initial chemical properties of soil used in field during the research work	182

LIST OF SYMBOLS AND ABBREVIATIONS

Symbols	Abbreviations
%	Per cent
@	At
t	Tons
cm	Centimeter
m	Meter
°C	Degree centigrade
g	Gram
kg	Kilogram
q	Quintal
ha	Hectare
CD	Critical difference
S.Em.	Standard error of mean
cv.	Cultivar
<i>et al.</i>	Et allii (and other)
<i>i.e.</i>	That is
<i>viz.</i>	Namely
DAS	Days after sowing
HI	Harvest index
DAC	Devihosur Ajwain Collection
GCV	Genotypic coefficient of variation
PCV	Phenotypic coefficient of variation
GAM	Genetic advance over per cent mean

1. INTRODUCTION

Spices have a long history dating back to human civilisation, which began with an exciting voyage that brought sailors to Indian beaches. These were the most valuable export commodities in ancient and medieval periods. A spice is a dried seed, fruit, root, bark, or vegetative component that is used in small amount as a flavour addition in food. Many spices have multiple applications, including food preservation, medicinal, religious rites, cosmetics, perfumes, and vegetable preparation (Thomas, 2013). They are high-value, low-volume crops that are critical to our national economy and give a solid foundation in the global market. Consumers all across the world use spices because they are fully natural and do not include any artificial ingredients.

India is regarded as the "Land of Spices" because no other country produces as many different types of spices as India does. India is the world's largest spice producer, consumer and exporter. Spices are natural plants or plant products that are used for imparting aroma, flavour, pungency, and seasoning to dishes in whole or ground form. Spices can be made up of various parts of the spice plant, such as flower parts (clove), fruits (cardamom, chilli), berries (black pepper), seeds (cumin, coriander, ajwain), rhizome (turmeric, ginger), kernel (nutmeg), aril (mace), bulbs (garlic, onion), bark (cinnamon), Saffron (flowers/style) or any other part of the plant. Of the total seed spices, India is leading in production of major seed spices such as cumin coriander, fennel, fenugreek and minor seed spices such as ajwain, dill, celery and nigella. Rajasthan and Gujarat are known as the "seed spices bowl" of India (Lal, 2019). Seed spices occupy an unique position in the countries spice basket. Seed spices can be increased in production by introducing them into new and non-traditional areas, as they are essential export-oriented agricultural commodities. Spices are grown on 43,17,552 hectares in India, with a yield of 1,01,25,880 tonnes (Spice Board, 2020).

More than 112 plant species have been designated as spices by the International Organization for Standardization (ISO), of which 63 are cultivated in India, 20 of which are seed spices. Seed spices are annuals with dried seeds that are used as condiments. The dry ecosystem economy relies heavily on seed spice.

Ajwain (Oma / Carum seed/ Bishop's weed) is a small seed spice botanically known as *Trachyspermum ammi* L. It belongs to the Apiaceae family and has a diploid chromosome number of $2n=18$, making it a significant *rabi* season seed spice. Ajwain is an Egyptian native that is primarily grown in eastern India, Egypt, Persia, Afghanistan, Pakistan, and Iran. Ajwain is Known as Zenyan or Nankhah in medical and pharmaceutical manuscript of medieval Persia (Mohammed *et al.*, 2014). Yemen, Dubai, Malaysia, Pakistan, Saudi Arabia, Indonesia, Singapore, the United Arab Emirates and the United States are the top ajwain importers (Ravindrababu *et al.*, 2012).

India consumes the most of the ajwain seeds. In India, small seeded varieties produce the greatest quality in Ujjain and Gwalior. Nadiad ajwain and desi ajwain (small and large versions, respectively) are two commercial types of ajwain in India (Pruthi, 2001).

Rajasthan, Gujarat, Madhya Pradesh, Uttar Pradesh, Maharashtra, West Bengal, Bihar, Telangana and Andhra Pradesh are among the Indian states, where ajwain is grown (Mohsenzadeh *et al.*, 2012). In an area of 41,134 hectare, 28,973 tonnes of ajwain seeds were produced in 2019-2020. Ajwain has a current average productivity of 704 kg/ha. Andhra pradesh is leading with respect to area (10.992 ha), whereas Gujarat is leading with respect to production (10.599 t) and Madhya Pradesh is leading with respect to productivity (1108 kg/ha) (Spice Board, 2020). Ajwain farming has extended in Bidar, Gulbarga, Raichur, Vijayapura and Bagalkote districts of Karnataka in recent years (Anon., 2018).

Ajwain is a white-flowered annual herbaceous plant with little brownish fruits. It is a densely branched herb that can reach to a height of 60–120 cm. The stem is striped and the inflorescence is a complex umbel with an average of 16 umbellates per umbel, each with 10-16 flowers. Flowers have 5 sepals, 5 petals, 5 stamens and an inferior ovary. Flowers are pedunculate and bear terminally or laterally. Flowers are protandrous in nature, honey bees are responsible for 70-77 per cent of cross pollination (Tiwari and Agarwal, 2004). Two mericarps, each about 1.7 mm broad, 2 mm long, greyish brown in colour with 5 ridges in each mericarp are found on fruit (Tomar and Malik, 2014, Farooqi *et al.*, 2005).

Ajwain seed contains 2-5 per cent volatile oil, which comprises 35-60 per cent thymol as the main ingredient and contains minor chemicals such as cymene (10-16%), terpinene (10-12%), dispinene (4-6%) and pinene (4-6%). The non-thymol fraction (Thymene) contains paracymene, gamma-terpinene, alpha-pinene, betapinene, α -terpinene, styrene, delta-3-carene, betaphyllanderene and carvacrol. On the other hand, in an investigation, carvone (46.2%), limonene (38.1%) and dillapiole (8.9%) were introduced as principal oil constituents (Mohagheghzadeh *et al.*, 2005)

Ajwain oil is used against treatment of diarrhea, dysentery, tonic dyspepsia, cholera, skin diseases, hysteria, flatulence, indigestion, abdominal pains, piles, bronchial problems, asthma, abdominal tumors, lack of appetite, galactagogue and amenorrhea. It has also proven to possess various pharmacological activities like anti-fungal, anti-oxidant, antimicrobial, cytotoxic, hypolipidemic, anti-hypertensive, anti-spasmodic, broncho-dilating actions, anti-lithiasis, diuretic, abortifacient, anti-tussive, nematocidal, anthelmintic, anti-filarial, antiplatelet-aggregatory and hepatoprotective property (Dubey and Kashyap, 2015, Bhatt *et al.*, 2018). The most common use of ajwain is as an indigestion cure. The stimulant, antioxidant, preservative, fragrant, and carminative characteristics of its seeds and oils are widely employed (Bairwa *et al.*, 2012, Muvel *et al.*, 2015).

A percentage of thymol is separated from the essential oil as crystals and sold as 'ajwain ka phul,' which is regarded as pharmaceutical. It is commonly used as an antiseptic in surgery and also used to cure hookworm (Ravindrababu *et al.*, 2012). Ajwain is used as an unrefined herbal product to increase the body's resistance in the Unani system of medicine, and it is also given for amoebiasis. Seeds have traditionally been used to treat a variety of stomach problems (Lateef *et al.*, 2006).

Ajwain oil is virtually colourless to pale yellowish fluid with a distinct thymol aroma and a harsh burning taste. Ajwain oil has a spicy, slightly oily aroma that lingers and leaves a burning sensation. Ayurvedic treatments and industry make use of the oil. The essential oil has been shown to have antibacterial, antifungal, cytotoxic, antispasmodic, antioxidant, diuretic, antihypertensive, hypolipidemic, abortifacient and nematocidal characteristics when used medicinally (Zahin *et al.*, 2010). Along with volatile oil, seeds also contain a moisture (8.9%), fat (18.1%), fibre (11.9%), protein

(15.4%), carbohydrates (38.6%), calcium (1.42%), phosphorous (0.30%), mineral (7.1%) and iron (14.6 mg/100g) (Dashora, 2005, Qureshi and Kumar, 2010).

Ajwain has a lot of genetic variation with respect to morphological, physiological, economic and quality criteria. As a result, numerous attempts were made to analyse the germplasm and characterize it for both of which are required for its use in a crop development programme.

Temperature, sunshine and other meteorological factors may limit plant development and productivity individually or together (Solemani *et al.*, 2011). Many seed spices, primarily coriander, dill and fenugreek are grown for vegetable use in Karnataka. These crops may also be cultivated for seed purposes, which require an optimum dry winter without high humidity, which is typical in Bagalkot district, due to the changing climate and fall in temperature during winter.

Ajwain is mostly a dryland crop that requires little water and little inputs to produce. Despite of this, the crop is farmed on a smaller scale, thus there is room for further expansion of ajwain production in dryland areas using high-yielding varieties or genotypes; genotypes play a significant role in yield optimization. They have varying adaptability to different agroclimatic situations, because of the fluctuating duration of the growing season, flowering and maturity. Genotype selection is mostly influenced by soil and climatic conditions in the location (Solemani *et al.*, 2011).

In most Apiaceae family, extensive conventional breeding work, particularly phenotypic-based variability assessment has been done. It is commonly known that the environment has a significant impact on morphological features, particularly quantitative traits. As a result of the genotype by environment interaction, the phenotyping value may be skewed and the information on variability may not be accurate (Kumar *et al.*, 2015). Molecular markers could be used to help solve this challenge (Rukhsar *et al.*, 2017). Despite of their economic relevance, most of the seed spices have not utilized modern molecular resources for crop improvement.

Limited work on diversity analysis using molecular markers like Random Amplified Polymorphic DNA (RAPD) and Inter-Simple Sequence Repeat (ISSR) has

been carried out in seed spices. But dominant nature and low reproducibility of such markers hinder the molecular breeding program in Apiaceae.

Morphological and molecular markers are the most common genetic methods used to identify and breed domesticated species cultivars (Tanksley *et al.*, 1993). SSRs are the most commonly utilised class of molecular markers in genetic studies, with applications in a wide range of domains such as genetic resource conservation, population genetics, molecular breeding and paternity testing (Ellegren, 2004). The SSR markers are codominant, multiallelic and highly repeatable, have high resolution, are adaptable to high throughput and are based on polymerase chain reaction (PCR), they have a wide range of uses (Oliveira *et al.*, 2006).

SSRs are the regions in the genome where a group of bases (1–8 bp long) are repeated in tandem (Richard *et al.*, 2008) throughout the genome. These regions can be isolated either by data mining of existing sequences or by generating SSR-enriched libraries. Microsatellites or simple sequence repeats (SSRs) are found throughout the eukaryotic genomes and occur in both coding and noncoding regions. Microsatellites are stretches of DNA consisting of tandemly arranged units in 1-6 bp (Gupta *et al.*, 1996, Thiel *et al.*, 2003), characterized by their co-dominant inheritance, wide genomic distribution, hyper variable and multiallelic nature (Powell *et al.*, 1996, Parida *et al.*, 2009). They are also termed as simple sequences (Tautz, 1989), Short Tandem Repeats (STRs) (Edwards *et al.*, 1991) and SSRs (Jacob *et al.*, 1991).

Keeping this in view, the present investigation entitled “**Morphometric and molecular characterization of ajwain (*Trachyspermum ammi* L.) genotypes under northern dry zone of Karnataka**” is proposed with the following objectives

1. To evaluate the ajwain genotypes for morpho-physico characters and seed yield.
2. To evaluate the ajwain genotypes for seed quality traits.
3. To estimate genetic variability among the ajwain genotypes.
4. To assess the diversity and association between growth, yield and seed quality traits.
5. Molecular characterisation of ajwain genotypes.

2. REVIEW OF LITERATURE

Ajwain is an emerging seed spice, condiment as well as a medicinal plant of great demand. But, scientific information available on its cultivation and its performance in South India is very meager even though several genotypes of ajwain are in vogue. Further, the performance of ajwain genotypes concerning growth, yield and quality is varied greatly over the regions. Hence, the growing interest of the crop has made researchers to work on suitability of ajwain genotypes for different agro-climatic conditions. There is limited literature on the performance of ajwain genotypes/varieties under varied agro-climatic zones. However apart from ajwain, the literature available on other related seed spices has been reviewed for a better understanding of the subject and presented here under with following headlines.

2.1 Growth parameters

Differences in growth parameters for days to germination, plant height, number of branches, days to flower initiation (10%), days to 50 per cent flowering, number of flowers per umbellates and days to physiological maturity, has been reported by various researchers in ajwain and other Apiaceae family crops are presented in the following headings.

2.1.1 Days to germination

Dhokle *et al.* (2006) conducted an experiment in Marathwada to compare the yield, quality and germination of several coriander genotypes. Their findings revealed that DWD-3 had the highest percentage of germination and the minimum number of days for germination, followed by Surbhi.

Meena (2012) investigated the performance of ajwain genotypes in Udaipur circumstances, it was observed that except for AA-01-272, all genotypes had significantly shorter germination times (7).

Giridhar *et al.* (2017) investigated the characterisation of germplasm for ajwain growth and yield. They reported that the time taken for ajwain to germinate ranges between 15 and 20 days depending on genotype.

Chaitanya *et al.* (2020) evaluated sixteen ajwain genotypes in the northern arid zone of Karnataka. They reported that the genotype DAC-5 had the minimum days to germination (11.00). AL-3 showed the maximum germination time in days (18.50).

2.1.2 Plant height

Sharma and Bhati (1988) analysed the plant heights of sixteen different coriander cultivars at the time of harvest, they discovered a difference among the genotypes. The accessions UD-41 reached the maximum height (75.46 cm).

The accession CS-2 had the minimum plant height (68.00 cm) in an evaluation of ten genotypes of coriander, whereas GC-35 cultivar had the maximum plant height (93.00 cm) (Maurya, 1989).

Rajagopalan *et al.* (1996) determined the maximum plant height to be in JC-147 (38.8 cm) and the shortest plant height to be in CS-287 (32.9 cm) at the time of harvest in their experiment evaluating 13 coriander cultivars during the *rabi* season from 1990 to 1992 at Coimbatore.

Gurbuz (2001) examined 25 coriander lines. The tallest plant was found in line 20 (125.4 cm) and the shortest was found in line 25 (85.1 cm).

Datta *et al.* (2001) tested five ajwain genotypes in West Bengal, Mohanpur region. According to their findings, the RA-2 genotype had the highest plant height (94.13 cm), whereas the local genotype had the lowest plant height (81.00 cm).

Selvarajan *et al.* (2002) evaluated nine coriander genotypes in their field experiment conducted over three years in Tamil Nadu under irrigated conditions and found that accession CS-12 had the highest mean values for plant height (55.47 cm), accession CS-102 had the second-highest mean values (49.67 cm) and variety CO-3 had the lowest mean values (49.67 cm) (40.71 cm).

Rajput and Dharendra (2003) assessed 20 genotypes of coriander under Jobner circumstances and resulted that RCr-435 recorded the maximum plant height (89.60 cm), followed by UD-728 (88.30 cm), while genotype UD-310 recorded the smallest plant height (44.00 cm).

A study on the evaluation of fennel genotypes in humid sub-temperate conditions on the mid-hill was conducted by Singh *et al.* (2003). According to their findings, JF-355 (120.96 cm) had the tallest plant, followed by JF-252 (116.55 cm), EC-279039 (116.44 cm), and JF-423 (120.44 cm) (112.44 cm). The shortest plant height was discovered to be JF-422 (70.59 cm).

Patidar *et al.* (2004) investigated the effects of cumin genotypes on growth characteristics and resulted that the highest plant height was recorded in RZ-19 (33.3 cm) among the genotypes, followed by RZ-209 (32.9 cm). In contrast, the indigenous genotype had the minimum plant height (29.7 cm).

Velayudham (2004) observed RCr-41 (49.03 cm) had highest plant height and the lowest plant height (38.74 cm) in Guntur Local in a field experiment including 11 genotypes of coriander. While in *rabi* season, CO-1 had the maximum plant height (66.97 cm) and Ghataprabha Local recorded the minimum plant height (41.47 cm).

Giridhar and Sarada (2005) tested 11 coriander genotypes in the Guntur region black soil under rainfed circumstances. Among them, LCC-216 recorded the highest plant height (65.90 cm) and it outperformed Sadhana by a wide margin (56.20 cm).

An experiment on coriander growth and yield was undertaken by Saxena *et al.* (2005). They concluded that UD-743 (120.73 cm) had the highest plant height, while LCC-128 had the lowest plant height (94.63 cm).

Evaluation of seventeen coriander germplasm lines in the Terai zone of West Bengal, indicated that genotype Pant Haritama, which was statistically on par to DW-246 (98.50 cm) had the highest plant height, while genotype DH-205 had the lowest (42.87 cm) (Datta and Choudhuri, 2006).

Divya (2007) evaluated twelve coriander cultivars and the genotype CIMPO-S-33 showed the maximum plant height at 30 DAS (16.03 cm), followed by other genotypes such as DWD-Purple, DWD-3 and Guntur Local (14.62, 14.19, and 14.04 cm, respectively) and that RCr-41 had the lowest plant height (6.82 cm). At harvest, CO-1 had the highest plant height (47.80 cm) and CO-2 had (37.43).

Sarada *et al.* (2009) investigated twenty-four genotypes of ajwain (*Trachyspermum ammi* L.) in Andhra Pradesh. According to their findings, the genotype LTA-3 had the highest plant height (126.18 cm), which was comparable to LTA-10, LTA-5 and LTA-6.

Sunilkumar (2010) observed that the genotype Sadhna (16.77 and 44.46 cm, respectively) recorded the highest plant height at 30 days after sowing and at harvest and the lowest plant height at 30 days after sowing and at harvest in Ghataprabha Local (8.45 and 30.36 cm respectively).

The maximum plant height in DCC-37 (18.98 cm) at 30 DAS followed by Sudha (16.55 cm), CO-4 (12.99 cm), DWD-3 (12.71) and the lowest 8.90 cm in DCC-13. At the harvest stage, DCC-38 had the highest maximum (45.70 cm), followed by Sudha (43.95 cm), CO-4 (38.89 cm), RCr-446 (39.95 cm), RCr-436 (36.60 cm) and DCC-13 had the lowest maximum (36.60 cm) (DCC 13) in an experiment evaluating coriander genotypes in hilly areas of Karnataka by Arif (2012)

Meena (2012) investigated the performance of ajwain genotypes in Udaipur circumstances. He concluded that AA-71 (114.19 cm) had the highest plant height, followed by AA-2 (114.13 cm) and AA-01-272 (112.00 cm).

In an experiment on coriander genotype carried out by Rajamanickam *et al.* (2012) at AICRP Spices HC&RI Periyakulam, ACr-1 recorded the maximum plant height at 40 days after sowing, while the genotype CS-II recorded the lowest.

The plant height ranged between 70.70 and 95.00 cm among forty-three ajwain genotypes evaluated under North Gujarat conditions (Ravindrababu *et al.*, 2012).

Giridhar *et al.* (2014) investigated the performance of thirteen coriander genotypes under Guntur circumstances. Their results revealed that LCC-237 produced the highest plant height of 68.00 cm, whereas DH-220 produced the lowest plant height (56.70 cm).

Meena *et al.* (2014) tested AA-93 at NRCSS Ajmer and MPUAT, Udaipur, Rajasthan. The experiment indicated that the AA-93 population attains a height of about

80.00 cm. In a trial with eighty-four genotypes of ajwain at Ajmer, Rajasthan, the plant height at harvest ranged between 85.06 and 140.72 cm (Meena *et al.*, 2015).

Bajad *et al.* (2017) investigated the seed yield performance of various coriander cultivars. Their findings revealed that the Sadhana had the highest plant height (73.9 cm), which was comparable to Pant Haritima (73.5 cm) and CO-2 (72.9cm). The variety Rajendra Swathi, on the other hand, was found to have the shortest plant height (62.9cm).

Singh *et al.* (2019) investigated thirty ajwain genotypes in Faizabad, Uttar Pradesh. According to the study, the plant height observed in the cases of NDAZ-21 and NDAZ-5 was 101.47 cm and 111.40 cm, respectively, with a general mean of 107.12 cm.

Ajwain genotypes were studied by Subramaniyan *et al.* (2019). GA-1 had a maximum plant height of 125.9 cm, according to their findings, which were accompanied by LTA-26 (115.4 cm). In Acc. No.9, the shortest plant height was found (85.92 cm).

Meena *et al.* (2020) tested different ajwain genotypes for growth and yield. They came to the conclusion that AA-93 (118.4 cm) had the highest plant height and AA-2 had the lowest plant height (109.7 cm).

Ranjeetha *et al.* (2020) tested different ajwain genotypes for growth and yield. The genotype GA-1 recorded the highest plant height (120.81 cm) at harvest and lowest height (85.77 cm) was registered in AA-93 at harvest.

Chaitanya *et al.* (2020) evaluated the sixteen ajwain genotypes under northern dry zone of Karnataka. They concluded that GA-1 recorded the highest plant height of 111.20 cm, whereas lowest plant height was noticed in DAC-4 (95.20cm).

2.1.3 Number of branches per plant

The coriander variety UD-347 had the greatest primary and secondary branches (12 and 29, respectively), whereas CO-1 had the fewest primary branches (6.3 per plant)

and CS-6 had the fewest secondary branches (9.0 per plant) according to Venkatareddy *et al.* (1986).

Easwarareddy *et al.* (1988) evaluated six varieties of coriander in Andhra Pradesh. The CO-2 plant has the most branches per plant (18.10), followed by the CS-4 plant (17.63).

The coriander genotype Pant-C-1 (9.33) had the most main branches during the *kharif* season, whereas DWD-3 had the fewest, according to Shridhar *et al.* (1990). (5.83). While IC-33728 has the most primary branches in *rabi* (11.00). The highest values for secondary branches were found in Pant-C-1 (19.40) and IC-67168 (26.20) during the *kharif* and *rabi* seasons, respectively.

Rajgopalan *et al.* (1996) examined 13 coriander cultivars and discovered that CO-3 had the most secondary branches per plant (17.8), followed by DH-5 (17.2), and CS-45 had the fewest (11.3). RCS-13 produced the most primary branches per plant (8.5).

Yadav (1999) examined the indigenous coriander germplasm under Jabhalpur circumstances, whereas RCS-2 and RCS-7 produced the least number of primary branches per plant.

Five ajwain genotypes were examined by Datta *et al.* (2001) in the Mohanpur area of West Bengal. They discovered that RA-2 had the most overall branches per plant (11.50). There were fewer branches per plant in the RA-6 genotype (6.85).

According to Gurbuz (2001), line-9 had 24.25 more branches per plant than line-15, which had the fewest (11.60). Singh *et al.* (2002) reported that among the 15 genotypes of coriander that were studied, C-8 (23.08) had the most branches and CS-7 the fewest (6.65).

Agarwal *et al.* (2003) evaluated the fennel accessions and examined for growth features. According to their findings, UF-178 had the most branches per plant (11.7), while UF-156 had the least branches per plant (5).

In the study of 11 coriander genotypes, CO-1 and RCr-41 had the highest primary (6.66/plant) and secondary (14.26/plant) branches and the lowest in Guntur Local (5.30/plant) and Gadag Local (11.06/plant) during the *kharif* season, respectively. In the *rabi* season, RCr-41 had the highest primary and secondary branches (8.20/plant and 16.53/plant, respectively) and the lowest in Gad (Velayudham, 2004).

Fennel genotypes were examined by Singh *et al.* in 2003 under humid sub-temperate conditions on the mid-hill. They discovered that EC-279039 (5.22), UF-(M)-1 (3.54), and UF-134 had the greatest main branches per plant (3.21). However, EC-278042 (1.20) and JF-345 have the fewest branches (1.20).

Patidar *et al.* (2004) conducted an investigation on evaluation of cumin genotypes for yield. They concluded that among different genotypes, RZ-19 showed maximum number of branches (4.2), whereas the minimum number of branches was observed in local genotype (3.9).

According to Giridhar and Sarada (2005), LCC-216 coriander variety had more primary branches (6.5/plant) and secondary branches (12.1/plant) than Sadhana (5.1 and 8.0, respectively). The results of the examination of seventeen coriander germplasm lines in the Terai zone of West Bengal, according to Datta and Choudhuri (2006) the primary and secondary branches per plant varied from 5.37-8.23 and 10.10-16.75, respectively. The genotype ACr-142 had the most primary branches per plant, while RCr-41 had the most secondary branches.

Divya (2007) examined 12 genotypes of coriander and discovered that IND-2 had the greatest primary branches (7.13), while Guntur Local had the lowest (4.87). However, when it comes to secondary branches, DWD-Purple (13.00) had the highest and Guntur Local had the lowest values (8.87).

In the Krishna-Godavari zone, twenty-four ajwain genotypes were examined by Sarada *et al.* (2009). According to the findings, genotypes LTA-3 and LTA-10 had similar numbers of main branches per plant (14.90 and 14.46), and LTA-3 had the most secondary branches per plant (51.29), on par with genotypes LTA-10 (49.34), LTA-6 (47.12), LTA-23 (43.44), and LTA-9 (43.44). (42.73).

Sunilkumar (2010) studied coriander genotypes and found that Sadhna had the most main and secondary branches (7.12 and 13.47, respectively), whereas Vijayavada Local had the lowest (5.82 and 9.07 cm respectively).

Arif (2012) assessed the genotypes of coriander. The genotype DCC-37 had the most main branches per plant (3.99) at 30 DAS, followed by Sudha (3.51), CO-4 (2.96), and RCr-446 (2.62), while Tarikere Local had the fewest (2.62) number of branches per plant. The maximum number of primary branches per plant were found in Sudha (5.19), CO-2 (4.37), CO-4 (4.23) and DWD-3 (3.99), while Tarikere Local had the fewest (2.03). The plant DCC-49 has the most secondary branches per plant (10.450), followed by Sudha (9.31), RCR-435 (8.94), RCr-436 (8.38), CO-4 (8.33), and Tarikere Local (2.03).

Meena (2012) assessed the performance of ajwain genotypes under Udaipur circumstances. The genotype AA-27 was found to have the most branches per plant, he concluded (11.70). However, AA-01-272 had the lowest number of branches per plant (7.00).

Rajamanickam *et al.* (2012) studied the evaluation among the nine genotypes evaluated, the genotype ACr-1 had the most primary branches and genotype CS-II had the fewest in an experiment carried out at AICRP Spices HC&RI Periyakulam.

At Tabji, Ajmer, Rajasthan, Meena *et al.* (2015) assessed eighty-four genotypes of ajwain. The primary branches per plant varied from 13.06 to 21.26 and the genotypes AA-73 and AA-01-272, which generated the most primary branches per plant were determined to be promising.

In Udaipur, Rajasthan, Nagar *et al.* (2019) evaluated the diversity in 25 ajwain genotypes and found that primary and secondary branches per plant ranged from 8.67 to 11.33 and 49.67 to 71.00, respectively.

Subramaniyan *et al.* (2019) evaluated ajwain genotypes. Their study revealed that Acc. No.3 showed highest number of branches per plant (16.80). The minimum number of branches per plant was observed in Acc. No.9 (11.90).

Meena *et al.* evaluated the growth and yield potential of various ajwain genotypes (2020). They came to the conclusion that AA-73 (14.3) had the most branches per plant, whereas AA-93 had the fewest branches per plant (12.9).

The growth and yield of various ajwain genotypes was examined by Ranjeetha *et al.* (2020). The genotypes DAC-8 and AA-93 reported the highest number of main branches (11.33) at harvest, whereas Lam Ajwain-2 recorded the lowest number (6.67).

Sixteen ajwain genotypes were evaluated under northern dry zone of Karnataka. Chaitanya *et al.* (2020) reported that the total number of branches in a single plant was maximum in AA-1 (18.20). The minimum number of branches in an individual plant was recorded in AL-4 (13.98).

2.1.4 Days to first flowering (10%) and 50 per cent flowering

Sharma and Bhati (1988) done field trial on varietal evaluation of coriander. RCr-41 an irrigated coriander variety of Rajasthan took 74 days to flowering and observed that day to 50 per cent flowering was less in case of CS-4 (66.71), while it was maximum in UD-41 (92.89 days).

Ten coriander genotypes and the check variety RD-41 were investigated by Maurya (1989). He believed that the genotype RD-42 required the fewest days (46.67) to reach 50% blooming. While the highest number of days (80.67) was found at position 5365.

According to Agrawal *et al.* (1990), among the 15 coriander entries investigated, entry CS-6 bloomed in 71.76 days whereas entry UD-374 took 97 days. The time it took for each of the nine accessions of coriander to reach 50% flowering also varied, ranging from 42.7 days in CS-208 to 44.3 days in CS-123.

Coriander cultivars UD-50, Rajendra Swati, UD-14, Pant Haritama, JCO-72, UD-115, UD-303 and a local cultivar were all studied in an experiment by Pan *et al.* (2003). They discovered that the local cultivar was the earliest for the beginning of blooming (61.22 days).

Velayudham (2004) evaluated the eleven genotypes of coriander, the RCr-41

recorded with maximum number of days taken for 50 per cent flowering (65.66 and 69.33 in *kharif* and *rabi* seasons, respectively). While, it was minimum in case of Guntur Local (39.00 and 42.33 days, respectively).

Giridhar and Sarada (2005) evaluated the coriander genotypes. Their results revealed that minimum days to 50 per cent flowering were found in LCC-192 (42.1). Whereas, the maximum number of days to 50 per cent flowering was observed in LCC-170 (49.3).

Divya (2007) evaluated 12 genotypes of coriander, she found that IND-2 (39.00 days), DWD-Purple (40.67 days), DWD-3 (41.67 days) and CIMPO-S-33 (42.33 days) had the lowest flowering days, while RCr-41 had the most flowering days (53.33 days).

Sudha is a high-yielding coriander (*Coriandrum sativum*) cultivar suitable for rainfed conditions of Andhra Pradesh (India) that performed better than existing cultivars but required a longer period of time to reach 50% flowering, according to Sarada *et al.* (2009) in their study on the evaluation of coriander cultivars.

Sunilkumar (2010) revealed that the variety Sadhana as the earliest to attain the stage of 50 per cent flowering by taking 40.00 days followed by DWD-3 (41.48 days), IND-2 (42.28 days) and the maximum days were taken by CO-1 (51.01 days) in a study on evaluation of coriander varieties.

The coriander genotypes DCC 8 (40.09) and DCC 37 (41.10) took minimum number of days to fifty per cent flowering followed by DWD-3 (42.55), CO-4 (47.79), RCr-446 (49.53), while DCC 2 (52.15) took maximum number of days for 50 per cent flowering was evaluated in coriander genotypes under hilly zone of Karnataka by Arif (2012)

Meena (2012) assessed the performance of ajwain genotypes under Udaipur circumstances. He came to the conclusion that the genotype AA-27 had the lowest number of days required to reach 50% flowering (80.67), whereas Lam selection-1 had the highest number of days required (86.33).

Rajamanickam *et al.* (2012) evaluated the nine genotypes of coriander at AICRP Spices, HC&RI Periyakulam, they discovered that ACr-1 (36.67 days) had the quickest

days to 50% flowering, while LCC-242 had the longest days to 50% flowering (42 days).

Forty-three genotypes were investigated by Ravindrababu *et al.* (2012) in North Gujarat and the range value for days to 50 per cent blooming was noted (87.00 to 98.00). Additionally, three year of data showed that, regardless of planting dates, the variety AA-93 only reaches 50 per cent blooming 46 days after sowing (Meena *et al.*, 2014).

Eight coriander genotypes were examined by Meena *et al.* (2013) in the southern plains of Rajasthan. The results showed that the genotype RKD-13 was equivalent to other genotypes and required significantly fewer days (minimum 56.00) to accomplish 50 per cent flowering than the best check RCr-436 (best 64.00). Similar to this, Moniruzzaman *et al.* (2013) found that CS001 and CS002 did not significantly vary, and that CS003 had the highest number of days for 50 per cent blooming (134.30 days), followed by CS002 (75.00 days) and CS001 (73.67 days). The genotype CS014 in Gazipur recorded the lowest time for 50% flowering (57.33 days).

Meena *et al.* (2014) performed research on an early maturing ajwain variety that was created at the National Research Centre for Seed Spices for all ajwain-growing regions. According to their findings, the AA-93 cultivar blooms (50%) early and within 46 days after seeding. It matures in 120–130 days, which is 30–40 days sooner than the other four ajwain cultivars.

In Jabalpur circumstances, Sengupta *et al.* (2014) evaluated thirteen fennel genotypes. In this study, FNL-39 recorded the shortest number of days to 50% blooming (102.66 days), whereas GF-11 required the longest number of days (116.00 days). Giridhar *et al.* (2016) investigated thirteen fenugreek genotypes in Guntur, Andhra Pradesh, and found that LFC-103 and PRM-45 were the first to blossom and used the fewest resources.

Bajad *et al.* (2017) assessed the performance of the coriander cultivars for seed output. According to their findings, Sadhana was the variety that started flowering at 50% of its potential in the fewest days (40.3), whereas Hissar Anand took the longest to reach 50% of its potential (64 days).

Twenty-five ajwain genotypes were examined by Meena *et al.* (2017) in Rajasthan, Udaipur and Pratapgarh. The study found that the genotype UA-53 (74.50) reported the fewest days to 50 per cent blooming, followed by UA-41 (75.25), UA-127 (75.33) and UA-168 (75.34).

Singh *et al.* (2019) assessed the performance of thirty genotypes of ajwain at NDUAT, Faizabad, Uttar Pradesh. Days to 50 per cent flowering was in the range from 86.33 days (NDAZ-20) to 103.33 days (NDAZ-2) and the general mean of this trait for all thirty genotypes was 95.74 days.

Meena *et al.* evaluated the growth and yield potential of various ajwain genotypes (2020). The least number of days required for 50 per cent blooming was found in AA-93 (65.00 days), while the largest number of days required for 50 per cent flowering was recorded in AA-2, they concluded (82.6 days).

The growth and yield of various ajwain genotypes was examined by Ranjeetha *et al.* (2020). While the genotype Lam Ajwain-2 recorded the largest number of days to first flower appearance (89.00 days), the genotype AA-93 recorded the smallest number of days to first flower appearance (53.00 days), and the days to 50 per cent blooming (65.00 days).

Chaitanya *et al.* (2020) evaluated the sixteen ajwain genotypes under northern dry zone of Karnataka. They concluded that the days taken for commencement of 50 per cent flowering AA-93 took minimum days (86.00). Whereas, the maximum days taken for commencement of 50 per cent commencement of flowering was noticed in DAC-7 (110.25).

2.1.5 Number of flowers per umbellates

Subramaniyan *et al.* (2019) evaluated ajwain genotypes. Their study revealed that Acc. No.3 showed highest number of flowers per umbel 339.6 followed by GA-1 (318.8). The least number of flowers per umbel was recorded in JA-172 (184.2).

Chaitanya *et al.* (2020) evaluated the sixteen ajwain genotypes under northern dry zone of Karnataka. They concluded that the highest number of flowers in an umbel

was noticed in AA-93 (304.10). While, the lowest number of flowers in an umbel was registered in AL-4 (150.70).

2.1.6 Days to physiological maturity

Venkatareddy *et al.* (1986) studied the twenty eight different coriander varieties in Andhra Pradesh under Lam circumstances. Of these, the genotype CS-6 matured in fewer days (78.3) than the regional cultivar Sital (98.3). When 19 coriander genotypes were produced in Dharwad settings, Shirdhar *et al.* (1990) looked into them and discovered that the genotypes showed different variances in days to maturity. The genotypes that matured in *kharif* the earliest (65 and 66 days, respectively) were DWD-6 and DWD-3, whereas Pant-C-1 took the longest (85). Days to maturity increased in *rabi* and ranged from 73 days for DWD-2 and DWD-3 each to 110 days for DWD/96/81-11.

Yadav (1999) carried out an experiment in Madhya Pradesh to assess the choice of Raigarh coriander. He claimed that RCS-1 and RCS-6 both reach maturity in 104 days, however that RCS-8 and RCS-11 displayed late maturation (110 days each).

Singhania *et al.* (2006) revealed that among the improved coriander cultivars of India, RCr-41 (130 days), RCr-20 (110 days), RCr-435 (115 days) and Swathi (95 days) and CO-4 (80-90 days) were among the cultivars that took the longest to reach physiological maturity.

According to Divya (2007) examination of 12 coriander genotypes, the genotype Guntur Local required the fewest days to reach physiological maturity (88.67 days), followed by Ghataprabha Local (91.33 days), DWD-3 (92.00 days) and DWD-Purple (93.33 days), while RCr-41 required the most (112.67 days).

Malhotra and Vashishtha (2008) described important coriander varieties in India and noted the days needed for each variety to reach maturity as follows: NRCSS-ACr-1 (130 days), GCr-1 (112 days), GCr-2 (120 days), Sadhna (100 days), Sindhu (102 days), and Azad Dhan (120-125 days) with Sadhna, Sindhu, GCr-1 and GCr-2 being described as medium duration varieties.

Sunilkumar (2010) examined the coriander varieties and reported that the variety

Swathi reached physiological maturity in the fewest days (72.13), followed by DWD-3 (73.33 days), Sadhana (74.14 days) and RCr-41 (which required the most days).

Sunilkumar (2010) noted the variety Swathi took the fewest days (72.13), followed by DWD-3 (73.33 days), Sadhana (74.14 days) and RCr-41 (the most days) to reach physiological maturity in the evaluation of coriander varieties.

Meena (2012) evaluated the performance of various ajwain genotypes in Udaipur. She deduced that AA-27 had an early maturation (149.55). On the other side, AA-2 displayed late maturity (159.17).

Arif (2012) studied the genotypes of coriander in the Karnataka hills. DCC-9 was the genotype that reached physiological maturity the earliest, maturing in 98.95 days, followed by Sudha (100.89 days), CO-4 (105.81 days), and Dharwad Local-3 (109.91 days), while genotype DCC-43 took the longest (112.18 days).

Moniruzzaman *et al.* (2013) examined the fourteen coriander genotypes at Gazipur, Bangladesh, the days to maturity ranged from 103.30 to 152.30. Similarly, early maturity was observed in FNL-37 (161.00 days) and late maturity was observed in FNL-43 (170.36 days) among thirteen genotypes of fennel evaluated under Jabalpur conditions (Sengupta *et al.*, 2014).

Meena *et al.* (2014) examined an early maturing ajwain variety developed at the National Research Centre for Seed Spices. According to their research, the AA-93 variety develops quicker than other ajwain cultivars (120–130 days). This cultivar does best is one with limited water resources.

Giridhar *et al.* (2016) evaluated thirteen fenugreek genotypes in Guntur, Andhra Pradesh and found that genotype PRM-45 took the fewest days to mature (80.10 days), followed by genotype AFG-3 (80.90 days), which was statistically comparable to one another and significantly earlier than the Hisar Sonali check (89.00 days).

In the Karnataka hill zone (Zone-9), fifteen coriander genotypes were examined by Hongal *et al.* (2018). The number of days to harvest in this research ranged from 86.00 to 90.00 days, with DCC-35 and DCC-36 having the lowest number of days to

harvest (86.00 days), and DCC-26 having the greatest number (90.00 days) (90.00 days).

Thirty ajwain genotypes were evaluated by Singh *et al.* (2019) at NDUAT, Faizabad, Uttar Pradesh. The results revealed that days to maturity ranged from 160.60 (NDAZ-12) to 193.73 (NDAZ-17).

Twenty genotypes of coriander were examined by Nandakumar *et al.* (2018) at Hiriyur, Karnataka, during the *rabi* season. In this study, genotype Rcr-446 (110 days) and Rcr-41 had the longest maturation times (110 days). While minimal in DCC-3 genotype (94.00 days).

The growth and yield of various ajwain genotypes was examined by Ranjeetha *et al.* in 2020. Maximum days to seed maturity were obtained in DAC-3 (168.33 days), AA-2 (168.33 days), Lam Sel-1 (168.33 days) and Lam Ajwain-2 (136.67 days) for the genotype AA-93 (168.33 days).

The sixteen ajwain genotypes were assessed by Chaitanya *et al.* (2020) in the northern arid zone of Karnataka. They came to the conclusion that the minimum harvest days documented in AA-93 (131.00). In DAC-7, late maturity was discovered (155.25).

2.2 Yield parameters

Differences in yield parameters were observed for number of umbels per plant, number of umbellates per umbel, number of seeds in an umbel, seed yield per plant (g), seed yield per plot (g) and kg/ha, harvest index (%) and test weight (g) by researchers in ajwain and other apiaceae family crops which are presented in the following headings.

2.2.1 Number of umbels per plant

According to Singh *et al.* (2003) among fennel genotypes assessed under mid-hill humid sub-temperate conditions, the number of umbels per plant was maximum in EC-279039 (74.47), followed by JF-345 (48.65) and JF-423 (44.77) and minimum in EC-243376-I (11.74).

Patidar *et al.* (2004) conducted an investigation on evaluation of cumin genotypes for yield. Among different genotypes, RZ-19 showed maximum number of

umbels in a plant (15.1). Whereas, the minimum number of umbels per plant were observed in local genotype (11.7).

An investigation was conducted to evaluate the coriander genotypes by Sunilkumar (2010). They found that among the different genotypes evaluated, genotype Sadhana recorded maximum number of umbels per plant (24.32). Whereas, the minimum 13.82 number of umbels per plant were recorded by Guntur Local, RCr-41 and LCC-128.

Performance of ajwain genotypes were evaluated by Meena (2012) under Udaipur conditions. He concluded that the maximum number of umbels in a plant was recorded in AA-27 (140.00), followed by AA-2 (135.16) and AA-84 (130.80).

Ravindrababu *et al.* (2012) assessed the performance of forty-three ajwain genotypes under North Gujarat conditions. The study revealed that the number of umbels per plant ranged from 12 to 22.

Malik and Tehlan (2013) assessed thirteen coriander varieties for growth parameters, seed yield and essential oil content at Hisar, India. In this study, the maximum number of umbels per plant was recorded in DH-233, which was significantly superior to all the other varieties except UD-475 and ACor-1.

Moniruzzaman *et al.* (2013) evaluated fourteen coriander genotypes at Gazipur, Bangladesh. In this study, umbels per plant ranged from 12.70 (CS010) to 33.37 (CS003).

An experiment was carried out to know the genetic variability of Ethiopian coriander genotypes for seed yield was studied by Awas *et al.* (2015). Their study revealed that accession 212830 had maximum number of umbels per plant (60.1), so that seed yield per plant was also maximum (14.5 g).

Sengupta *et al.* (2014) assessed thirteen genotypes of fennel under Jabalpur conditions. The results indicated that the genotypes FNL-40 (25.56) and FNL-42 (25.53) recorded maximum number of umbels per plant. While, the lowest was recorded in genotype FNL-39 (17.56).

Meena *et al.* (2015) screened eighty-four genotypes of ajwain at Ajmer, Rajasthan. The results revealed that number of umbels per plant varied from 97.98 to 339.12 and the genotype AA-73, as well as AA-01-272 were promising which reported maximum number of umbels per plant.

Jain *et al.* (2017) evaluated seventy-three accessions of coriander at Faizabad, Uttar Pradesh, wherein the umbels per plant varied from 31.36 (NDCor-33) to 96.67 (NDCor-64) and 30.24 (NDCor-40) to 88.48 (NDCor-50) in first and second year, respectively.

Anilkumar *et al.* (2018) evaluated sixteen coriander genotypes such as RCr-684, RCr-728, RCr-446, RCr-20, RCr-436, RCr-41, RCr-480, RCr-475, RCr-435, ACr-1, GCo-1, GCo-2, CO-1, CO-2, CO-3 and CO (Cr-4) for yield and yield attributes at Bengaluru, Karnataka. The study indicated that maximum number of umbels per plant (31.70) were recorded in (CO (Cr)-4).

In a study by Hongal *et al.* (2018) with fifteen coriander genotypes under hill zone of Karnataka, the maximum number of umbels per plant was recorded in DCC-28 (18.03 and 7.93), DCC-36 (16.83 and 7.70) and DCC-29 (16.33 and 7.50).

Subramaniyan *et al.* (2019) evaluated different ajwain genotypes. Their study revealed that Acc. No.3 showed highest number of umbels per plant 322.6. The least number of umbels per plant was noticed in Acc. No. 14 (148).

Singh *et al.* (2019) evaluated thirty ajwain genotypes at Faizabad, Uttar Pradesh for assessing genetic variability and heritability. The results indicated that, the number of umbels per plant ranged from 31.00 (NDAZ-16) to 37.20 (NDAZ-21). The general mean of the traits for all genotypes were found to be 33.85.

Telugu *et al.* (2019) evaluated fifty fennel genotypes at Hisar, Haryana, India. In this study, umbels per plant, umbellet per umbel and seeds per umbellet ranged from 23.67 to 71.40 and the maximum number of umbels per plant was recorded in genotype HF-169 (71.40) followed by HF-171 (69.93), HF-167 (69.10), HF-168 (66.67) and HF-173 (62.63) and the minimum was recorded in JF-12 (23.67).

Evaluation of different ajwain genotypes for growth and yield was conducted by Meena *et al.* (2020). They concluded that the maximum number of umbels per plant observed in AA-73 (249.5) and the minimum number of umbels per plant was observed in AA-93 (175.8).

As per Ramgiri and Nair (2020) the maximum umbels per plant among fennel genotypes were observed in check variety RF-101 (22.22), which was *at par* with UF-291 (18.47) and another check variety RF-205 (18.27). Similarly, the minimum number of umbels per plant was noticed in HF-212 (13.12) at Madhya Pradesh.

Ranjeetha *et al.* (2020) tested different ajwain genotypes for growth and yield. The genotype GA-1 reported significantly maximum number of umbels per plant (207.20) and minimum number of umbels per plant was reported in the genotype Lam Sel-1 (99.33).

Chaitanya *et al.* (2020) evaluated the sixteen ajwain genotypes under northern dry zone of Karnataka. They concluded that the AA-1 showed the highest number of umbels in an individual plant (213.00). The lowest number of umbels in an individual plant was recorded in AL-4 (98.25).

2.2.2 Number of umbellates per umbel

An investigation was conducted to evaluate the coriander genotypes by Sunilkumar (2010). Among the different genotypes evaluated, genotype Sadhana recorded maximum number of umbellates per umbels (5.43). Whereas, the minimum number of umbellates per umbel (4.17) were recorded in Guntur Local, RCr-41 and LCC-128.

Performance of ajwain genotypes were evaluated by Meena (2012) under Udaipur conditions. He concluded that the maximum number of umbellates per umbel was observed in AA-27 (12.30) and AA-2 (12.30). While, the minimum number of umbellates per umbel was observed in AA-01-272 (10.90).

Ravindrababu *et al.* (2012) assessed the performance of forty-three ajwain genotypes under North Gujarat conditions. The study revealed that the number of umbellates per umbel ranged from 8.70 to 16.70.

Moniruzzaman *et al.* (2013) evaluated fourteen coriander genotypes at Gazipur, Bangladesh. In this study, the maximum umbellates per umbel was observed in CS010 (6.67) and the lowest was noticed in CS003 (4.75).

Sengupta *et al.* (2014) assessed thirteen genotypes of fennel under Jabalpur conditions. The results indicated the umbellates per umbel were maximum in FNL-40 (38.16) and minimum in FNL-44 (27.30).

Meena *et al.* (2015) screened eighty-four genotypes of ajwain at Ajmer, Rajasthan. The results revealed that AA-73 and AA-27 were found to be promising w.r.t number of umbellates per umbel which ranged from 10.82 to 22.96.

Anilkumar *et al.* (2018) evaluated sixteen coriander genotypes such as RCr-684, RCr-728, RCr-446, RCr-20, RCr-436, RCr-41, RCr-480, RCr-475, RCr-435, ACr-1, GCo-1, GCo-2, CO-1, CO-2, CO-3 and CO-4 for yield and yield attributes at Bengaluru, Karnataka. The study indicated the maximum umbellates per umbel (8.30) were recorded in CO-4.

Singh *et al.* (2019) evaluated thirty ajwain genotypes at Faizabad, Uttar Pradesh for assessing genetic variability and heritability. The results indicated that, the umbellates per umbel ranged from 14.40 (NDAZ-29) to 27.20 (GA-1) respectively. The general mean of the traits for all genotypes were found to be 19.46.

Telugu *et al.* (2019) evaluated fifty fennel genotypes at Hisar, Haryana, India. In this study, umbellates per umbel and seeds per umbellates ranged from 17.93 to 33.37 and the maximum number of umbellates per umbel was recorded in HF-171 (33.37) followed by HF-169 (32.95), HF-168 (32.55) HF-173 (31.92) and HF-167 (29.39). While, minimum number of umbellates per umbel was observed in JF-12 (17.93).

Evaluation of different ajwain genotypes for growth and yield was conducted by Meena *et al.* (2020). They concluded that the maximum number of umbellates per umbel was observed in AA-73 (20.7) and the minimum number of umbellates per umbel was observed in AA-93 (17.3).

Ranjeetha *et al.* (2020) tested different ajwain genotypes for growth and yield. Maximum number of umbellates per umbel was reported in the genotype AA-1 (20.00), while minimum was recorded in the genotype Lam Sel-1 (11.33).

Chaitanya *et al.* (2020) evaluated the sixteen ajwain genotypes under northern dry zone of Karnataka. They concluded that AA-1 showed the highest number of umbellates in an umbel (15.33). The lowest number of umbellates per umbel was recorded in DAC-5 (10.40) and DAC-6 (10.40).

2.2.3 Number of seeds per umbel

Singh *et al.* (2003) tested fennel genotypes in humid sub-temperate conditions at a mid-hill elevation. According to their findings, EC-279039 (237.50) had the high number of seeds per umbel, followed by JF-345 (199.35) and JF-414 (414). (195.28). Genotype UF-(M)-1 had the low number of seeds in an umbel (71.52).

Patidar *et al.* (2004) investigated the yield of cumin genotypes. RZ-19 had the more number of seeds per umbel of all the genotypes (28). In contrast, the local genotype had the low quantity of seeds in an umbel (25.2).

Meena (2012) tested the performance of different ajwain genotypes in Udaipur. She came to the conclusion that AA-27 (149.20) had the more number of seeds per umbel, followed by AA-84 (149.40). (135.16). Local Bht had the fewest seeds per umbel (102.16).

Malik and Tehlan (2013) assessed thirteen coriander varieties for growth parameters, seed yield and essential oil content at Hisar, India. In this study, the maximum number of seeds per umbellet and seeds per umbel was recorded in variety DH-233 followed by DH-220 and UD-801.

Moniruzzaman *et al.* (2013) evaluated fourteen coriander genotypes at Gazipur, Bangladesh. In this study, maximum seeds per umbel were recorded in CS011 (35.63) and the minimum was recorded in CS005. Further, CS011 (6.74) followed by CS007 (6.42) and CS003 (5.48) recorded the highest number of seeds per umbellet but minimum was noticed in CS010 (3.020).

Sengupta *et al.* (2014) assessed thirteen genotypes of fennel under Jabalpur conditions. The results indicated that, the number of seeds per umbel was maximum in genotype FNL-40 (931.0) whereas, minimum in RF-205 (C) (556.60).

Meena *et al.* (2015) screened eighty-four genotypes of ajwain at Ajmer, Rajasthan. The results revealed the range value of the number of seeds per umbel (195.34 to 614.08). Besides, the genotypes AA-73 and AA-21 were found to give maximum number of seeds per umbel.

In a study by Hongal *et al.* (2018) with fifteen coriander genotypes under hill zone of Karnataka, the maximum seeds per umbellates was recorded in DCC-28 (18.03 and 7.93), DCC-36 (16.83 and 7.70) and DCC-29 (16.33 and 7.50). Similarly, among twenty coriander genotypes evaluated by Nandakumar *et al.* (2018) under the central dry zone of Karnataka, the maximum number of seeds per umbellates was recorded in the genotype Rcr-475 (5.70). While minimum was found in the genotype DCC-4 (3.80).

Ajwain genotypes were studied by Subramaniyan *et al.* (2019). According to their findings, Acc. No. 3 had the greater number of seeds per umbel (315). In contrast, Acc. No. 11 had the low quantity of seeds per umbel (166.7).

An investigation was conducted by Singh *et al.* (2019) with seventy-three coriander genotypes at Faizabad, Uttar Pradesh. In this study, seeds per umbellates ranged from 5.09 (NDCor-108) to 9.89 (NDCor-21). Accordingly, seeds per umbel varied from 32.06 (NDCor-14) to 42.83 (NDCor-92) with a general mean of 37.43.

Telugu *et al.* (2019) evaluated fifty fennel genotypes at Hisar, Haryana, India. In this study, seeds per umbellates ranged from 14.93 to 25.60. The maximum seeds per umbellates was observed in genotype HF-171 (25.60) followed by HF-168 (24.17), HF-167 (23.67), HF-169 (22.78), NDF-28 (22.73), HF-173 (22.65) and HF-180 (22.57). Whereas, a minimum number of seeds per umbellates was noticed in JF-12 (14.93).

Meena *et al.* (2020) tested different ajwain genotypes for growth and yield. The largest number of seeds per umbel in AA-73 (362.40) and the lowest number of seeds per umbel in AA-93 were discovered (291.11).

Ranjeetha *et al.* (2020) tested different ajwain genotypes for growth and yield. The genotype GA-1 registered maximum number of seeds per umbel (415.73), while minimum number of seeds per umbel was reported in Lam Sel-1 (177.33).

Chaitanya *et al.* (2020) evaluated the sixteen ajwain genotypes under northern dry zone of Karnataka. They concluded that AA-1 showed the highest number of seeds in an umbel (226.88) and the minimum number of seeds in an umbel was recorded in AL-4 (129.45).

2.2.4 Seed yield per plant (g)

Singh *et al.* (2003) investigated suitable fennel genotypes in Himachal Pradesh conditions. EC-279039 had the highest seed yield per plant (46.73 g), followed by JF-252 (30.01 g), EC-279042 (29.81 g) and EC-386375 (29.81 g) (28.76 g). As a result, they came to the conclusion that EC-279039, JF-252, EC-279042 and EC-386375 were promising genotypes in terms of yield.

An investigation by Sengupta *et al.* (2014) with thirteen genotypes of fennel under Jabalpur conditions revealed that significantly highest seed yield per plant was recorded in genotypes FNL-40 (62.43 g) and FNL-43 (59.23 g). Whereas, minimum seed yield was recorded in FNL-39 (27.60 g/plant).

Awas *et al.* (2015) conducted an experiment to determine the genetic variability of Ethiopian coriander genotypes for seed yield. They concluded that accession 212830 produced the highest seed yield (14.5 g) of any plant because it contains the most umbels (60.1).

Phurailatpam *et al.* (2016) assessed nineteen coriander cultivars under semi-arid conditions of Gujarat, India. In this study, the highest seed yield per plant was observed in JD-1 (10.78 g), which was *at par* with Sudha, Sindhu and RCr-41 and the lowest yield per plant was observed in RCr-20 (1.81 g) followed by Azad Dhanian-1 (2.65 g).

Bajad *et al.* (2017) investigated the seed yield performance of coriander cultivars. Their study revealed that the maximum seed yield per plant was recorded in the variety Pant Haritima (13.4 g), followed by Swati (11.9 g) and CO-2 (11.3 g). While, the minimum yield per plant was observed in Hissar Anand (7.1 g).

The seed yield per plant among twenty genotypes of fenugreek at Lucknow, Uttar Pradesh ranged from 4.74 (UM-401) to 12.12 g (UM410) and highest seed yield per plant was recorded in UM-410 followed by UM-408, UM-392, UM-395, UM-409, UM-398 and UM-393 (Narolia *et al.*, 2017).

Ranjeetha *et al.* (2020) tested different ajwain genotypes for growth and yield. The genotype GA-1 registered maximum seed yield per plant (13.37 g/plant), seed yield per plot (507.90 g/plot) and seed yield per hectare (13.37 q/ha). While, the genotype Lam Sel-1 recorded minimum seed yield per plant (5.02 g/plant), seed yield per plot (154.60 g/plot) and seed yield per hectare (4.06 q/ha).

Chaitanya *et al.* (2020) evaluated the sixteen ajwain genotypes under northern dry zone of Karnataka. They concluded that AA-1 noticed for its highest seed yield (10.99 g) per plant. While, AL-4 noted less for its seed yield of a single plant (5.20 g).

2.2.5 Seed yield (g) and (kg) per plot

Datta *et al.* (2001) tested five ajwain genotypes in West Bengal, Mohanpur region According to their findings, RA-2 had the highest seed output (503.32 kg/ha) while RA-6 had the lowest yield (273.5 kg/ha).

Thakral and Tehlan (2006) tested ten fennel types for growth and seed yield They discovered that the variety HF-33 had the highest seed output, with a 34.9 per cent increase over the local check, and that it outperformed all other cultivars except JF-200 and HF-39.

Sarada *et al.* (2009) tested twenty-four ajwain genotypes at the Lam Regional Research Station in Guntur. According to their findings, the LTA-3 genotype had greater number of umbellates per umbel and umbels per plant, followed by the LTA-10 genotype. As a result, the LTA-3 genotype had the highest yield (873 kg ha⁻¹) and was followed by the LTA-10 genotype (853 kg ha⁻¹).

Meena (2012) investigated the performance of ajwain genotypes in Udaipur circumstances. She concluded that the genotype AA-27 had the highest plant seed yield per plant (29.24 g), plot seed yield (1.43 kg) and seed yield per hectare (23.84 q).

Malik and Tehlan (2013) evaluated thirteen coriander genotypes for growth parameters, seed yield and essential oil content at Hisar, Haryana, India. In this study, maximum seed yield was recorded in DH-233 (2104 kg/ha) followed by DH-220 (2053 kg/ha) and UD-475 (1932 kg/ha) as indicated by three years pooled data.

Meena *et al.* (2013) assessed eight coriander genotypes under south-eastern plains of Rajasthan, India. The genotype RKD-18 recorded significantly higher seed yield (19.16 q/ ha) over RKD-25 (14.20 g/ha), RKD-29 (16.10 g/ha) and CS-6 (check) (16.43 g/ ha) and were statistically *at par* with RKD-27, RKD-36, RKD-13 and RCr-436 (check).

At the Horticultural Research Station in Lam, Andhra Pradesh, Giridhar *et al.* (2014) conducted an experiment on coriander genotype evaluation. The largest seed yield was observed in genotype LCC-237 (959.0 kg ha⁻¹) among ten genotypes studied, and they concluded that LCC-237 genotype performed best for that site.

Giridhar *et al.* (2017) looked at fourteen different ajwain genotypes in Andhra Pradesh. They came to the conclusion that LTA-26 was the best genotype for high grain yields of 1080 kg/ha, followed by LTA-25 (1007 kg/ha). These two genotypes produce the best yield and are relatively stable over a wide range of conditions.

Kurubetta *et al.* (2017) evaluated six coriander genotypes during *rabi* season at Haveri, Karnataka, India. Six years pooled data of this study revealed that the coriander genotype DCC 46 recorded significantly higher seed yield (1303.00 kg/ha) compared to check variety DWR-1 and was *on par* with the other genotypes of DCC 15, DCC 69, DCC 70, DCC 76 and DCC 81.

Hongal *et al.* (2018) tested fifteen coriander genotypes under the hill zone (Zone-9) of Karnataka. The study indicated that the genotype DCC-28 recorded the highest seed yield per plant (6.28 g), per plot (256.71 g) and per hectare (6.43 q) followed by DCC-36 (5.73 q/ha) and the lowest yield was recorded in DCC-37 (2.45 q/ha).

Ramgiri and Nair (2020) conducted a seed yield evaluation of fennel genotypes in Madhya Pradesh. They came to the conclusion that AF-206 had the highest seed

production (11.55 q/ha) followed by AF-205 (11.53q/ha) and NDF-67 (11.34q/ha). Early flowering was observed in AF-206. The per cent increase in yield over check is 37.17 and 17.14 per cent in RF-101 and RF-205, respectively.

Chaitanya *et al.* (2020) evaluated the sixteen ajwain genotypes under northern dry zone of Karnataka. They concluded that maximum seed yield was noticed in AA-1 (4.14 q). While, the minimum seed yield was recorded in AL-4 (1.88 q).

2.2.6 Harvest index (%)

Velayudham (2004) assessed coriander genotypes. He concluded that CO-1 had the highest harvesting index (57.05 per cent) and Guntur had the lowest (46.99 per cent).

Ajwain genotypes suitable for Jobner's semi-arid regions were explored by Singh and Choudhary (2008). According to their findings, harvest index (%) varied between 16.21 and 40.51 per cent in the genotypes JA-109, RPA-68, AA-35 and AA-4.

Meena *et al.* (2015) conducted a trial with eighty-four ajwain genotypes at Ajmer, Rajasthan. In this study, the genotypes AA-73, AA-21 and AA-27 were found to be promising w.r.t harvest index (%) and the range was from 26.15 to 56.55 per cent.

Hongal *et al.* (2018) investigated fifteen coriander genotypes for yield and quality under hill zone of Karnataka and reported that the genotype DCC-40 recorded a maximum harvest index (%) (56.67%) and the lowest was recorded in DCC-37 (34.63%). Similarly, in an investigation carried by Nandakumar *et al.* (2018) with twenty coriander genotypes under central dry zone of Karnataka, the harvest index (%) was maximum (56.52%) in the genotype Acr-1 while the genotype DCC-2 (38.36%) had the lowest harvest index.

Telugu *et al.* (2019) assessed fifty fennel genotypes at Haryana, India. In this study, harvest index (%) ranged from 9.06% to 24.16% and maximum harvest index (%) was recorded in genotype HF-171 (24.16 %) followed by HF- 173 (23.84%), HF-168 (23.13%), HF-169 (22.51 %), HF-167 (22.38 %) and NDF-38 (21.66%). While the minimum harvest index (%) was recorded in JF-12 (9.06 %).

Meena *et al.* (2020) studied the growth and yield of different ajwain genotypes. They discovered that AA-73 (35.33 per cent) had the highest harvest index (%), while AA-93 had the lowest harvest index (33.96 per cent).

Ranjeetha *et al.* (2020) tested different ajwain genotypes for growth and yield. The genotype DAC-8 recorded maximum harvest index (19.97 %) and minimum was recorded in the genotype DAC-5 (14.38 %).

Chaitanya *et al.* (2020) evaluated the 16 ajwain genotypes under Northern dry zone of Karnataka. They concluded that AA-1 recorded maximum harvest index (30.29 %). Whereas, the harvest index (%) was recorded minimum in DAC-2 (13.66%).

2.2.7 Test weight (g)

An investigation was conducted to evaluate the coriander genotypes by Sunilkumar (2010). His study showed that among the different genotypes evaluated, genotype Sadhana recorded maximum test weight (17.10 g). Whereas, the lowest test weight (9.76 g) was recorded by Guntur Local, RCr-41 and LCC-128.

Performance of ajwain genotypes was evaluated by Meena (2012) under Udaipur conditions. She concluded that the maximum test weight was observed in Local Bht (1.50 g), followed by GA-1, AA-2 and AA-21 (0.87 g).

Ravindrababu *et al.* (2012) assessed forty-three ajwain genotypes under North Gujarat conditions. In this study, the seed weight was in the range from 0.66 to 1.14 g. The genotypes AA-27 and AA-84 were found to be promising w.r.t test weight and the range of test weight recorded was 0.48 to 1.40g (Meena *et al.*, 2015).

Meena *et al.* (2013) evaluated eight coriander genotypes under south-eastern plains of Rajasthan. In this study, the genotype RKD-18 recorded the highest test weight (12.60 g) followed by RKD-27 (12.50 g) which was significantly superior to check RCr-436 (11.13 g) and RKD-25 (10.95 g).

Moniruzzaman *et al.* (2013) tested fourteen coriander genotypes at Gazipur, Bangladesh. In this study, maximum test weight was recorded in CS002 (12.00 g) followed by CS001 (11.00 g) and CS003 (11.00 g) and no significant difference was

observed between CS001 and CS003. While, lowest test weight (8.00 g) was observed in six genotypes viz., CS005, CS006, CS009, CS010, CS012, and CS014.

Nandakumar *et al.* (2018) tested twenty genotypes of coriander for growth, yield and quality under central dry zone of Karnataka. In this test, the genotype Rcr-475 (14.53 g) recorded the highest test weight and was lowest in the genotype Rcr-436 (8.07 g).

In an evaluation conducted by Telugu *et al.* (2019) with fifty fennel genotypes at Haryana, India, the test weight ranged from 3.47 g to 9.51 g and the maximum was recorded in genotype HF-171 (9.51 g) followed by HF-169 (9.27 g), HF-168 (8.53 g), HF-173 (8.22 g), HF-167 (7.43 g) and NDF-38 (7.37 g). In contrast, the minimum was recorded in JF-12 (3.47 g).

Singh *et al.* (2019) assessed the performance of thirty genotypes of ajwain at NDUAT, Faizabad, Uttar Pradesh and the range of test weight was between 1.19 g (NDAZ-14) and 3.09 g (NDAZ-8). Also, the general mean of this trait for all thirty genotypes was found to be 2.35 g.

Evaluation of different ajwain genotypes for growth and yield was conducted by Meena *et al.* (2020). They concluded that the maximum test weight was observed in AA-2 (1.17 g) and the least test weight was observed in AA-93 (0.88 g).

Ranjeetha *et al.* (2020) tested different ajwain genotypes for growth and yield. The maximum test weight was recorded in the genotype DAC-6 (1.15 g per 1000 seeds) and minimum test weight was reported in the genotype AA-93 (0.62 g per 1000 seeds).

Chaitanya *et al.* (2020) evaluated the sixteen ajwain genotypes under northern dry zone of Karnataka. They concluded that the maximum test weight was observed in AA-1 (1.67 g). The genotype AL-4 showed least test weight of 0.89 g.

2.3 Quality Parameter

Differences in quality parameters was observed for essential oil, oleoresin and thymol content by researchers in ajwain and other apiaceae family crops. A brief review of results is presented as under.

In the quality attributes of ten genotypes of coriander, Maurya (1989) found the highest oil content of 0.52 per cent in RD-44 followed by 0.40 per cent in RD-42 whereas minimum oil content was observed in CS-2 (0.19%).

Agrawal *et al.* (1993) evaluated the coriander varieties for essential oil purpose and reported that the yield of essential oil was maximum in local variety and CS-287 (0.37% each). It was minimum in DH-5 and UD-436 (0.18% each).

In a study regarding the quality attributes of fifteen genotypes of coriander, Singh *et al.* (2002) found that the highest oil content of 0.40 per cent was in S-33 followed by 0.10 per cent in RCr-20, whereas oil yield was more in RCr-41 (4.18 kg/ha).

Agrawal *et al.* (2003) evaluated seventy-four fennel genotypes for quality parameters. UF-177 was found to have highest essential oil content (2.6 per cent). UF-179 was having high anethole content (40.49 per cent).

Performance of coriander genotypes for quality characters was studied by Prabhu and Balakrishnamurthy (2006). They concluded that accession UD-243 was found to have highest volatile oil content of 0.34 per cent. Whereas, the least oil content was found in local accession 812 (0.19 per cent).

In a study on evaluation of coriander genotypes at northern Karnataka by Velayudham *et al.* (2004), 11 genotypes were evaluated for quality during *kharif* and *rabi* seasons. The cultivars CO-3 and RCr-41 recorded the highest oil yield of 5.83 kg/ha and 5.84 kg per hectare respectively.

In an investigation on evaluation of 12 genotypes of coriander Divya (2007) noticed the highest essential oil content in CIMPO-S-33 (0.73%) followed by Sindhu and CO-4 (0.43%), and the lowest in Ghataprabha Local (0.30%). As per the yield of essential oil per hectare is concerned the highest oil yield was in CIMPO-S-33 (5.03 kg/ha) and the lowest was in Ghataprabha Local (1.47 kg/ha).

Tehlan *et al.* (2007) in their experiments on evaluation of coriander varieties described Hisar Surbhi (DH-246), a very promising variety of coriander which is high yielding having good oil content (0.425%).

Sunilkumar (2010) in a study on evaluation of coriander varieties observed the variety CIMPO-S-33 registered highest essential oil content of 0.74 per cent followed by RCr-41 (0.61%), CO-4 (0.55%), Swathi (0.49%) and the lowest was in Ghataprabha Local (0.23%). The essential oil yield per hectare was highest in CIMPO-S-33 (3.98 kg/ha) followed by RCr-41 (3.70 kg/ha) and the lowest was in Ghataprabha Local (1.21 kg/ha).

In an experiment to evaluate the coriander genotypes, it was reported that Indian corianders are poor in essential oil content (0.2 to 0.8%) as compared to European types (1.4 to 1.7%). Among the genotypes evaluated CS-101 recorded maximum oil content (0.54%), followed by UD-685 (0.47%) and CS-136 (0.43%) and these genotypes can be used successfully for further breeding programmes. They also reported that variation in the in essential oil might have been due to the promotive or inhibiting mechanism through physiological and biochemical reactions in the genotypes (Palanikumar and Rajamani, 2012).

Two genotypes of ajwain were evaluated for the estimation of total essential oil content by Saxena *et al.* (2012). They reported that Ajmer Ajwain-1 was found superior for essential oil content of 4.94 per cent with an oil recovery of 7.66 per cent. While, Ajmer Ajwain-2 gave 3.93 per cent of essential oil with an oil recovery of 11.5 per cent.

Malik and Tehlan (2013) studied the performance of thirteen coriander cultivars/accessions for various growth parameters, seed yield and essential oil at Hisar, India. The three years pooled data of this study indicated that, the variety DH-220 gave the highest essential oil content (0.39 %). Similarly, in an experiment conducted by Meena *et al.* (2013) under south-eastern plains of Rajasthan with eight coriander genotypes, the highest essential oil content was obtained in RKD-18 (0.40 %) which was 20.60 % higher over best check RCr-436 (0.03 %) and essential oil content in seed was lowest in RKD-13 (0.24 %) and check CS-6 (0.24 %).

In an investigation with five black cumin populations collected from different provinces, maximum essential oil content and fixed oil was recorded in Eskisehir population (Kara *et al.*, 2015).

Saxena *et al.* (2016) conducted an experiment on evaluation of fennel genotypes. They concluded that essential oil content in fennel genotypes varies from 1.0 to 3.3 per cent. AF-05-12-1 genotype was found to have maximum volatile oil content (3.3 per cent) and GF-2 contains minimum essential oil content (1.0 per cent).

Ahl and Omer (2016) tested eight dill cultivars under Egyptian conditions and reported that the essential oil content ranged from 1.93-3.26 % and the highest oil content was recorded in variety Common and Compatto. In case of thirty-seven black cumin accessions evaluated, fixed oil per cent ranged from 13.76 to 30.12 per cent (Emran *et al.*, 2017). The essential oil yield in cumin varieties RZ-209 and GC-4 was 4.0 % and 4.33 % respectively at Western Rajasthan (Khan *et al.*, 2017).

Agarwal *et al.* (2018) evaluated five varieties of fennel for essential oil content. They observed that the total essential oil of five fennel varieties varied between 1.51 per cent and 2.02 per cent. Hisar swarup variety was found superior for oil content (2.02 per cent).

Anilkumar *et al.* (2018) evaluated sixteen coriander genotypes under Eastern dry zone of Karnataka and observed maximum essential oil content (0.66 %) in the genotype CO (Cr-4). Similarly, seed oil content in coriander genotypes under hill zone of Karnataka ranged from 0.06 to 0.27 per cent and maximum was observed in DCC-33 (0.27 %) followed by DCC-27 (0.26 %) and least in DCC-30 (0.06 %) (Hongal *et al.*, 2018). Similarly, the maximum essential oil content (0.8 %) was found in genotype Acr-1 and Rcr-728. While, the lowest essential oil content (0.1 %) was noticed in genotype DCC-4 under the central dry zone of Karnataka (Nandakumar *et al.*, 2018).

An experiment was carried out to know the performance of twelve fennel varieties for quality traits under eastern dry zone of Karnataka by Shivaprasad *et al.* (2018). They revealed that among twelve fennel varieties, RF 281 was found to have maximum oil content (1.94 per cent).

Ranjeetha *et al.* (2020) tested different ajwain genotypes for growth and yield. The oil content was maximum in the genotype DAC-7 (3.60 %) and minimum oil content was recorded in the genotype DAC-3 (2.43 %).

Chaitanya *et al.* (2020) evaluated the sixteen ajwain genotypes under northern dry zone of Karnataka. Their study revealed that the highest essential oil content was recorded in AA-1 (2.33 per cent). whereas, lowest oil content was found in GA-1 (1.20 per cent). Oleoresin content in ajwain differed remarkably among the ajwain genotypes. The highest oleoresin content was noticed in DAC-5 (7.15 per cent), followed by DAC-4 (6.36 per cent) and AL-4 (4.29 per cent). The lowest oleoresin content was found in AL-3 (1.91 per cent).

2.4 Disease and pest scoring

Pest and disease incidence was more in *rabi* season due to favourable climatic conditions. Some of the pests and diseases were most serious in specific region and they become major problem in production of ajwain. Thus, identifying the resistance genotypes in ajwain crop improvement programme is of prime importance. The research on this aspect is cited as under.

2.4.1 Powdery mildew

In Madhya Pradesh, Keshwal and Khatri (1998) evaluated coriander cultivars for their resistance to powdery mildew. CS-15, CS-362, and CS-52 had the lowest disease incidence percentages (19.6-24.3%). CS-7 and CS-358 had the highest occurrence.

Kalra *et al.* (2003) conducted an experiment on screening of coriander genotypes against powdery mildew. They revealed that CIMAP 2096 and CIMAP 2053 showed tolerance to powdery mildew and were found suitable for high yield and essential oil.

Among the 224 coriander accessions from Tamil Nadu, Coimbatore district were examined for powdery mildew resistance and it was demonstrated that 14 accessions, with CS-1 receiving the lowest grade (26.00) were resistant to illnesses caused by powdery mildew (Subramanian *et al.*, 2003).

According to Datta and Choudhuri (2006) study of coriander genotypes from West Bengal, Terai zone, coriander germplasm lines exhibited high variability for the bulk of the parameters considered. In RCr-41 or ACr-69, there was no indication of wilt or stem gall disease.

Tehlan *et al.* (2007) identified Hisar Surbhi (DH-246) a very promising coriander variety that is high producing and less prone to powdery mildew disease, in their study on the evaluation of coriander varieties.

Meena *et al.* (2013) discovered that the Sindhu, CO-3, RCr-41, GCr-1 and GCr-2 cultivars of coriander were resistant to powdery mildew in their screening trial of coriander genotypes at the National Research Centre on Seed Spices, Ajmer.

In Gwalior, Madhya Pradesh, Kashyap *et al.* (2020) tested fifteen coriander cultivars for the powdery mildew disease (*Erysiphe polygoni*). The powdery mildew disease was observed to affect all fifteen coriander cultivars with Jawahar Dhania-1 showing the lowest prevalence (20.83%), followed by CS-6 (21.67%), CO-2 (24.32%), UD-375 (24.81%) and G-5365 (25.56%). While, the cultivar CS-7 (56.56%) showed the highest level of disease intensity.

2.4.2 Wilt

Out of 25 cultivars of cumin were examined by Arora and Kant (2004) for their ability to against blight and wilt in uncultivated settings. The cultivars UC-220, EC-232684 and UC63 shown the highest levels of wilt resistance, whereas cultivars RZ-19, UC-90, UC-231, JC-2000-72, CMB-134, and Jobner local demonstrated the highest levels of vulnerability. Out of the 12 cumin cultivars, UC-310 had the best blight resistance, while UC-220 and UC-231 had the best wilt resistance.

Champawat and Singh (2008) identified *Fusarium oxysporum f. sp. cumini* resistance-bearing sources and employ them in resistance-breeding programmes. Although a few high producing cumin strains, including S404, MC43, GC1, GC3 and RZ19 have recently been produced and there are currently no wilt resistant variants available due to the limited genetic diversity of cumin.

Thirty fenugreek varieties were tested by Choudhary *et al.* (2016) for resistance to *Fusarium oxysporum* and the results showed that none of the entries were immune or wilt-resistant. However, the types UM-100, 112, 116, 118, 124, 126, 127, 134, 137, 301, 302, 304, 322 and 325 were found to be only moderately resistant to *Fusarium*

oxysporum, while UM-128, 136, 140, 152, 163, 222, RMT-1 and RMT-361 were shown to be susceptible are UM-144, 189, 193, 202, 228, 321, 35.

Thirty coriander genotypes/varieties were tested in the field under artificial inoculation circumstances for resistance to *Fusarium oxysporum*. Based on two years of observations, it was noted that 19 genotypes/varieties, including RCr-475, RCr-480, RCr-728, UD-796, RD-366, UD-426, UD-483, CO-3, UD-743, UD-744, were resistant (R) to four of the genotypes/varieties., UD-744, DH-246, NS-2, UD-728, UD775, UD-630, UD-707, DH-208, RD-120 and RD-154 as moderately resistant, four genotypes/varieties viz., NS-1, J.Co-387, Co-2, and UD-529 as susceptible and rest three genotype/varieties viz., RCr-435, RCr-446, DH-205 as highly Susceptible (Jat and Ahir, 2019).

2.4.3 Aphids

Meena *et al.* (2002) conducted an experiment on genotypes reaction of coriander against aphids. They concluded that UD-684, RCr-436 and RCr-446 were least susceptible. RCr-41 and local cultivars were highly susceptible to aphids.

Nair *et al.* (2007) screened fifty-nine accessions representing twenty-six *Trigonella* species and two *Medicago* species for resistance against blue-green aphid (*Acyrtosiphon kondoi* Shinji) and spotted alfalfa aphid (*Therioaphis trifolii* (Monell) *fm. maculata*) at California. The study revealed that the accession SA 32223 was found to be highly resistant to both the aphids.

Ghadage *et al.* (2009) conducted an experiment on screening of genotypes of coriander against aphid. Their results revealed that the genotype Dhana-98 was susceptible, which was on a line with K-selection, Gcr-2, Jcr-391 and Gcr-1. While, the genotype EC-363974 was most susceptible.

Coriander varieties were screened for their susceptibility to aphid by Tatarwal *et al.* (2012). They revealed that RCr-436 and RCr-684 were less susceptible. Whereas UD-728 and RCr-41 were highly susceptible.

A study conducted by Yadav *et al.* (2018) at Bikaner, Rajasthan revealed that late sown cumin (5th December) crop had higher aphid (*Myzus persicae*) infestation

followed by crop sown on 25th November. While, early sown crop (25th October) had the least aphid infestation but highest yield (2.30 q/ha) was obtained from the November 5th sown crop.

2.4.4 Stem fly

Since, there was no report of stem fly on ajwain crop, the reviews on stem fly incidence on soyabean crop was discussed and compared with the present incidence of stem fly on ajwain crop.

Upadhyay (2017) carried out an investigation on screening of soybean genotypes against stem fly (*Melanagromyza sojae*). Among genotypes, JS 20-122 recorded the less per cent of stem fly incidence (4.67 per cent). Whereas, the maximum per cent of stem fly incidence was observed in genotype JS 20-111 (20.82 per cent).

Among the 50 genotypes of soyabean, 5 genotypes exhibited minimum stem fly incidence viz., TGX 849-D-13-4 (25.69%), EC-390981 (28.50%), VP-1143 (28.97), EC 241 771 (32.24%) and SQL-89 (34.74%), 23 genotypes had medium stem tunneling incidence percentage and 16 genotypes had maximum stem tunneling incidence percentage (Azmi and Sharma, 2020).

The sixteen ajwain genotypes were assessed by Chaitanya *et al.* (2020) in the northern arid zone of Karnataka. Their research showed that the incidence of stem flies ranged from 20.91 to 45.40 percent. The incidence of stem flies was lower in the genotype AA-1 (20.91 per cent). AL-4 had the highest incidence of stem flies (45.40 per cent).

2.5 Genetic variability

Singh and Choudhary (2008) experimented the ajwain genotypes which is most suited for semi-arid climates. The largest genetic advance and genotypic coefficient of variation were found in seed yield per plant and harvest index (%), whereas plant height, total number of branches per plant, umbels per plant, days to 50 per cent flowering, seeds per umbel, umbellates per umbel, and 1000 seed weight had moderate to low GCV.

Among the forty two genotypes of ajwain germplasm were evaluated by Ravindrababu *et al.* (2012) in the conditions of Northern Gujarat. Their research showed that every qualitative and quantitative characteristic, including the number of umbels per plant (12–22), the number of umbellates per plant (8–16), the number of days until physiological maturity (15–162) and the number of umbellates per plant (8–16) had a wide range of variability.

According to research by Meena *et al.* (2015), ajwain exhibits low genetic variability for traits like AA-93 for earliness, AA-21 and AA-73 for high seed output per plant, AA-84 and AA-27 for high test weight and AA-21, AA-27, AA-73 for high harvest index (%). It can be used to develop cultivars with high yields.

Meena and Dhakar (2017) carried out a study on genetic variability, correlation, and route analysis in fennel genotypes. Their research showed that the largest genotypic and phenotypic coefficients of variation were found in the number of umbels per plant (24.65%), number of secondary branches (20.93%), and seed production per plot (21.74). Umbel density per plant (94.9%) and seed production per plot. The number of umbels per plant (94.9 per cent) and seed output per plot had a high heritability (96.1 per cent). The highest levels of genetic progress were seen in the number of umbels per plant (24.25) and seed output per plot (0.53).

An experiment was carried out by Patel *et al.* (2018) to ascertain the genetic diversity in fennel. They discovered that the two plant characteristics with the largest genotypic and phenotypic coefficients of variation were the number of umbels (15.85 and 17.72%) and seed production (25.14 and 26.97 per cent). High heritability was seen in the number of branches in a plant (46.79%) and the number of umbellates per umbel, whereas days to 50% blooming (93.02%), umbels in a plant (80.06%), days to maturity (96.89%) and seed production of a plant (86.90%) exhibited medium heritability (28.62 per cent).

An investigation on the genetic diversity of coriander germplasm was done by Verma *et al.* (2018). Among the various germplasms examined, NDCor-63, NDCOR-79, NDCOR78, NDCor-91 and NDCor-81 were identified to be promising genotypes for plant seed production. The phenotypic coefficient of variation was highest for seed

production and lowest for days to 50% blooming, whereas the genotypic coefficient of variation was highest for umbels in a plant.

A study was conducted by Singh *et al.* (2019) to ascertain the genetic diversity of ajwain. The number of main branches per plant, the number of umbellates per umbel, and the weight of the grains per umbel were the factors with the largest phenotypic and genotypic coefficients of variation, respectively. For seed yield per plant, the genotypes NDAZ-22, NDAZ-20, NDAZ-27, NDAZ-25, and NDAZ-5 were shown to be the most promising. High heritability was discovered for a variety of traits, including test weight (93.19%), weight of grains per umbel (89.64%), number of branches per plant (85.99%), number of umbellates per umbel and days to maturity.

The sixteen ajwain genotypes were assessed by Chaitanya *et al.* (2020) in the northern arid zone of Karnataka. For every characteristic examined, the phenotypic coefficient of variation (PCV) exceeded the genotypic coefficient of variation (GCV). The oleoresin content, number of umbels per plant, and harvest index had the highest genotypic coefficient of variance and phenotypic coefficient of variation. All of the qualities have substantial heritability estimates. However, at 150 DAS, the least for plant height. The oleoresin content and quantity of umbels per plant were determined to have the largest genetic progress as a percentage of the mean.

2.6 Correlation and path analysis

Bahraminejad *et al.* (2011) assessed 49 cumin ecotypes in Iran. Association study revealed the highest correlation between seed output and the number of seeds per umbel and umbel per plant. According to the path analysis research, the quantity of umbels and seeds per umbel had a direct impact on seed output.

Jain *et al.* (2013) examined fifty samples of fenugreek germplasm in Ajmer, Rajasthan, together with five standard controls, including Hisar Suvarna, Hisar Sonali, RMt-361, RMt-1 and AFg-3. Path coefficient analysis revealed that the test weight, seeds per pod, total number of pods per plant, number of pods on the main axis, secondary branches per plant and plant height were all important factors in the selection of high yielding lines.

In Southern Ethiopia, 39 coriander accessions were examined by Kassaun *et al.* (2013). The research discovered that the genotypic level and the phenotypic level showed stronger correlation coefficients. The number of seeds per plant and seed output per plant were significantly and favourably correlated at the phenotypic and genotypic levels. Additionally, it was shown that the majority of the qualities examined were adversely connected to essential oil and fatty oil levels. Path analysis revealed that seeds per umbellates, plant height, days to 50% maturity, longest basal leaf length and days to 50% blooming all had a favourable direct impact on seed output per plant.

Meena *et al.* (2014) evaluated the twenty four different coriander genotypes in Akola, Maharashtra. The findings of path coefficient analysis showed that the number of seed per umbel, number of secondary branches, number of umbels per plant, test weight (g), plant height, leaf area and chlorophyll content all had a favourable effect on seed output.

Patahk *et al.* (2014) evaluated forty genotypes of fenugreek in Navsari, Gujarat. In this study, it was discovered that the number of seeds per pod, the number of pods per plant, the length of the pod and the protein content all had a significant and positive link with seed output per plant. According to the results of the path coefficient analysis, plant height has the biggest positive direct impact.

Ghanshyam *et al.* (2015) carried out an experiment on how to determine the correlation and path analysis in ajwain for yield and its components. They came to the conclusion that the number of umbellates in each umbel and the total number of umbels on a plant had the most favourable impact on seed production.

Thirty fenugreek genotypes were examined by Gurjar *et al.* (2016) in Mandsaur, Madhya Pradesh. Dry matter per plant, biological yield per plant and 1000 seed weight were shown to be positively correlated with seed production per plant. Path coefficient study revealed that seed production per plant, dry matter content per plant and the number of seeds per pod had the most direct beneficial effects of biological yield.

At Tabiji, Ajmer, Rajasthan, Meena *et al.* (2016) evaluated nineteen genotypes of cumin. The path coefficient analysis revealed that seed yield was directly influenced by primary branches, secondary branches and seed per umbel.

Singh *et al.* (2016) tested thirty fenugreek genotypes during the *rabi* season in Mandsaur, Madhya Pradesh. The correlation coefficients at the phenotypic and genotypic levels were significant and favourably correlated with leaf chlorophyll content, pods per plant, straw yield per plant, 1000 seed weight, plant dry matter content and seed yield per plant, while negatively correlated with harvest index (%). Similarly, route co-efficient analysis revealed that biological yield per plant, harvest index, dry weight at flower initiation, chlorophyll content in leaves, number of branches per plant and 1000 seed weight were all significant factors in seed production.

In fennel genotypes, Meena and Dhakar (2017) conducted a study on genetic variability, correlation, and path analysis. At the phenotypic and genotypic level, they concluded that seed output was significantly and positively associated with test weight, number of umbellates in an umbel and essential oil. The quantity of umbels per plant (7.09) had the maximum positive direct effect on seed yield, according to path coefficient analysis.

Faravani *et al.* (2018) investigated morphological features of cumin and ajwain populations in Iran using correlation and path coefficient analysis. Their research resulted that 27 ajwain germplasm had significantly different seed yields, ranging from 38 to 61.3 g per plant to 72-245 g per plant, with an oil content of 3.08-11.22 per cent. Flowering period varied by 45 days, while physiological maturity varied by 69 days according to the genotypes.

The genotypes of ajwain (*Trachyspermum ammi* L.) were evaluated by Ranjeetha *et al.* (2020) for growth, yield, and quality in the eastern dry zone of Karnataka. Primary branches per plant, umbels per plant, umbellates per umbel, seeds per umbel, thousand seed weight and harvest index (%) all showed a positive direct genotypic and phenotypic influence on seed yield per plant, according to path coefficient analysis.

Twenty-five ajwain genotypes correlation and path coefficients for factors that contribute to yield were examined by Rawat *et al.* in 2020. The path coefficient analysis showed that the factors with the largest direct impact on seed output per plant were days to start flowering, test weight, the number of seeds in an umbel, plant height at maturity, the number of umbellates per umbel and days to maturity.

Singh *et al.* (2020) conducted research to determine the correlation and path analysis for seed yield and its component qualities in ajwain. They concluded that at the phenotypic level, there was a positive and substantial association between seed yield per plant and the number of umbels per plant, plant height, weight of grains per umbel and 1000 seed weight. Whereas, negative and significant correlation was observed by number of branches per plant.

Using sixteen genotypes, Chaitanya *et al.* (2020) investigated the relationships between yield components and their direct and indirect impacts on seed yield. The number of umbels per plant, harvest index, branches, test weight, flowers per umbel, and number of seeds per umbel all showed positive associations with seed output per plant. Genotypic path coefficient study revealed that plant height at 150 DAS, days to 50% blooming, the number of flowers and umbellates in each umbel, harvest index (%) and test weight (g) all had a positive direct impact on ajwain seed output.

2.7 Genetic diversity

Singh *et al.* (2002) evaluated the genetic relationship and distances in a collection of 15 Indian accessions of coriander, consisting of 8 land races and 7 cultivars. The analysis showed that the material had a significant amount of genetic distance, with D^2 values ranging from 37.4 (between the genotypes C-2 and DH-5) to 1309. (between the genotypes C-1 and RCr-20). Eight clusters were formed from the genotypes. The geographical variety of the genotypes was discovered not to affect genetic diversity. When genetic association and D^2 analyses were combined, the findings showed that the variation in seed yield was the most significant factor accounting for both changes in oil yield and genetic distance in the material.

Mahalanobis distance (D^2) analysis based on 15 characteristics that was used to determine the genetic divergence among 49 Ethiopian coriander (*Coriandrum sativum* L.) accessions. Eight clusters were formed from the accessions. Clusters I and V, which each had seven accessions, were the next largest with 12 accessions after Clusters II and III. Clusters I and VIII had the greatest intercluster distance (480.5), followed by clusters V and VIII (462.2) and clusters II and VIII (336.1). (Mengesha *et al.*, 2011).

Fourteen coriander genotypes were subjected to assess the genetic diversity and Mahalanobis generalized distance (D^2) was used to assess the divergence present among the genotypes. Three clusters were formed from the 14 genotypes. Maximum genotypes were found in cluster III (19), followed by 3 in cluster I and 2 in cluster II. In every situation, the inter-cluster distances are bigger than the intra-cluster distances. Cluster II had the most intra cluster distance, whereas cluster III had the lowest. Clusters I and III were predicted to have the greatest intercluster distance (16.470), followed by Clusters I and II (16.372) and Clusters II and III (16.370). highest leaves per plant, plant weight, foliage output, days to first umbel unfolding and seed harvest, plant height at green plant harvest, at bolting age, days to green plant harvest and to bolting stage were all greatest in Cluster I, days to seed harvest, umbel circumference, umbels per plant, days to 1st umbel unfolding and 1000-seed weight. Cluster III showed maximum primary and secondary branches per plant, seeds per umbel, seed yield both per plant and hectare. The plants of cluster I and cluster III were free from stem gall disease (Moniruzzaman *et al.*, 2013).

Fufa (2013) studied the principal component and cluster analysis based on 8 characteristics to analyse the genetic divergence of 25 land races of coriander. Five clusters were created out of the accessions. The largest cluster was found in cluster I, which had 19 accessions. The accessions included in these clusters seeds to maturity (17.01%) contributed the most to genetic divergence and so had a significant part in the improvement of ajwain. High inter-cluster distance (47.42) was discovered between cluster IV, cluster II and IV (47.33), and cluster I and IV (41.47).

Awas *et al.* (2016) used Mahalanobis D^2 statistics to study the genetic divergence of eighty one coriander genotypes, which were then divided into eight clusters. About 51.8 per cent and 2.4 per cent of the genotypes under study are found in the largest cluster (II) and the smallest cluster (VIII), respectively. Clusters II and VIII showed the greatest and smallest intra-cluster distances ($D^2=7.48$ and 1.31, respectively). Cluster VI and Cluster VIII had the greatest intercluster distance ($D^2=329.85$), while Cluster I and Cluster IV had the smallest distance ($D^2=19.02$), suggesting that there may be genotypes among the genotypes that are ideal for a hybridization programme.

Using Mahalanobis D^2 analysis, Singh *et al.* (2017) calculated the genetic divergence among the 30 ajwain genotypes for ten characteristics. The six groups formed by the genotypes under study. With seven genotypes, cluster IV was the biggest of the six clusters. Greater genetic variety between the genotypes of various groups is suggested by the fact that the inter-cluster distance was greater than the intra-cluster distance. Clusters IV (83.61) and VI (29.15) had the greatest and smallest intra-cluster distances, respectively. Between clusters III and IV (198.03), the intercluster D^2 values were at their highest, indicating a large range of genetic diversity. Cluster VI had the highest cluster mean for both number of branches per plant and seed yield/plant (36.44g) (10.45). The characters like test weight (32.41%), number of umbellets per umbel (20.46%) and days to maturity (17.01%) contributed maximum to genetic divergence and hence played a major role in improvement of ajwain.

Singh *et al.* (2017) found that cluster V with three genotypes (NDAZ-7, GA-1, and NDAZ-10) had the highest plant height (108.22 cm), followed by cluster IV (107.71 cm) with seven genotypes (NDAZ-6, NDAZ-11, NDAZ-13, NDAZ-19, NDAZ-12, NDAZ-14, and NDAZ-15) and cluster II with four genotypes (106.45 cm) (NDAZ-4, NDAZ-18, NDAZ-8 and NDAZ-23).

Meena *et al.* (2018) assessed twenty-eight genotypes of coriander during *rabi* season. Genotypes were grouped into 12 clusters. Minimum inter-cluster D^2 value (2.57) was estimated between clusters II and V, whereas the maximum inter-cluster D^2 value (9.54).

Twenty-eight varieties were grouped into 5 clusters on the basis of observed similar D^2 values among genotypes within a cluster as compared to genotypes in another cluster. Cluster II includes a maximum number of genotypes *i.e.* 14 followed 9 in cluster V, 3 in cluster I and cluster III, IV were monogenotypic. The clustering pattern revealed that, in general varieties from the same origin showed no tendency to be in the same cluster (Nagar *et al.*, 2019).

2.8 Molecular characterization

Aiello *et al.* (2010) selected thirty-nine SSR markers from carrot and tested for their transferability score and only 23% of them resulted suitable for fennel. The low

rate of SSR transferability between the two species evidences the difficulties of the use of genomic SSR in cross-genera transferability.

Five RAPD-PCR primers were used to identify polymorphism in the three different coriander cultivars. A total of 33 fragments were delineated, 10 out of them were polymorphic. The genotype frequencies of the examined coriander cultivars RAPD-PCR variations were 55.56, 20, 25, 0 and 27.27, with an average polymorphism of 30.30 percent indicating minimal genetic diversity (Kordy *et al.*, 2013).

A total of 38 Randomly Amplified Polymorphic DNA (RAPD) markers produced a total of 3721 fragments with an average of 7.13 bands. Jaccard's similarity coefficient ranged from 88 percent to 56 percent whereas the polymorphism using RAPD primers ranged from 38 percent to 100 percent. Inter Simple Sequence Repeats (ISSR) were detected using a total of 28 primers, resulting in 142 total fragments and an average of 5.07 bands. The overall grouping pattern of cluster analysis clearly showed the variability among each genotype (Tomar *et al.*, 2014).

Choudhary *et al.* (2017) discovered that 35 of the 39 SSR loci were monomorphic and specific to carrot primers, indicating that the size of SSR loci was similar to that previously reported for carrot. Four SSRs were polymorphic, and seven primer pairs were non-specific, with band sizes that differed from the SSR source. The primer GSSR-113 was non-specific, however the microsatellite loci showed polymorphism. Coriander breeding and genetics should benefit greatly from these SSR markers.

For marker validation, 25 primer pairs were randomly selected and amplified in 30 cumin genotypes and five other species of family apiaceae namely, dill seed, parsley, celery, fennel and ajwain. From 23 markers, a total of 79 alleles were identified with the mean of 3.43 alleles per marker with polymorphism information content (PIC) ranged from 0.03 to 0.70. The average gene diversity and heterozygosity was 0.44 and 0.53, respectively (Bharti *et al.*, 2018).

Thirty molecular markers for carrots from eight different taxa, including five seeds, three vegetables, and two seasonings or sauces. The study showed that phylogenetic assessment utilising an un-rooted neighbour joining tree (NJ) and principal

coordinate analysis was used to analyse the genetic diversity across the genera for the various loci and the transferability of these carrot markers (PCoA). Eight crops with an average of 3.39 alleles/locus showed an average amplification of 66.66 percent, with a total of 73 alleles from 30 loci. Gene diversity was 0.56, the effective number of alleles was 2.92, the average polymorphism information content was 0.50 and the greatest fixation index of 0.82 was found among 18 polymorphic markers (Cholin *et al.*, 2018).

Jethra *et al.* (2018) investigated the identification and characterisation of microsatellite markers in fenugreek. They discovered 100 carrot SSR loci in fenugreek, with 19% of SSRs amplified and 5 primers that were monomorphic. 14 SSRs were polymorphic, with bands ranging from two to five. GSSR-87, GSSR-92, GSSR-136, and BSSR-8 all had monomorphic bands and were specific for fenugreek genotypes, making them a valuable tool for fenugreek breeding and genetic research. GSSR-81 and GSSR-96 were the most polymorphic in nature and can be used to differentiate fenugreek from other seed spices.

Jogarana *et al.* (2019) used the genome of the ajwain to generate and validate simple sequence repeat markers. They reported that they tested 25 SSR primers in 5 genotypes of ajwain, including Ajmer ajwain-1, Ajmer Ajwain-2, Ajmer Ajwain-93, Gujarat Ajwain-1, and Gujarat Ajwain-2. 19 primers were amplified from a total of 25 primers, yielding a total of 24 bands. The amplicon with the biggest amplicon, 734 bp, was amplified by SSR primer AJ 12 and smallest fragment of 58 bp was applied by SSR primer AJ16. The polymorphic primer can be used in genetic diversity analysis of Ajwain and its relatives.

Budania *et al.* (2019) selected fifteen decamer random primers of which 12 primers gave good amplified products with template DNA. They gave 64 scorable fragments. Out of 64 scorable bands, 44 bands were polymorphic. The average percentage of polymorphism was found to be 64.58 per cent. The amplified product size ranged between 100 to 1800 bp. From RAPD profiling, similarity matrix was obtained and jaccard's similarity coefficient ranged from 0.40 to 0.83 and on this basis a dendrogram was constructed with UPGMA method. Dendrogram differentiate 15 Coriander genotypes in nine major clusters. Average effective multiplex ratio (2.79), multiplex ratio (3.89), Rp (6.19), MI (1.95), band informativeness (mIb) (1.47) and PIC

(0.70) of the primers were calculated for RAPD marker system. In conclusion, RAPD markers are effective in establishing relationship among the genotypes.

For molecular characterization two DNA based molecular marker techniques viz., random amplified polymorphic DNA (RAPD) and inter-simple sequence repeat (ISSR) were used in coriander. A total of 27 polymorphic primers (18 random and 9 ISSR) were used. Amplification of genomic DNA of 24 genotypes, using RAPD analysis, yielded 83 fragments in which 57 (70.46%) were polymorphic. The 9 ISSR primers produced 37 bands across 24 genotypes, of which 17 (49.81%) were polymorphic (Choudhary *et al.*, 2019).

Using morphological and molecular markers, Nagar *et al.* (2019) evaluated 28 genotypes of ajwain (*Trachyspermum ammi* L.), consisting of 25 genotypes and 3 checks and assessed their genetic diversity (RAPD markers). 10 of the 18 decamer RAPD primers were found to be polymorphic with an average of 5.16 polymorphic bands per primer. The similarity coefficient ranged from 0.07 (GP-113 and GP-7) to 0.58 for various genotypes (Gujarat ajwain-1). The average similarity (0.32) across all genotypes shows minimal genetic similarity between genotypes and high polymorphism (100%) and variability (78%) for all genotypes under investigation, according to RAPD and morphological analyses, respectively.

To determine genetic diversity using a random amplified polymorphic DNA (RAPD) marker, 23 genotypes of coriander were chosen. Using 14 RAPD primers, a total of 72 amplified bands were produced, 48 of which were polymorphic. An study of RAPD data revealed 64.34 percent polymorphism. With an average of 7 bands per primer, the total number of amplified bands ranged from 3 (primer S-34) to 11 (primer OPB-06). The PCR-amplified products total sizes varied from 300 bp to 3000 bp. The PIC ranged from 0.041 to 0.695, with an average of 0.229. Three RAPD primers and three genotypes produced three distinct bands. These distinct bands have widths between 300 and 1400 bp.

Kumar *et al.* (2020) performed survey sequencing as well as in-silico generation and validation of genome SSR markers in Indian dill seed. They discovered that 10 (83%) of the 12 primers could be effectively amplified in dill seed, yielding 11 amplicons. 9 out of 10 primers could be successfully amplified in related genera during cross-genera amplification of markers.

3. MATERIAL AND METHODS

The present investigation entitled “**Morphometric and molecular characterization of ajwain (*Trachyspermum ammi* L.) genotypes under northern dry zone of Karnataka**” was carried out at department of Plantation, Spices, Medicinal and Aromatic Crops (PMA), College of Horticulture, Bagalkot during October 2020 to March 2021 and October 2021 to March 2022. The details of material used and experimental methods adopted are described under following headings.

3.1 Geographical location of the experimental site

The field experiment was carried out at department of PMA, College of Horticulture, Bagalkote, at an altitude of 533 meters above mean sea level (MSL) at 16° 46' N latitude and 74° 59' E longitude in the Northern dry zone of Karnataka (zone-III).

3.2 Climatic conditions of the experimental site

Bagalkote comes under zone-3 of region-2 among the agroclimatic zones of Karnataka, which has benefits of both North-East and South-West monsoons. The average rainfall, temperature, relative humidity, wind speed *etc* during the experiment period is enclosed in Appendix I and II.

3.3 Soil conditions of the experimental site

The soil of the experimental site was black loamy with the pH of 8.62, EC (0.35 dS/m) and organic carbon content (0.36%).

3.4 Experimental details: The present experiment was conducted for 2 seasons during *rabi* 2020-21 and 2021-22.

Evaluation of ajwain (*Trachyspermum ammi* L.) genotypes under northern dry zone of Karnataka

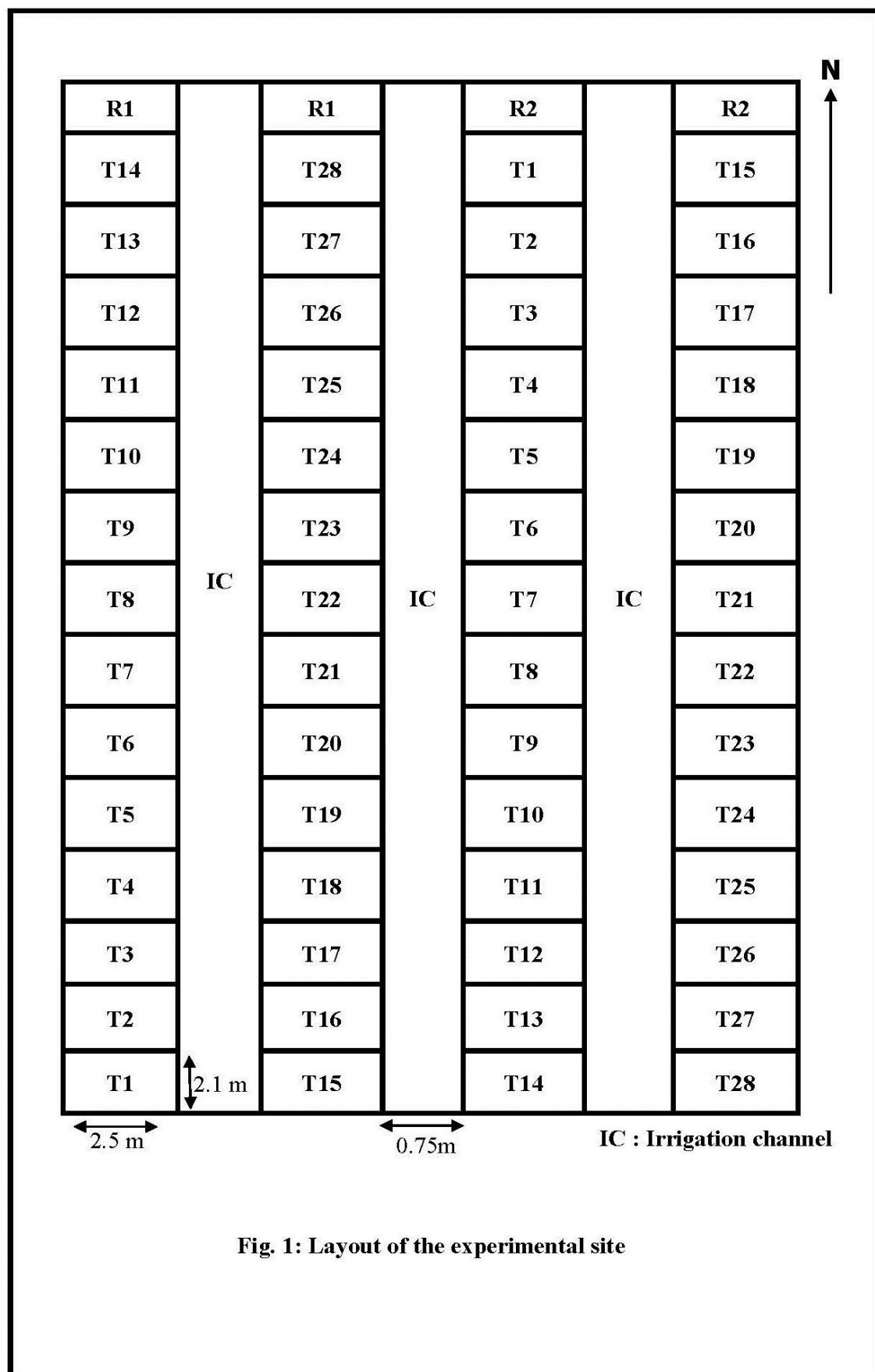
1. Year: 2020-21 and 2021-22 (Two seasons)
2. Crop: Ajwain
3. Design: Randomized Complete Block Design (RCBD)
4. Number of treatments: 28

5. No. of replications: 2
6. Season: *Rabi* (October)
7. Spacing: 50 cm × 30 cm
8. Plot size: 2.5 m × 2.10 m
9. Seed rate: 2.5 kg per ha

3.4.1 Treatments details:

Twenty-eight germplasm were evaluated during 2020-21 and 2021-22 of *rabi* season for growth yield and quality traits. Out of 28 genotypes, 16 were released varieties and 12 were local collections. The treatments were as follows:

- | | |
|-----------------------------------|---------------------------------|
| T ₁ : Ajmer Ajwain 1 | T ₂₅ : HUB-10 |
| T ₂ : Ajmer Ajwain 2 | T ₂₆ : HUB-11 |
| T ₃ : Ajmer Ajwain 93 | T ₂₇ : HUB-13 |
| T ₄ : Gujarat Ajwain 1 | T ₂₈ : Rajendra mani |
| T ₅ : Ajwain Local 3 | |
| T ₆ : Ajwain Local 4 | |
| T ₇ : Lam Selection 1 | |
| T ₈ : Lam Selection 2 | |
| T ₉ : LTA 26 | |
| T ₁₀ : DAC-1 | |
| T ₁₁ : DAC-2 | |
| T ₁₂ : DAC-3 | |
| T ₁₃ : DAC-4 | |
| T ₁₄ : DAC-5 | |
| T ₁₅ : DAC-6 | |
| T ₁₆ : Azad Ajwain - 1 | |
| T ₁₇ : HUB-1 | |
| T ₁₈ : HUB-2 | |
| T ₁₉ : HUB-3 | |
| T ₂₀ : HUB-4 | |
| T ₂₁ : HUB-5 | |
| T ₂₂ : HUB-6 | |
| T ₂₃ : HUB-8 | |
| T ₂₄ : HUB-9 | |



3.4.2 Experimental materials

Table 1. List of genotypes and source of collection

SN	Genotypes	Source
1	Ajmer Ajwain -1 (AA-1)	National Research Centre for Seed Spices (NRCSS), Ajmer, Rajasthan.
2	Ajmer Ajwain -2 (AA-2)	National Research Centre for Seed Spices (NRCSS), Ajmer, Rajasthan.
3	Ajmer Ajwain -93 (AA-93)	National Research Centre for Seed Spices (NRCSS), Ajmer, Rajasthan.
4.	Gujarat Ajwain 1 (GA-1)	Sardarkrushinagar Dantiwada Agricultural University, Gujarat.
5	Ajwain Local 3 (AL-3)	National Research Centre for Seed Spices (NRCSS), Ajmer, Rajasthan.
6	Ajwain Local 4 (AL-4)	National Research Centre for Seed Spices (NRCSS), Ajmer, Rajasthan.
7	Lam Selection-1 (LS-1)	Regional Agricultural Research Station (RARS), Guntur, Andhra Pradesh.
8	Lam Selection-2 (LS-2)	Regional Agricultural Research Station (RARS), Guntur, Andhra Pradesh.
9	LTA-26	Regional Agricultural Research Station (RARS), Guntur, Andhra Pradesh.
10	DAC-1	Horticulture Research and Extension Centre (HREC), Devihosur, Haveri.
11	DAC-2	Horticulture Research and Extension Centre (HREC), Devihosur, Haveri.
12	DAC-3	Horticulture Research and Extension Centre (HREC), Devihosur, Haveri.
13	DAC-4	Horticulture Research and Extension Centre (HREC), Devihosur, Haveri.
14	DAC-5	Horticulture Research and Extension Centre (HREC), Devihosur, Haveri.
15	DAC-6	Horticulture Research and Extension Centre (HREC), Devihosur, Haveri.
16	Azad Ajwain-1	Azad Agricultural University, Kanpur, UP
17	HUB-1	Famers collection from Bidar

18	HUB-2	Famers collection from Raichur
19	HUB-3	Famers collection from Gulbarga
20	HUB-4	Famers collection from Belgavi
21	HUB-5	Famers collection from Bijapur
22	HUB-6	Famers collection from Gadag
23	HUB-8	Famers collection from Bagalkot
24	HUB-9	Famers collection from Bagalkot
25	HUB-10	Famers collection from Bagalkot
26	HUB-11	Famers collection from Bagalkot
27	HUB-13	Famers collection from Bagalkot
28	Rajendra mani	Ranjendra Prasad Agriculture University, Bihar

3.5 Cultural practices

3.5.1 Land preparation

Land was furrowed, harrowed and then plots were made. Experimental plot was partitioned into plots size of 2.5 m × 2.10 m. While, the land preparation well decayed farmyard manure at the rate of 10 tons per hectare was applied.

3.5.2 Application of fertilizers

Recommended dose of fertilizer (100: 50: 50 NPK kg ha⁻¹) was applied in the form of urea at 217.00 kg per ha , MOP at 83.00 kg per ha and SSP at the rate of 312.50 kg per ha. Full dose of potash, phosphorous and half dose of nitrogen were applied as basal dose and remaining nitrogen was given after 30 days after sowing (DAS).

3.5.3 Sowing of seeds

The seeds were line sown drill as per the recommended seed rate (2.5 kg ha^{-1}) at the spacing of 50 X 30 cm. Seeds were sown in individual plots separately.

3.5.4 Thinning of seedlings

Thinning of seedlings was done after complete emergence in the field, the excess seedlings in the rows were thinned out to maintain a plant spacing of 30 cm between the two plants within the rows in order to maintain the recommended spacing of 50 X 30 cm.

3.5.5 Irrigation

A light irrigation was given immediately after sowing of seeds and subsequent irrigations were given to the crop at different intervals according to the need of crop. A total of 15 irrigations were given during the experimental period.

3.5.6 Weeding

The plots were kept weeds free by regular hand weeding at 30, 60 and 90 days after sowing.

3.5.7 Plant protection

Stem fly (*Melanagromyza* sp.) occurrence was noticed in the field. Stem fly damage was effectively managed by spraying Spinosad 45 SC at 0.62 ml/l and application of fipronil 0.3% granules.

3.5.8 Harvesting

Depending upon the maturity of genotypes, ajwain plants were harvested when 80 per cent of the seeds were completely matured and seeds turn to brown colour. The matured plants were harvested by uprooting the whole plant and after that tied with little thread for making the bundles and stacked for shade drying. After drying of bundles, the seeds were separated by beating the plant delicately against threshing floor, winnowed and stored in moist free condition.

3.6 Observations on growth parameters

Five plants from each plot were randomly chosen and then labeled for recording the observations. The border row plants were avoided.

3.6.1 Days to germination

After sowing as per treatments, the experimental location was visited daily and all the seeds under the experiment were observed and the days taken for germination were recorded.

3.6.2 Plant height (cm) at 60, 90, 120, 150 days

The height of the plants was recorded with meter scale from the base of the plant to its developing tip at 60, 90, 120 and 150 days after sowing (DAS). Mean plant height was obtained by summing up the height of all the five labeled plants and partitioning it by five.

3.6.3 Number of branches per plant at 60, 90, 120, 150 days

The branches from the five randomly chosen plants of each plot were counted at harvest. The average value was computed and expressed as number of branches per plant.

3.6.4 Days to first flowering (10%)

Five rows were chosen in each plot except the border plant and dates of completion of blossoming on 10 per cent were observed and recorded. Based on date, days taken to 10 per cent was worked out for each of the plot.

3.6.5 Days to 50 per cent flowering

Five rows were chosen in each plot except the border plant and dates of completion of blossoming on 50 per cent were observed and recorded. Based on date, days taken to 50 per cent was worked out for each of the plot.

3.6.6 Number of flowers per umbellates

Two umbellates were selected randomly from each tagged plants at flowering stage and total flowers were counted and then average flowers per umbellates was worked out.

3.6.7 Days to physiological maturity

Days taken by plants when the blooming ceases and seeds start to develop and the seed colour become brown in umbels was taken as days taken for maturity.



Plate 1. General view of experimental plot

3.7 Observations on yield parameters

3.7.1 Number of umbels per plant

All seed-bearing umbels were checked from the labeled plants and their mean number of umbels per plant was calculated.

3.7.2 Number of umbellates per umbel

The number of seed bearing umbellates in main umbel was counted from the individually labeled plants and average esteem was recorded.

3.7.3 Number of seeds per umbel

Two umbels were selected randomly from each tagged plants, total seeds were counted and then average seeds per umbel was worked out.

3.7.4 Seed yield per plant (g)

After threshing and winnowing, seeds obtained from five randomly labeled plants were weighed. The average esteem was recorded and expressed as seed yield per plant in grams.

3.7.5 Seed yield per plot (g) and (kg/ha)

After threshing and winnowing of seeds obtained from individual plots were weighed. The average esteem was recorded and expressed as seed yield per plot in grams and kg per hectare.

3.7.6 Harvest index (%)

Harvest index (HI) is the proportion of seed yield to biological yield of the plant and it was calculated by using the following formula:

$$\text{Harvest index (H.I.)} = \frac{\text{Seed yield per plant (g)}}{\text{Biological yield per plant (g)}} \times 100$$

For biological yield, the whole biomass including seed was calculated by weighing the entire plant at maturity.

3.7.7 Test weight in grams (1000 seed weight)

1000 seeds were counted from each sample were taken from the winnowed seeds and weight was expressed in grams.

3.8 Observations on quality parameters

3.8.1 Essential oil (%)

The ajwain oil from the dried ajwain seeds was extracted by hydro-distillation using using Clevenger apparatus (Sadgrove and Jones, 2015). For distillation process, dried ajwain seeds of known amount (100 g) was used in powdered form and taken in the flask, water is added (1000 ml) to the flask and distilled for three hours. During the distillation process care was be taken to keep the condenser cool by using tap water. The temperature for boiling was kept up at 70° C until boiling and after that it was decreased to 60° C for three hours for distillation. The liberated oil was condensed and collected in graduated portion of refining unit. The quantity of essential oil obtained was noted after the completion of distillation. The essential oil collected was isolated from the water and stored in air tight glass vessel. The oil content was calculated and expressed as percentage using the following formula;

$$\text{Essential oil (v/w)} = \frac{\text{Volume of oil (ml)}}{\text{Weight of the sample (g)}} \times 100$$

3.8.2 Oleoresin estimation (%)

One gram of dried ajwain seeds were coarsely powdered and after that subjected to Soxhlet apparatus for oleoresin extraction (Sontakke *et al.*, 2018). One gram of ajwain powder was filled into thimble of Soxhlet assembly. This Soxhlet apparatus has four extraction units (beaker), each beaker was filled with 80 ml of petroleum ether through the open end so that the seeds were properly dipped in it. After completion of extraction with petroleum ether to expel greasy acids, extraction was carried out progressively by distinctive solvents of the increasing polarity such as benzene, chloroform, ethyl acetic acid derivation and methanol. The oleoresin content was calculated and expressed as percentage using the following formula:

$$\text{Oleoresin (\%)} = \frac{\text{Final weight of the beaker (g)} - \text{initial weight of the beaker (g)}}{\text{Weight of the sample (g)}} \times 100$$

3.8.3 Thymol content

Sample (1.0 g) was extracted using methanol (10 mL) under shaking for overnight at 37 °C. The sample extracts were centrifuged at 5000 rpm for 15 min at 4 °C. The supernatants obtained were filtered using PVDF membrane (0.2 µ) and used for HPLC further analysis.

HPLC experiment was performed using a Waters Alliance system attached to a Phenomenex C18 column (4.6 mm x 250 mm, 5µ), quaternary pump and diode array detector. The mobile phase was an isocratic combination of acetonitrile (ACN): H₂O (50:50) with a flow rate of 1 ml/min. Injection volume for all samples and standard solutions was 10 µl. The quantification was done at 280 nm.

3.9 Disease and pest scoring

3.9.1 Powdery mildew

There was no incidence of powdery mildew in the experimental plot.

3.9.2 Wilt

Plants were not affected by wilt.

3.9.3 Aphids

Plants were not affected by aphids.

3.9.4 Stem fly

Stem fly incidence was observed in the experiment at 60 DAS, even though it was not a pest of ajwain. Infected leaves and stems turn to pinkish red colour later turns to yellow colour and distinct zigzag tunnel was made by maggots or pupae inside, some exit holes were present on the stem. Later whole plant dries up and ultimately plant died. The stem fly incidence was calculated and expressed as percentage using the following formula:

$$\text{Stem fly incidence (\%)} = \frac{\text{Number of plants infested}}{\text{Total number of plants}} \times 100$$

The stem fly incidence was scored based on following index (Azmi and Sharma, 2020).

0: Immune

1-10 per cent: Highly resistance

10-25 per cent: Resistance

25-50 per cent: Moderately resistance

50-75 per cent: Susceptible

>75 per cent: Highly susceptible

3.10 Statistical analysis

The experimental details were subjected to statistical analysis of variance according to Panse and Sukhatme (1967). Statistical significance was tested by F value at five per cent level of significance. The critical differences at five per cent were worked out, where “F” test was found significant.

3.10.1 Analysis of variance (ANOVA)

ANOVA was done separately for each character of all the treatments.

Source of variation	Degrees of freedom	SS	MSS	F-ratio/s
Genotypes	t-1	GSS	$MSSg = \frac{GSS}{t-1}$	$MSSg/MSSe$
Replication	r-1	RSS	$MSSr = \frac{RSS}{r-1}$	
Error	(t-1) (r-1)	ESS	$MSSe = \frac{ESS}{(t-1) (r-1)}$	
Total	tr-1	TSS		

SS- Sum of square

RSS-Replication sum of square

MSS- Mean sum of square

GSS-Genotype sum of squares

ESS- Error sum of square

MSSg-Genotypic mean sum of square

MSSe- Error mean sum of square

MSSr- Replication mean sum of square

3.10.2 Study of variability parameters in ajwain genotypes

The variability among the ajwain genotypes for different traits were estimated as mentioned below.

3.10.2.1 Genotypic, phenotypic and environmental variances

Genotypic, phenotypic and environmental variances were computed based on the expected mean sum of squares from the ANOVA.

$$\text{Genotypic variance } (\sigma_g^2) = \frac{\text{Treatment MSS} - \text{Error MSS}}{r}$$

Where, σ_g^2 = Genotypic variance

r = replications

$$\text{Phenotypic variance } (\sigma_p^2) = \sigma_g^2 + \sigma_e^2$$

Where, σ_g^2 = Genotypic variance

σ_p^2 = Phenotypic variance

σ_e^2 = Environmental variance

3.10.2.2 Genotypic (GCV) and Phenotypic (PCV) coefficient of variation

Phenotypic and genotypic coefficient of variances was estimated according to Burton and Devane (1953) based on estimate of genotypic and phenotypic variance.

$$\text{Genotypic coefficient of variance (GCV)} = \frac{\sqrt{\sigma_g^2}}{\bar{X}} \times 100$$

$$\text{Phenotypic coefficient of variance (PCV)} = \frac{\sqrt{\sigma_p^2}}{\bar{X}} \times 100$$

Where, $\bar{X}$ = General mean

σ_g^2 = Genotypic variance

σ_p^2 = Phenotypic variance

Burton and Devane (1953) classified GCV and PCV as follows, Low: Less than 10%; Moderate: 10-20%; High: More than 20%.

3.10.2.3 Heritability (h^2)

Heritability in broad sense was estimated as the ratio of genotypic variance to the phenotypic variance and expressed in percentage (Falconer, 1981).

$$\text{Heritability } (h^2) = \frac{\sigma_g^2}{\sigma_p^2} \times 100$$

Where, σ_g^2 = Genotypic variance

σ_p^2 = Phenotypic variance

Robinson *et al.* (1949) classified heritability percentage as follows, Low: Less than 30%; Moderate: 30-60%; High: More than 60%.

3.10.2.4 Expected genetic advance

Expected genetic advance (GA) was calculated using the formula given by Robinson *et al.* (1949).

$$\text{Expected genetic advance (GA)} = i \times h^2 \times \sigma_p$$

Where, i = selection differential (2.06) at 5 per cent selection intensity

h^2 = Heritability in broad sense

σ_p = Phenotypic standard deviation

3.10.2.5 Genetic advance over per cent mean (GAM)

Genetic advance over mean was calculated according to Johnson *et al.* (1955).

$$\text{Genetic advance over per cent mean (GAM)} = \frac{GA}{\bar{X}} \times 100$$

Where, $\bar{X}$ = General mean

GA = Genetic advance

Johnson *et al.* (1955) classified genetic advance as percentage over mean as follows, Low: Less than 10%; Moderate: 11-20%; High: More than 20%.

3.10.3 Correlation analysis

To examine the degree of association of traits with growth, yield and also among the yield components between the genotypes, the correlation coefficient were estimated and tested as per procedures narrated by Panse and Sukhatme (1967).

$$\text{Genotypic correlation} = r_{xy}(g) = \frac{\text{Cov}_{xy}(G)}{\sqrt{V_x(G) \times V_y(G)}}$$

$$\text{Phenotypic correlation} = r_{xy}(p) = \frac{\text{Cov}_{xy}(P)}{\sqrt{V_x(P) \times V_y(P)}}$$

Where

$\text{Cov}_{xy}(G)$ = Genotypic covariance between y and x

$\text{Cov}_{xy}(P)$ = Phenotypic covariance between y and x

$V_x(G)$ = Genotypic variance of trait 'x'

$V_x(P)$ = Phenotypic variance of trait 'x'

$V_y(G)$ = Genotypic variance of trait 'y'

$V_y(P)$ = Phenotypic variance of trait 'y'

The test of significance for association between the traits was done by comparing table r values at n-2 error degrees of freedom for phenotypic and genotypic correlations with estimated values, respectively.

3.10.4 Path coefficient analysis

Path co-efficient analysis suggested by Wright (1921) and Dewey and Lu (1959) was worked out to know the direct and indirect outcome of the morphological traits on plant yield. The following set of equations were formed and used for evaluating various direct and indirect outcomes.

$$r_{1y} = a + r_{12}b + r_{13}c + \dots + r_{1I}i$$

$$r_{2y} = a + r_{21}a + b + r_{23}c + \dots + r_{2I}i$$

$$r_{3y} = r_{31}a + r_{32}b + c + \dots + r_{3I}i$$

$$r_{1y} = r_{11}a + r_{12}b + r_{13}c + \dots + I$$

Were,

r_{1y} to 1_{1y} = Co-efficient of correlation between causal factors 1 to I with dependent characters y.

r_{12} to r_{II} = Co-efficient of correlation among causal factors

a, b, c,..... i = Direct effects of characters 'a' to 'I' on the dependent character 'y'

Residual effect (R) was computed as follows,

$$\text{Residual effect (R)} = 1 - \sqrt{a^2 + b^2 + c^2 + \dots i^2 + 2abr_{12} + 2acr_{13} + \dots}$$

3.11 Genetic divergence analysis

The genetic divergence between genotypes was estimated using Mahalanobis's D^2 statistic (1936). The distance D from the sample was computed using the formula

$$D^2p = d^1 S^{-1} d$$

Where,

D^2p = Square of distance considering 'p' variables

d = Vector observed differences of the mean values of all the characters ($x_{i1}-x_{i2}$)

S^{-1} = Inverse of variance and covariance matrix

3.12 Molecular marker profiling

3.12.1 Collection of samples for DNA extraction

Leaf samples of the chosen cultivars were taken from the field, covered with aluminium foil and properly labelled. The samples were then carried in ice basket to the laboratory and kept at -20°C until extraction.

DNA extraction was performed using the cetyltrimethyl ammonium bromide (CTAB) method described by Doyle and Doyle (1990) with some modifications.

3.12.2 The standard protocol followed is as follow:

1. 100 mg of leaf sample was mix with 500 μ l of CTAB extraction buffer (3% CTAB; 100mM Tris-HCL, pH 8.0; 20Mm EDTA, pH 8.0; 1.3 M NaCl; 4% polyvinylpyrrolidone; 2% β - mercaptoethanol) and ground by using pestle and mortar, then transferred to 2ml Eppendorf tube and gently shaken to mix the buffer with the sample. Samples were then incubated at 65°C for 45 minutes in water bath
2. Samples were cooled to room temperature and to this mixture volume of phenol: chloroform: isoamyl alcohol (25:24:1) was added, mixed gently and centrifuged at 15000 rpm for 15 minutes at room temperature.
3. The clear supernatant was collected and transferred to 1.5 ml Eppendorf tube and to this, 500 μ l of chilled isopropanol was added and stored overnight at -20°C.
4. The DNA was pelleted by centrifugation at 15000 rpm for 15 minutes at 4°C.
5. The supernatant was decanted and DNA pellets were washed with 70 per cent ethanol and centrifuged at 10000 rpm for 10 minutes at 4°C.
6. The ethanol was poured out and pellets were air dried for 3-4 hours. Afterwards the dried pellets were dissolved in 100 μ l of TE buffer (10Mm Tris-HCl, pH 8.0, 1Mm EDTA, pH 8.0). The extracted DNA was stored at -20°C for further use.

3.12.3 Qualitative and Quantitative determination of DNA

The extracted sample DNA was quantified using a spectrophotometer (Nanodrop Thermo). DNA Absorbance was recorded at 260 nm and 280 nm. A ratio of in and around 1.8 represented pure DNA. The DNA concentration was calculated using the formula, $\text{DNA (mg/ml)} = A_{260} \times 50 \times \text{dilution factor}$ 100. Qualitative analysis of DNA was done by running the extracted DNA samples on 1% agarose gel using 0.5X TAE buffer (10 mM Tris- HCl and 1mM EDTA, pH 8.0). The gel was stained with ethidium bromide and visualized under UV fluorescence in gel documentation system.

3.12.4 Polymerase chain reaction (PCR) amplification of gene specific primers

Diluted DNA samples were used for PCR amplification using the selected gene specific 25 primers (Microsatellites, table 3) (Cholin *et al.*, 2018 and Bharti *et al.*, 2018) in an automated thermo cycler (Eppendorf master cycler model nexus). Primers were diluted to a concentration of 10 Pico moles/ μl from the stock. PCR was performed for 10 μl reaction mixtures, the details of PCR components as mentioned below.

Compositions of PCR reactions for genotyping

Components	Concentration	PCR reaction (10 μl)
Primers (F+R)	10Pm/ μl	1
PCR master mix	2X	4
Template (DNA)	50ng/ μl	2
Nuclease free water		3
Total		10.0 μl

Table 2. PCR protocol followed for microsatellite primers for different ajwain

SN	Steps	Microsatellite Primers		Cycles
		Temperature ($^{\circ}\text{C}$)	Time (mins)	
1	Initial denaturation	94	5	35
2	Denaturation	94	45	
3	Annealing	52-60	45	
4	Primer extension	72	45	
5	Final extension	72	7	
6	Hold	4	-	

*Specific annealing temperature as per the primers.

3.12.5 Agarose gel electrophoresis

Reagents:

Tris Acetate EDTA (TAE) Buffer stock (50x): 242g of Tris base 57.1 ml of Glacial acetic acid and 100ml of 0.5 M EDTA were dissolved in litre of distilled water, sterilized by autoclaving and stored at room temperature.

TAE working solution: 1X TAE buffer prepared by diluting 50X TAE using distilled water and was used for preparation of agarose gel and tank buffer to run gel electrophoresis.

Bromophenol blue: 1-2 μ l

Ethidium bromide: 5 μ l/100ml of 1X TAE buffer

100bp DNA ladder (Gene Direx): 3 μ l

Preparation of agarose gels and electrophoresis:

PCR amplification products were resolved on 3 per cent agarose gel on the electrophoresis system (Bio-Rad).

- 200ml of 1X TAE buffer was warmed in a micro wave oven and 3g of agarose was mixed without forming any clumps.
- Agarose solution was heated until complete melting of agarose with frequent shaking.
- Agarose solution was cooled to 45°C by incubating at room temperature and 5 μ l of ethidium bromide (10mg/ml) was added, mixed by gentle swirling.

Table 3. Microsatellite primers used for analysis of ajwain genotype

SN	Primers	Forward primer sequence	Reverse primer sequence	Ann. temp (°C)
1	Cumin-SSR_7	CGGGTGAAATGGAAGATGATAG	TGAGGTTGAGACTTGAGACCTTG	58
2	Cumin-SSR_12	GGCCAAGAAACAAACTGCTAAA	CTCCGACCAAACACAGGAAC	58
3	Cumin-SSR_25	TTTAACGAATGTCACCCACACC	TCCAACACCAAGAGCATACAA	58
4	Cumin-SSR_48	CTTTCGGGGTCTTCCTCTTTT	TCTTTAACCTTGGGACCTGTG	58
5	Cumin-SSR_53	ACACAACCCAAACAGTCCAAA	TGTCAATTTCCATTCCAGCAC	58
6	Cumin-SSR_129	ACACAGAACAGCAGGCAACTC	TCGCTTTTTATCCTTCCATCC	58
7	Cumin-SSR_151	GCATTCAACACACACATTCCA	TGAACTCCTCGTTTTTCATCTTC	-
8	Cumin-SSR_169	TAAATGGGCGACTTGGA AAA	TCCCTCACTTTCAACCCTACA	58
9	Cumin-SSR_186	ACCATCACGCGAATATCAAAG	TGACCTCAA AATCACACACACA	-
10	Cumin-SSR_281	CCTTTCACCTGCCAAACAAA	CGGGGTCTAGTGGAAGAAAGA	60.5
11	Cumin-SSR_256	ATAACCAAACCAGGAGGAGGA	TTGTGATTGTTTGAGGACTGG	58
12	Cumin-SSR_269	AATCCATTGGCACGACTAAAC	AAGATGTGACCAACACAAGCA	58
13	Cumin-SSR_306	GCATGGAACGGAGAGAAAGA	ACTCAACTTAAACCCACCTCAAC	58.9
14	Cumin-SSR_632	ATCCAGCATTTGAGACCCTTT	GGAATATGCGACTCTTTTCACC	51
15	GSSR-4	CAATCTTGCCACTAAAAG AGCA	CAGATACAATAGACAGGA	55
16	GSSR-6	TCTCCTCTTGATTCTTCT TCGC	CCAATAAGCGTAAGCGTT	57
17	GSSR-12	TGTATTGTGTGTATGCAA TTTTGG	CAAATCACACAATGCATG	54
18	GSSR-14	CCACCTTGGACAAAGCAA AC	GCCCAGTTCTTCTTAATT	55
19	GSSR-16	ATGCAAACGACAATATCC ACAG	GCCCAGCCACTTCCT	57
20	GSSR-17	GGTCTCTTCCCACTCAT GGAT	CCAGCATTCATATGTCC	54
21	GSSR-19	CCGAGTTGGATTTCGG AGAG	GTAAATTGAGGATTGCGA	58
22	GSSR-44	AACTTCACCCCAGCT CACC	CAAAGCAAGTAAAGA	58
23	GSSR-63	ACACTTTTCATCCTCCAA CTCC	TGCGACCATGACTATACG	54
24	DCM-37	ATCACCAGCAATACAAGC AC	GGCTAGGATGCAGAA	60
25	Exon1-Exon2	TGGTGGGAGCTCTGGATA TT	AAATGGACAGTACTGGGG	55

- Agarose casting tray was prepared by placing appropriate combs and the gel was poured into the gel tray to solidify.
- Combs were carefully removed from the casted gel and the gel was placed in the electrophoresis system.
- 10 µl of PCR product was mixed with 2 µl bromophenol blue and loaded into the wells. A 4 µl 100bp DNA ladder was loaded into the first as reference markers.
- Electrophoresis was carried out at 80V for 20 min followed by fixed voltage (90 V) until bromophenol reaches the end of the gel.
- PCR amplified bands were visualized and recorded in tissue gel documentation unit and bands were manually scored.

3.12.6 Data scoring and statistical analysis

A total of 25 SSR markers available in the public data source were selected for the study to screen the 28 ajwain genotypes. Scoring was done based on the presence/absence of bands, Polymorphism for the respective cultivars were taken for consideration.

The informativeness of diversity of each marker was evaluated using (Power marker software) the polymorphic information content (PIC). PIC is the probability in detecting polymorphism by a primer $PIC = 1 - \sum (p_i)^2$, where P_i is the frequency of the i th allele. Genetic diversity within each population was estimated through observed number of alleles (N_a), effective number of alleles (N_e) Shannon's information index (I), Expected Heterozygosity (H_e) and Unbiased Expected Heterozygosity (uH_e) and employing GenAlEx 6.5 software.

H_e - expected heterozygosity for a genetic marker was calculated as: $H_e = 1 - \sum p_i^2$, where p_i is the allele frequency of the i^{th} allele. The observed heterozygosity was calculated according to Nei (1978), i.e., it was given as $H_o = \text{No. of accessions harbouring heterozygous genotypes at the } i^{th} \text{ allele} / \text{No. of total accessions}$. The similarity matrix obtained was subjected to cluster analysis using the UPGMA (unweighted pair-group method with arithmetic average) algorithm Darwin version 5.0 software.

4. EXPERIMENTAL RESULTS

The field experiment on ajwain was undertaken during October 2020 to March 2021 and October 2021 to March 2022 to study the performance of ajwain (*Trachyspermum ammi* L.) genotypes under northern dry zone of Karnataka and the laboratory analysis was carried out at the department of Plantation, Spices, Medicinal and Aromatic Crops (PMA) and Central Laboratory, College of Horticulture, Bagalkot. The results obtained from the experiment are presented in this chapter.

4.1 Growth parameters

4.1.1 Days to germination

In the season 2020-21, the minimum days to germination was noticed in AZ-1 (10.00), which was on par with HUB-8 (10.50), AA-1 (11.00), HUB-2 (11.00), AA-93 (11.50), DAC-3 (11.50), DAC-4 (11.50), DAC-5 (11.50) and RM (11.50). The maximum days taken for germination were noticed in HUB-10 (17.00) (Table 4).

In the season 2021-22, the minimum days to germination was noticed in AZ-1 (9.50) and HUB-8 (9.50), which was on par with DAC-3 (10.50) and DAC-5 (10.50), whereas the maximum days taken for germination were noticed in HUB-10 (14.00) (Table 4).

In pooled average over both the season, the minimum days to germination was noticed in AZ-1 (9.75), which was on par with HUB-8 (10.00), AA-1 (11.00), DAC-3 (11.00), DAC-5 (11.00), AA-93 (11.50), DAC-4 (11.50) and RM (11.50), whereas the maximum days taken for germination were observed in HUB-10 (15.50) (Table 4).

4.1.2 Plant height (cm)

Significant differences in plant height at 60, 90, 120 and 150 days were recorded among the genotypes.

At 60 DAS

In the season 2020-21, RM recorded the highest plant height (40.40 cm), followed by AA-93 (35.55 cm) and DAC-6 (35.20 cm), whereas, least plant height was noticed in HUB-11 (13.20 cm) (Table 5).

In the season 2021-22, HUB-2 recorded the highest plant height (43.80 cm), which was statistically on par with HUB-1 (40.6 cm), RM (40.00 cm), whereas least plant height was noticed in HUB-9 (22.60 cm) (Table 5).

In pooled average over both the season, the highest plant height was recorded with RM recorded (40.20 cm), which was statistically on par with AA-93 (37.03 cm), HUB-8 (36.50 cm), DAC-6 (35.20 cm), AZ-1 (34.63 cm), HUB-1 (34.55 cm), AL-3 (33.88 cm), LS-2 (33.85 cm), DAC-2 (33.78 cm), GA-1 (33.40 cm) and HUB-2 (33.00 cm). HUB-9 (20.55 cm) recorded the lowest plant height (Table 5).

At 90 DAS

In the season 2020-21, RM recorded the highest plant height (79.60 cm), which was on par with AA-93 (73.80 cm), AZ-1 (70.70 cm), DAC-6 (67.60 cm), HUB-1 (66.90 cm) and HUB-8 (66.90 cm), whereas the least plant height was noticed in HUB-11 (35.80 cm) (Table 5).

In the season 2021-22, HUB-2 recorded the highest plant height (87.45 cm), followed by HUB-1 (81.05 cm), AA-93 (80.60 cm), RM (79.50 cm) and DAC-6 (79.25 cm), whereas least plant height was noticed in HUB-10 (43.10 cm) (Table 5).

In pooled average over both the season, RM recorded the highest plant height (79.55 cm) which was on par with AA-93 (77.20 cm), AZ-1 (74.35 cm), HUB-1 (73.98 cm), DAC-6 (73.43 cm), LS-1 (70.45 cm), AA-2 (70.28 cm), DAC-2 (69.98 cm), AL-4 (68.90 cm), HUB-8 (67.70 cm) and HUB-2 (67.38 cm), whereas least plant height was recorded in HUB-11 (43.00 cm) (Table 5).

At 120 DAS

In the season 2020-21, RM recorded the highest plant height (85.27 cm), which was statistically on par with AA-93 (80.80 cm), HUB-8 (80.15 cm), AZ-1 (79.45 cm), DAC-6 (75.60 cm) and HUB-1 (73.70 cm), whereas least plant height was noticed in HUB-10 (43.30 cm) (Table 6).

In the season 2021-22, HUB-2 recorded the highest plant height (105.80 cm), which was statistically on par with HUB-1 (102.40 cm), RM (100.40 cm), HUB-8

(99.65 cm), AA-93 (98.40 cm), AZ-1 (97.80 cm) and DAC-2 (96.70 cm), whereas the least plant height was noticed in HUB- 11 (78.30 cm) (Table 6).

In pooled average over both the season, the highest plant height was observed in RM (92.84) was statistically on par with HUB-8 (89.90 cm), AA-93 (89.60 cm), AZ-1 (88.63 cm), HUB-1 (88.05 cm), DAC-6 (84.93 cm), DAC-2 (84.50 cm), DAC-3 (83.73 cm), AA-2 (82.35 cm) DAC-5 (81.15 cm) and AL-4 (81.00 cm), whereas least plant height was recorded in HUB-11 (63.10 cm) (Table 6).

At 150 DAS

In the season 2020-21, RM recorded the highest plant height (87.25 cm), which was on par with HUB-8 (83.10 cm), AZ-1 (82.55 cm), AA-93 (81.00 cm) and DAC-6 (78.85 cm), whereas least plant height was noticed in HUB-10 (48.1 cm) (Table 6).

In the season 2021-22, HUB-2 recorded the highest plant height (111.8 cm), which was on par with HUB-1 (108.4 cm), RM (106.4 cm), HUB-8 (105.65 cm), AZ-1 (104.30 cm), HUB-4 (102.40 cm) and AA-93 (102.05 cm), whereas the least plant height was noticed in HUB- 11 (82.45 cm) (Table 6).

In pooled average over both the season, higher plant height was recorded in RM (96.83 cm), which was on par with HUB-8 (94.38 cm), AZ-1 (93.43 cm), HUB-1 (93.30 cm), AA-93 (91.53 cm), DAC-6 (89.55 cm), DAC-3 (88.68 cm), DAC-2 (88.33 cm), AA-2 (87.40 cm), AL-4 (86.45 cm), AA-1 (85.10 cm) and HUB-3 (84.80 cm), whereas HUB-11 (66.23 cm) recorded the lowest plant height (Table 6).

4.1.3 Number of branches per plant

All the genotypes differed significantly with respect to number of branches per plant.

At 60 DAS

In the season 2020-21, AA-93 recorded the highest number of branches (9.70) per plant, which was statistically on par with AZ-1 (9.50), HUB-8 (9.30), RM (9.10) and DAC-5 (8.90), whereas the least number of branches per plant was noticed in HUB-10 (5.15) (Table 7).

Table 4. Performance of ajwain genotypes for days to germination

Treatment	Genotype	Days to germination		
		2020-21	2021-22	Pooled
T1	AA-1	11.00	11.00	11.00
T2	AA-2	12.50	12.50	12.50
T3	AA-93	11.50	11.50	11.50
T4	GA-1	13.50	11.50	12.50
T5	AL-3	16.50	13.50	15.00
T6	AL-4	16.00	12.50	14.25
T7	LS-1	13.50	11.50	12.50
T8	LS-2	14.00	12.00	13.00
T9	LTA 26	12.00	12.00	12.00
T10	DAC-1	12.00	12.50	12.25
T11	DAC-2	12.50	11.50	12.00
T12	DAC-3	11.50	10.50	11.00
T13	DAC-4	11.50	11.50	11.50
T14	DAC-5	11.50	10.50	11.00
T15	DAC-6	12.50	11.00	11.75
T16	AZ-1	10.00	9.50	9.75
T17	HUB-1	12.5	12.00	12.25
T18	HUB-2	11.00	13.00	12.00
T19	HUB-3	12.00	13.00	12.50
T20	HUB-4	12.00	12.00	12.00
T21	HUB-5	12.50	13.00	12.75
T22	HUB-6	12.50	12.50	12.50
T23	HUB-8	10.50	9.50	10.00
T24	HUB-9	15.00	13.50	14.25
T25	HUB-10	17.00	14.00	15.50
T26	HUB-11	16.00	14.00	15.00
T27	HUB-13	15	13.50	14.25
T28	RM	11.5	11.50	11.50
	S. Em ±	0.58	0.51	0.64
	C.D. (P = 0.05)	1.68	1.48	1.85

In the season 2021-22, HUB-2 recorded the highest number of branches (13.10) per plant, which was statistically on par with AZ-1(12.40), AA-93 (12.20), HUB-1 (12.10), whereas the least number of branches per plant was noticed in HUB-10 (6.10) (Table 7).

In pooled average over both the season, AA-93 (10.95) and AZ-1 (10.95) recorded the highest number of branches per plant, which was statistically on par with HUB-2 (10.45), HUB-8 (10.30), RM (10.10), HUB-1(10.05), GA-1 (9.50) and DAC-5 (9.33). HUB-10 (5.63) was found least number of branches per plant (Table 7).

At 90 DAS

In the season 2020-21, AA-93 recorded the highest number of branches (14.40) per plant, which was on par with AZ-1 (13.85), HUB-8 (13.55) and RM (13.35), whereas least number of branches per plant was noticed in HUB-10 (8.00) (Table 7).

In the season 2021-22, HUB-2 recorded the highest number of branches (14.90) per plant, which was on par with HUB-8 (14.05), HUB-1 (14.00), AZ-1 (13.85) and AA-93 (13.60), whereas least number of branches per plant was noticed in HUB-10 (10.50) (Table 7).

In pooled average over both the season, the highest number of branches per plant was recorded in AA-93 (14.00), which was on par with AZ-1 (13.85), HUB-8 (13.80), RM (13.25), HUB-1 (13.13), HUB-2 (13.08), AA-2 (12.75), AL-4 (12.70), GA-1 (12.68), DAC-4 (12.65), DAC-6 (12.58), AA-1 (12.55), DAC-5 (12.45), LS-2 (12.40) and DAC-2 (12.35), whereas lowest number of branches per plant was recorded in HUB-10 (9.25) (Table 7).

At 120 DAS

In the season 2020-21, AA-93 recorded the highest number of branches (18.20) per plant, which was statistically on par with AZ-1 (17.90), AA-2 (17.10) HUB-8 (16.65) and AA-1(16.55). Whereas, least number of branches per plant was noticed in HUB-10 (9.50) (Table 8).

In the season 2021-22, RM recorded the highest number of branches (18.90) per plant, which was statistically on par with AA-93 (18.15), AA-2 (17.40) and HUB-2 (17.25). Whereas, least number of branches per plant was noticed in HUB-10 (11.00) (Table 8).

In pooled average over both the season, AA-93 recorded the highest number of branches per plant (18.18), which was statistically on par with AZ-1 (17.38), RM (17.38), AA-2 (17.25), HUB-8 (16.85) and AA-1 (16.65), whereas least number of branches per plant was noticed in HUB-10 (10.25) (Table 8).

At 150 DAS

In the season 2020-21, AA-93 recorded the highest number of branches (18.20) per plant, which was on par with AZ-1 (17.90), AA-2 (17.10) and HUB-8 (16.65), AA-1 (16.55). Whereas, least number of branches per plant was noticed in HUB-10 (9.50) (Table 8).

In the season 2021-22, RM recorded the highest number of branches (18.90) per plant, which was on par with AA-93 (18.15), AA-2 (17.40) and HUB-2 (17.25). Whereas, least number of branches per plant, was noticed in HUB-10 (11.00) (Table 8).

In pooled average over both the season, AA-93 recorded the highest number of branches per plant (18.18), which was on par with AZ-1 (17.38), RM (17.38), AA-2 (17.25), HUB-8 (16.85) and AA-1 (16.65), whereas lowest number of branches per plant was recorded in HUB-10 (10.25) (Table 8).

4.1.4 Days to flower initiation (10%)

All the genotypes differed significantly with respect to days to flower initiation (10%).

In the season 2020-21, the minimum days taken for commencement of flower initiation (10%) was observed in AZ-1 (63.00), which was statistically on par with HUB-8 (66.50), whereas the maximum days for commencement of flower initiation (10%) was noticed in HUB-11 (104.00) (Table 9).

Table 5. Plant height at 60 and 90 days in ajwain genotypes

Treatment	Genotype	Plant height at 60 days			Plant height at 90 days		
		2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T1	AA-1	26.90	31.70	29.30	53.60	67.30	60.45
T2	AA-2	29.25	29.90	29.58	62.90	77.65	70.28
T3	AA-93	35.55	38.50	37.03	73.80	80.60	77.20
T4	GA-1	31.60	35.20	33.40	60.70	63.70	62.20
T5	AL-3	31.05	36.70	33.88	63.70	58.15	60.93
T6	AL-4	30.00	31.80	30.90	62.30	75.50	68.90
T7	LS-1	26.90	37.10	32.00	64.50	76.40	70.45
T8	LS-2	30.90	36.80	33.85	63.40	64.30	63.85
T9	LTA 26	24.40	25.70	25.05	44.10	67.80	55.95
T10	DAC-1	22.70	30.40	26.55	52.70	61.40	57.05
T11	DAC-2	30.05	37.50	33.78	65.20	74.75	69.98
T12	DAC-3	23.10	31.00	27.05	62.10	68.30	65.20
T13	DAC-4	22.65	32.20	27.43	52.40	58.00	55.20
T14	DAC-5	31.20	33.70	32.45	63.50	63.70	63.60
T15	DAC-6	35.20	35.20	35.20	67.60	79.25	73.43
T16	AZ-1	33.05	36.20	34.63	70.70	78.00	74.35
T17	HUB-1	28.50	40.60	34.55	66.90	81.05	73.98
T18	HUB-2	22.20	43.80	33.00	47.30	87.45	67.38
T19	HUB-3	23.10	30.00	26.55	54.30	73.60	63.95
T20	HUB-4	24.05	33.20	28.63	53.90	59.90	56.90
T21	HUB-5	27.80	28.30	28.05	48.20	67.60	57.90
T22	HUB-6	23.40	29.10	26.25	38.90	53.40	46.15
T23	HUB-8	34.50	38.50	36.50	66.90	68.50	67.70
T24	HUB-9	18.50	22.60	20.55	41.60	54.50	48.05
T25	HUB-10	16.50	30.10	23.30	36.60	43.10	39.85
T26	HUB-11	13.20	28.90	21.05	35.80	50.20	43.00
T27	HUB-13	23.90	29.60	26.75	55.90	64.50	60.20
T28	RM	40.40	40.00	40.20	79.60	79.50	79.55
	S. Em $\pm$	1.11	1.42	2.55	4.62	3.00	4.42
	C.D. (P = 0.05)	3.21	4.13	7.39	13.40	8.71	12.83

Table 6: Plant height at 120 and 150 days in ajwain genotypes

Treatment	Genotype	Plant height at 120 days			Plant height at 150 days		
		2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T1	AA-1	64.90	96.00	80.45	69.50	100.70	85.10
T2	AA-2	71.20	93.50	82.35	75.30	99.50	87.40
T3	AA-93	80.80	98.40	89.60	81.00	102.05	91.53
T4	GA-1	63.60	92.70	78.15	68.50	98.70	83.60
T5	AL-3	68.10	89.60	78.85	72.40	95.60	84.00
T6	AL-4	70.90	91.10	81.00	75.80	97.10	86.45
T7	LS-1	67.80	87.80	77.80	72.40	93.80	83.10
T8	LS-2	61.00	89.50	75.25	73.40	95.50	84.45
T9	LTA 26	62.30	87.80	75.05	67.00	93.80	80.40
T10	DAC-1	61.70	90.40	76.05	72.05	95.90	83.98
T11	DAC-2	72.30	96.70	84.50	76.60	100.05	88.33
T12	DAC-3	72.00	95.45	83.73	78.30	99.05	88.68
T13	DAC-4	64.30	89.35	76.83	68.70	95.35	82.03
T14	DAC-5	70.00	92.30	81.15	74.40	99.80	87.10
T15	DAC-6	75.60	94.25	84.93	78.85	100.25	89.55
T16	AZ-1	79.45	97.80	88.63	82.55	104.30	93.43
T17	HUB-1	73.70	102.40	88.05	78.20	108.40	93.30
T18	HUB-2	51.50	105.80	78.65	55.10	111.80	83.45
T19	HUB-3	65.80	95.00	80.40	68.60	101.00	84.80
T20	HUB-4	59.20	95.40	77.30	63.70	102.40	83.05
T21	HUB-5	54.70	90.45	72.58	59.10	96.45	77.78
T22	HUB-6	53.90	90.70	72.30	56.95	98.20	77.58
T23	HUB-8	80.15	99.65	89.90	83.10	105.65	94.38
T24	HUB-9	55.60	81.15	68.38	58.90	87.65	73.28
T25	HUB-10	44.30	84.20	64.25	48.10	90.20	69.15
T26	HUB-11	47.90	78.30	63.10	50.00	82.45	66.23
T27	HUB-13	56.70	86.70	71.70	59.90	92.70	76.30
T28	RM	85.27	100.40	92.84	87.25	106.40	96.83
	S. Em $\pm$	4.18	3.34	4.14	2.92	3.62	4.28
	C. D. (P = 0.05)	12.13	9.68	12.01	8.48	10.49	12.41

Table 7. Number of branches per plant at 60 and 90 days in ajwain genotypes

Treatment	Genotype	Number of branches per plant at 60 days			Number of branches per plant at 90 days		
		2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T1	AA-1	8.50	9.30	8.90	12.40	12.70	12.55
T2	AA-2	8.40	9.20	8.80	12.60	12.90	12.75
T3	AA-93	9.70	12.20	10.95	14.40	13.60	14.00
T4	GA-1	8.70	10.30	9.50	12.50	12.85	12.68
T5	AL-3	7.50	8.60	8.05	11.60	12.75	12.18
T6	AL-4	7.80	8.80	8.30	12.60	12.80	12.70
T7	LS-1	7.30	8.10	7.70	11.50	11.80	11.65
T8	LS-2	7.75	8.55	8.15	12.20	12.60	12.40
T9	LTA 26	8.25	7.90	8.08	11.40	11.90	11.65
T10	DAC-1	8.10	9.00	8.55	11.30	11.75	11.53
T11	DAC-2	8.70	9.30	9.00	12.25	12.45	12.35
T12	DAC-3	7.30	9.00	8.15	11.20	11.50	11.35
T13	DAC-4	7.20	9.20	8.20	12.55	12.75	12.65
T14	DAC-5	8.90	9.75	9.33	13.20	11.70	12.45
T15	DAC-6	8.50	9.70	9.10	12.35	12.80	12.58
T16	AZ-1	9.50	12.40	10.95	13.85	13.85	13.85
T17	HUB-1	8.00	12.10	10.05	12.25	14.00	13.13
T18	HUB-2	7.80	13.10	10.45	11.25	14.90	13.08
T19	HUB-3	6.90	10.40	8.65	10.20	12.05	11.13
T20	HUB-4	7.30	10.00	8.65	10.65	11.85	11.25
T21	HUB-5	7.50	9.10	8.30	11.55	11.70	11.63
T22	HUB-6	7.60	10.60	9.10	11.40	12.05	11.73
T23	HUB-8	9.30	11.30	10.30	13.55	14.05	13.80
T24	HUB-9	5.75	8.10	6.93	9.50	12.00	10.75
T25	HUB-10	5.15	6.10	5.63	8.00	10.50	9.25
T26	HUB-11	5.85	7.40	6.63	9.00	11.50	10.25
T27	HUB-13	7.55	7.30	7.43	10.00	12.65	11.33
T28	RM	9.10	11.10	10.10	13.35	13.15	13.25
	S. Em $\pm$	0.33	0.48	0.63	0.42	0.46	0.57
	C. D. (P = 0.05)	0.96	1.39	1.83	1.21	1.34	1.66

Table 8. Number of branches per plant at 120 and 150 days in ajwain genotypes

Treatment	Genotype	Number of branches per plant at 120 days			Number of branches per plant at 150 days		
		2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T1	AA-1	16.55	16.75	16.65	16.55	16.75	16.65
T2	AA-2	17.10	17.40	17.25	17.10	17.40	17.25
T3	AA-93	18.20	18.15	18.18	18.20	18.15	18.18
T4	GA-1	15.95	14.90	15.43	15.95	14.90	15.43
T5	AL-3	13.50	15.10	14.30	13.50	15.10	14.30
T6	AL-4	14.70	15.58	15.14	14.70	15.58	15.14
T7	LS-1	13.80	14.80	14.30	13.80	14.80	14.30
T8	LS-2	15.20	15.15	15.18	15.20	15.15	15.18
T9	LTA 26	14.45	14.90	14.68	14.45	14.90	14.68
T10	DAC-1	14.55	14.25	14.40	14.55	14.25	14.40
T11	DAC-2	15.25	15.70	15.48	15.25	15.70	15.48
T12	DAC-3	14.50	16.30	15.40	14.50	16.30	15.40
T13	DAC-4	15.50	16.25	15.88	15.50	16.25	15.88
T14	DAC-5	13.80	16.35	15.08	13.80	16.35	15.08
T15	DAC-6	14.35	14.80	14.58	14.35	14.80	14.58
T16	AZ-1	17.90	16.85	17.38	17.90	16.85	17.38
T17	HUB-1	13.25	16.15	14.70	13.25	16.15	14.70
T18	HUB-2	12.00	17.25	14.63	12.00	17.25	14.63
T19	HUB-3	11.70	15.15	13.43	11.70	15.15	13.43
T20	HUB-4	13.15	15.85	14.50	13.15	15.85	14.50
T21	HUB-5	14.05	14.70	14.38	14.05	14.70	14.38
T22	HUB-6	13.40	14.05	13.73	13.40	14.05	13.73
T23	HUB-8	16.65	17.05	16.85	16.65	17.05	16.85
T24	HUB-9	11.50	13.00	12.25	11.50	13.00	12.25
T25	HUB-10	9.50	11.00	10.25	9.50	11.00	10.25
T26	HUB-11	11.00	12.00	11.50	11.00	12.00	11.50
T27	HUB-13	12.00	14.65	13.33	12.00	14.65	13.33
T28	RM	15.85	18.90	17.38	15.85	18.90	17.38
	S. Em ±	0.58	0.62	0.72	0.58	0.62	0.72
	C. D. (P = 0.05)	1.67	1.81	2.08	1.67	1.81	2.08

In the season 2021-22, the minimum days taken for commencement of flower initiation (10%) was observed in AZ-1 (69.00), which was statistically on par with RM (71.50), HUB-8 (73.50) and AA-93 (80.00), whereas the maximum days for commencement of flower initiation (10%) was noticed in HUB-9 (101.50) (Table 9).

In pooled average over both the season, the minimum days taken for commencement of flower initiation (10%) was observed in AZ-1 (66.00), which was statistically on par with HUB-8 (70.00), whereas maximum days for commencement of flower initiation (10%) was recorded in HUB-11 (101.50) (Table 9).

4.1.5 Days to 50 per cent flowering

All the genotypes differed significantly with respect to days to 50 per cent flowering.

In the season 2020-21, the minimum days taken for commencement of 50 per cent flowering was observed in AZ-1 (74.50), which was statistically on par with HUB-8 (80.50) and AA-93 (82.00), whereas the maximum days for commencement of 50 per cent flowering was noticed in HUB-11 (113.50) (Table 9).

In the season 2021-22, the minimum days taken for commencement of 50 per cent flowering was observed in AZ-1 (80.00), which was statistically on par with RM (81.00), HUB-8 (82.00), GA-1 (90.00), HUB-4 (90.00), AA-93 (91.00), DAC-5 (93.00) and HUB-2 (93.00), whereas, the maximum days for commencement of 50 per cent flowering was noticed in HUB-9 (110.50) (Table 9).

In pooled average over both the season, the minimum days taken for commencement of 50 per cent flowering was observed in AZ-1 (77.25), which was statistically on par with HUB-8 (81.25), RM (85.50) and AA-93 (86.50), whereas maximum days for commencement of 50 per cent flowering was recorded in HUB-11 (109.75) (Table 9).

4.1.6 Number of flowers per umbellates

Number of flowers per umbellates differed remarkably among the genotypes.

In the season 2020-21, the highest number of flowers per umbellates was noticed in AZ-1 (23.60) which was statistically on par with HUB-8 (23.20) and AA-93 (22.00), whereas the lowest number of flowers per umbellates was registered in HUB-9 (11.20) (Table 10).

In the season 2021-22, the highest number of flowers per umbellates was noticed in HUB-8 (24.50), which was statistically on par with AZ-1 (23.25) and AA-93 (22.40), whereas the lowest number of flowers per umbellates was registered in HUB-9 (12.15) (Table 10).

In pooled average over both the season, the highest number of flowers per umbellates was observed in HUB-8 (23.85), which was statistically on par with AZ-1 (23.43) and AA-93 (22.20), whereas lowest number of flowers per umbellates was registered in HUB-9 (11.67) (Table 10).

4.1.7 Days to physiological maturity

Considerable differences among the genotypes of ajwain was exhibited for the maturity of the crop.

In the season 2020-21, the minimum days taken for harvest recorded in AZ-1 (125.00) and HUB-8 (125.00), which was statistically on par with AA-2 (131.00), HUB-5 (131.00), AA-1 (133.50), AA-93 (134.00), GA-1 (135.00), RM (135.00), DAC-1 (135.00), HUB-3 (136.50), HUB-4 (136.50), AL-3 (139.00) and LTA 26 (139.00) Late maturity was identified in HUB-11 (154.00) (Table 10).

In the season 2021-22, the minimum days taken for harvest recorded in AA-93 (125.50), which was statistically on par with AA-1 (126.00), AA-2 (129.00), AZ-1 (132.00), GA-1 (132.00), DAC-6 (133.00), RM (133.50), DAC-2 (134.50), HUB-2 (134.50), AL-4 (135.00), DAC-3 (135.00), AL-3 (136.00), DAC-4 (136.00), LTA-26 (136.00), HUB-1 (136.00), HUB-8 (136.50), DAC-1 (137.00), LS-1 (137.00), DAC-5 (137.00), HUB-3 (137.00) and LS-2 (139.50) Late maturity was identified in HUB-9 (160.00) (Table 10).

In pooled average over both the season, the minimum days taken for harvest was recorded in AZ-1 (128.50), which was statistically on par with AA-93 (129.75), AA-1

(129.75), AA-2 (130.00), HUB-8 (130.75), GA-1 (133.50), RM (134.25), DAC-1 (136.00), HUB-5 (137.25), DAC-3 (137.25), LTA 26 (137.50), DAC-2 (137.75) and HUB-1 (138.00) and the maximum days taken for harvest was observed in HUB-10 (156.00) (Table 10).

4.2 Yield parameter

4.2.1 Number of umbels per plant

Total number of umbels in an individual plant of ajwain differed considerably among the genotypes during crop growth (Plate 2).

In the season 2020-21, AZ-1 showed the highest number of umbels in an individual plant is 298.00 which was statistically on par with HUB-8 (288.00). The lowest number of umbels in an individual plant was recorded in HUB-9 (65.80) (Table 11).

In the season 2021-22, AZ-1 showed the highest number of umbels in an individual plant is 306.50, which was statistically on par with HUB-8 (291.80). The lowest number of umbels in an individual plant was recorded in HUB-11 (84.55) (Table 11).

In pooled average over both the season, AZ-1 showed the highest number of umbels in an individual plant is 302.25, which was statistically on par with HUB-8 (289.90). The lowest number of umbels in an individual plant was recorded in HUB-11 (75.68) (Table 11).

4.2.2 Number of umbellates per umbel

Total number of umbellates per umbel of ajwain differed remarkably among the genotypes during crop growth (Plate 2).

Table 9. Days to flower initiation (10%) and days to 50 percent flowering in ajwain genotypes

Treatment	Genotype	Days to flower initiation (10%)			Days to 50 per cent flowering		
		2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T1	AA-1	85.50	90.00	87.75	94.00	98.50	96.25
T2	AA-2	82.00	88.00	85.00	93.00	97.00	95.00
T3	AA-93	74.00	80.00	77.00	82.00	91.00	86.50
T4	GA-1	89.50	81.00	85.25	97.00	90.00	93.50
T5	AL-3	88.00	82.50	85.25	94.50	98.00	96.25
T6	AL-4	86.50	93.00	89.75	93.00	101.00	97.00
T7	LS-1	86.50	92.00	89.25	95.50	102.00	98.75
T8	LS-2	90.00	91.50	90.75	97.50	94.00	95.75
T9	LTA 26	92.50	90.50	91.50	100.50	95.00	97.75
T10	DAC-1	85.50	90.00	87.75	93.00	102.00	97.50
T11	DAC-2	94.50	91.50	93.00	102.50	101.00	101.75
T12	DAC-3	92.00	87.50	89.75	101.50	96.00	98.75
T13	DAC-4	98.00	90.50	94.25	106.50	98.00	102.25
T14	DAC-5	89.00	84.00	86.50	96.50	93.00	94.75
T15	DAC-6	91.00	84.50	87.75	99.50	95.00	97.25
T16	AZ-1	63.00	69.00	66.00	74.50	80.00	77.25
T17	HUB-1	82.00	89.50	85.75	89.00	99.00	94.00
T18	HUB-2	85.00	85.50	85.25	91.00	93.00	92.00
T19	HUB-3	87.00	95.50	91.25	93.00	103.50	98.25
T20	HUB-4	89.00	82.50	85.75	98.50	90.00	94.25
T21	HUB-5	82.00	90.00	86.00	93.00	98.50	95.75
T22	HUB-6	87.00	93.00	90.00	94.50	103.00	98.75
T23	HUB-8	66.50	73.50	70.00	80.50	82.00	81.25
T24	HUB-9	96.50	101.50	99.00	105.50	110.50	108.00
T25	HUB-10	102.50	95.50	99.00	112.50	104.50	108.50
T26	HUB-11	104.00	99.00	101.50	113.50	106.00	109.75
T27	HUB-13	101.00	92.50	96.75	110.00	101.50	105.75
T28	RM	79.50	71.50	75.50	90.00	81.00	85.50
	S. Em ±	3.30	3.93	3.10	3.59	4.73	3.42
	C.D. (P =0.05)	9.57	11.40	8.99	10.41	13.72	9.91

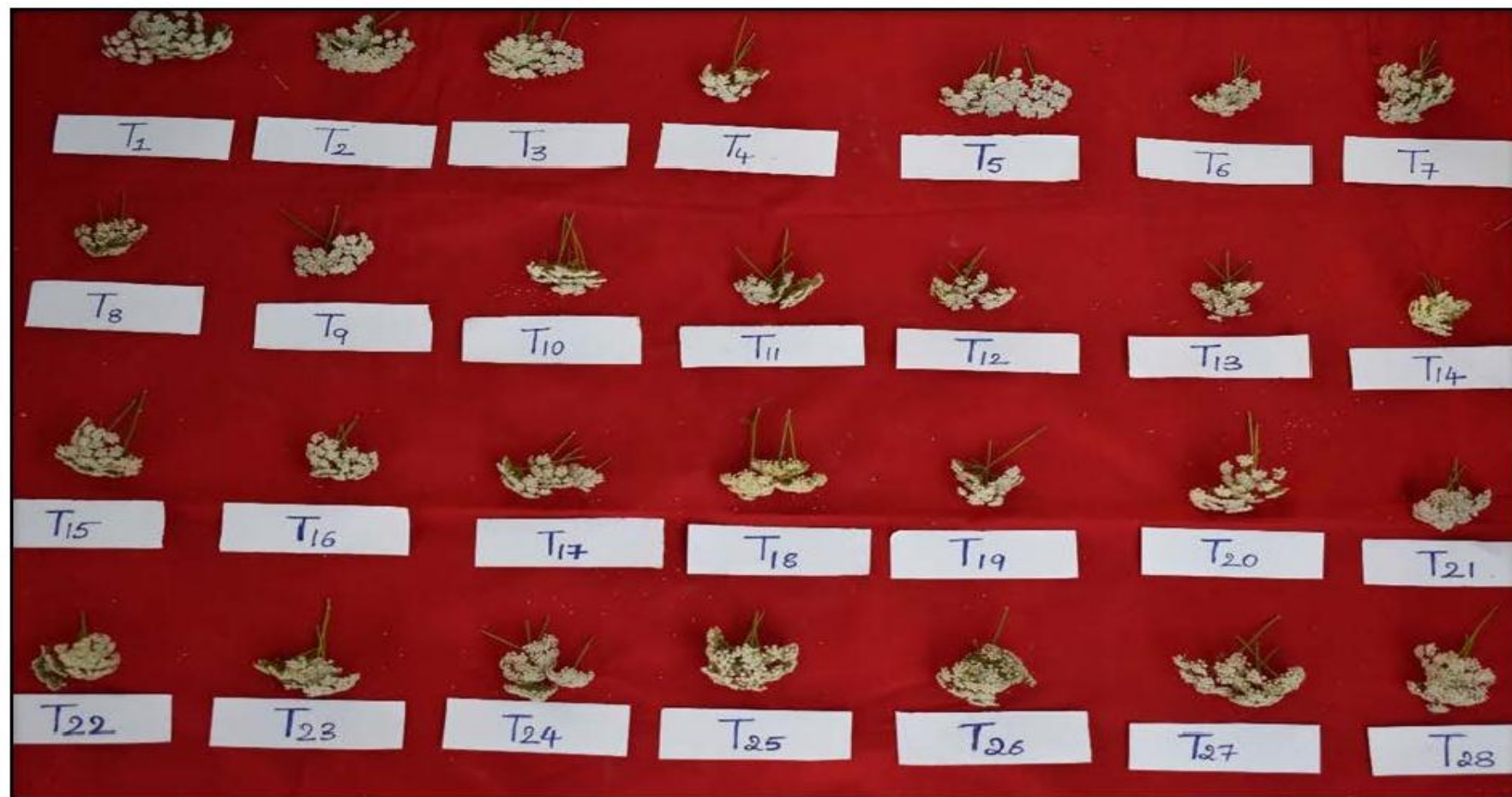


Plate 2. Variability of umbels and umbellates in ajwain genotypes

Table 10. Number of flowers per umbellates and days to physiological maturity in ajwain genotypes

Treatment	Genotype	Number of flowers per umbellates			Days to physiological maturity		
		2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T1	AA-1	19.70	20.30	20.00	133.50	126.00	129.75
T2	AA-2	20.60	20.05	20.33	131.00	129.00	130.00
T3	AA-93	22.00	22.40	22.20	134.00	125.50	129.75
T4	GA-1	19.05	20.25	19.65	135.00	132.00	133.50
T5	AL-3	16.00	16.70	16.35	139.00	136.00	137.50
T6	AL-4	15.90	15.70	15.80	143.00	135.00	139.00
T7	LS-1	12.00	13.75	12.88	140.50	137.00	138.75
T8	LS-2	14.40	15.60	15.00	142.50	139.50	141.00
T9	LTA 26	15.60	16.20	15.90	139.00	136.00	137.50
T10	DAC-1	17.35	17.00	17.18	135.00	137.00	136.00
T11	DAC-2	17.50	18.00	17.75	141.00	134.50	137.75
T12	DAC-3	17.80	17.30	17.55	139.50	135.00	137.25
T13	DAC-4	18.50	19.05	18.78	147.50	136.00	141.75
T14	DAC-5	16.60	16.85	16.73	139.50	137.00	138.25
T15	DAC-6	14.00	14.60	14.30	141.50	133.00	137.25
T16	AZ-1	23.60	23.25	23.43	125.00	132.00	128.50
T17	HUB-1	12.40	18.20	15.30	140.00	136.00	138.00
T18	HUB-2	11.60	16.25	13.93	143.00	134.50	138.75
T19	HUB-3	18.50	19.40	18.95	136.50	137.00	136.75
T20	HUB-4	17.50	16.90	17.20	136.50	141.50	139.00
T21	HUB-5	12.50	12.40	12.45	131.00	143.50	137.25
T22	HUB-6	14.20	14.10	14.15	142.50	142.50	142.50
T23	HUB-8	23.20	24.50	23.85	125.00	136.50	130.75
T24	HUB-9	11.20	12.15	11.67	147.00	160.00	153.50
T25	HUB-10	13.00	14.70	13.85	153.00	159.00	156.00
T26	HUB-11	11.30	12.70	12.00	154.00	156.00	155.00
T27	HUB-13	15.70	16.25	15.98	146.50	142.50	144.50
T28	RM	21.00	21.05	21.03	135.00	133.50	134.25
	S. Em ±	0.80	0.77	0.72	4.9	4.89	3.28
	C. D. (P = 0.05)	2.32	2.22	2.08	14.35	14.18	9.51

Table 11. Number of umbels per plant and number of umbellates per umbel in ajwain genotypes

Treatment	Genotype	Number of umbels per plant			Number of umbellates per umbel		
		2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T1	AA-1	229.00	231.50	230.25	12.20	12.70	12.45
T2	AA-2	233.50	250.30	241.90	12.30	13.20	12.75
T3	AA-93	256.00	273.50	264.75	13.10	14.00	13.55
T4	GA-1	204.90	207.50	206.20	11.60	11.80	11.70
T5	AL-3	95.00	96.80	95.90	10.10	10.50	10.30
T6	AL-4	101.00	103.50	102.25	10.50	10.70	10.60
T7	LS-1	104.60	107.50	106.05	11.00	11.00	11.00
T8	LS-2	106.50	109.00	107.75	11.80	12.00	11.90
T9	LTA 26	105.00	112.30	108.65	11.50	11.50	11.50
T10	DAC-1	141.80	151.00	146.40	12.50	12.60	12.55
T11	DAC-2	126.10	135.00	130.55	12.10	12.50	12.30
T12	DAC-3	120.00	145.60	132.80	11.85	12.00	11.93
T13	DAC-4	101.20	106.20	103.70	11.00	11.00	11.00
T14	DAC-5	131.00	157.70	144.35	12.25	12.50	12.38
T15	DAC-6	117.50	122.50	120.00	11.40	12.70	12.05
T16	AZ-1	298.00	306.50	302.25	13.80	16.00	14.90
T17	HUB-1	125.00	132.50	128.75	11.15	13.30	12.23
T18	HUB-2	123.50	152.50	138.00	11.20	15.00	13.10
T19	HUB-3	80.50	115.40	97.95	11.80	11.60	11.70
T20	HUB-4	139.00	152.25	145.63	12.00	11.00	11.50
T21	HUB-5	105.00	110.20	107.60	11.60	9.70	10.65
T22	HUB-6	125.00	140.30	132.65	12.20	10.10	11.15
T23	HUB-8	288.00	291.80	289.90	13.60	14.30	13.95
T24	HUB-9	65.80	96.50	81.15	9.25	9.50	9.38
T25	HUB-10	75.50	97.00	86.25	10.50	10.25	10.38
T26	HUB-11	66.80	84.55	75.68	10.50	10.60	10.55
T27	HUB-13	87.70	124.00	105.85	9.70	10.50	10.10
T28	RM	245.50	252.50	249.00	12.75	13.80	13.28
	S. Em ±	5.66	6.72	5.41	0.57	0.60	0.57
	C. D. (P = 0.05)	16.42	19.51	15.70	1.65	1.74	1.65

In the season 2020-21, AZ-1 showed the highest number of umbellates per umbel (13.80), which was statistically on par with HUB-8 (13.60), AA-93 (13.10), RM (12.75), DAC-1 (12.50), AA-2 (12.30), DAC-5 (12.25), AA-1 (12.20) HUB-6 (12.20). The lowest number of umbellates per umbel was recorded in HUB-9 (9.25) (Table 11).

In the season 2021-22, AZ-1 showed the highest number of umbellates per umbel (16.00), which was statistically on par with HUB-2 (15.00). The lowest number of umbellates per umbel was recorded in HUB-9 (9.50) (Table 11).

In pooled average over both the season, AZ-1 showed the highest number of umbellates per umbel (14.90), which was statistically on par with HUB-8 (13.85), AA-93 (13.55) and RM (13.28). The lowest number of umbellates per umbel was recorded in HUB-9 (9.38) (Table 11).

4.2.3 Number of seeds per umbel

There were noticeable differences among the genotypes of ajwain with respect to the number of seeds in an umbel.

In the season 2020-21, AZ-1 showed the highest number of seeds per umbel (266.40) which was statistically on par with AA-93 (261.30) and HUB-8 (260.20). The minimum number of seeds per umbel was recorded in HUB-9 (66.05) (Table 12).

In the season 2021-22, HUB-8 showed the highest number of seeds in an umbel (299.80), which was statistically on par with AA-93 (278.30) and AZ-1 (269.50). The minimum number of seeds per umbel was recorded in HUB -9 (69.35) (Table 12).

In pooled average over both the season, HUB-8 showed the highest number of seeds per umbel (280.00), which was statistically on par with AA-93 (269.80) and AZ-1 (267.95). Minimum number of seeds per umbel was recorded in HUB -9 (67.70) (Table 12).

4.2.4 Seed yield per plant (g)

There was a considerable difference among the genotypes of ajwain with respect to the seed yield of an individual plant (Plate 3).

In the season 2020-21, HUB-8 noticed for its highest seed yield (11.60 g) per plant, which was statistically on par with AZ-1 (11.45), AA-93 (10.75 g) and AA-1 (10.61 g), whereas HUB-11 noted less for its seed yield of a single plant (4.81 g) (Table 12).

In the season 2021-22, AZ-1 noticed for its highest seed yield (12.47 g) per plant, which was statistically on par with HUB-8 (11.63 g), AA-93 (11.30 g) and AA-1 (11.28 g), whereas HUB-9 noted less for its seed yield of a single plant (5.01 g) (Table 12).

In pooled average over both the season, the genotype AZ-1 showed the highest seed yield per plant (11.96 g), which was statistically on par with HUB-8 (11.62 g), AA-93 (11.03 g) and AA-1 (10.95 g), whereas HUB-9 noted less for its seed yield of a single plant (4.93 g) (Table 12).

4.2.5 Seed yield (g/plot) and (kg/plot)

The seed yield per hectare varied significantly among genotypes in accordance with the variation in seed yield per plant.

In the season 2020-21, HUB-8 recorded the highest seed yield of 375.00 g per plot, which was statistically on par with AZ-1 (356.50 g), while the lowest was noted in HUB-9 (112.50 g). HUB-8 recorded the highest seed yield of 714.29 kg/ha, followed AZ-1 (679.05 kg/ha), while the lowest was noted in HUB-9 (214.29 kg/ha) (Table 13).

In the season 2021-22, AA-93 recorded the highest seed yield of 394.50 g per plot, which was statistically on par with AZ-1 (392.75 g/plot) and HUB-8 (371.75 g/plot). While, the lowest was noted in HUB-10 (122.00 g/plot). AA-93 recorded the highest seed yield of 768.10 kg/ha which was statistically on par with AZ-1 (744.52 kg/ha), while the lowest was noted in HUB-10 (227.62 kg/ha) (Table 13).

In pooled average over both the season, AZ-1 recorded the highest seed yield of 374.63 g per plot, which was statistically on par with HUB-8 (373.38 g/plot) and AA-93 (363.00 g/plot), while lowest was noted in HUB-9 (118.25 g). AZ-1 recorded the highest seed yield of 711.79 kg per ha, which was statistically on par with HUB-8 (704.17 kg/ha) and AA-93 (699.76 kg/ha), while lowest was noted in HUB-9 (220.95 kg/ha) (Table 13).

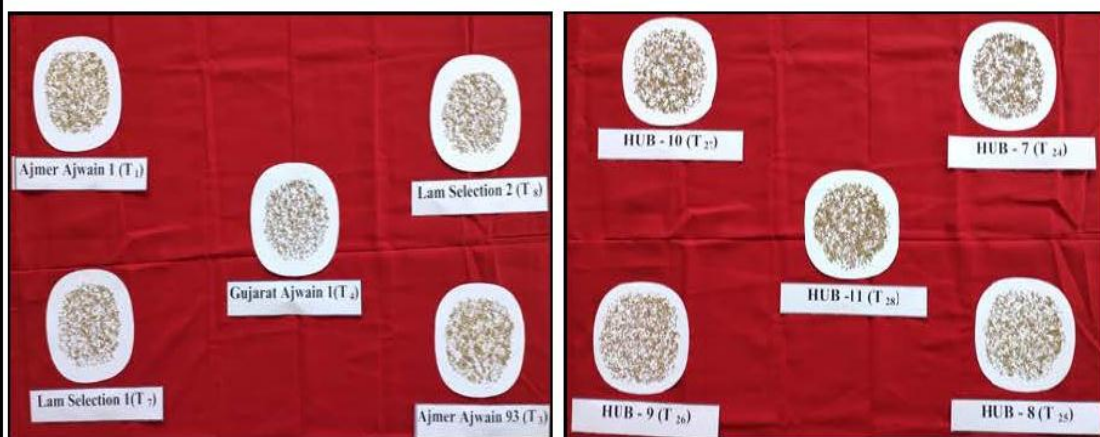
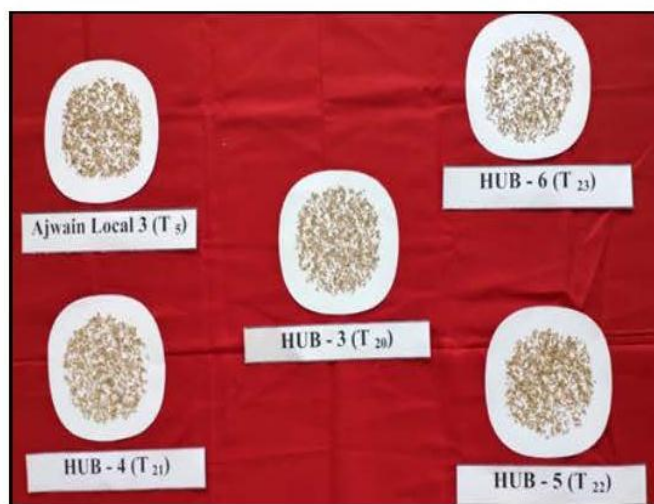
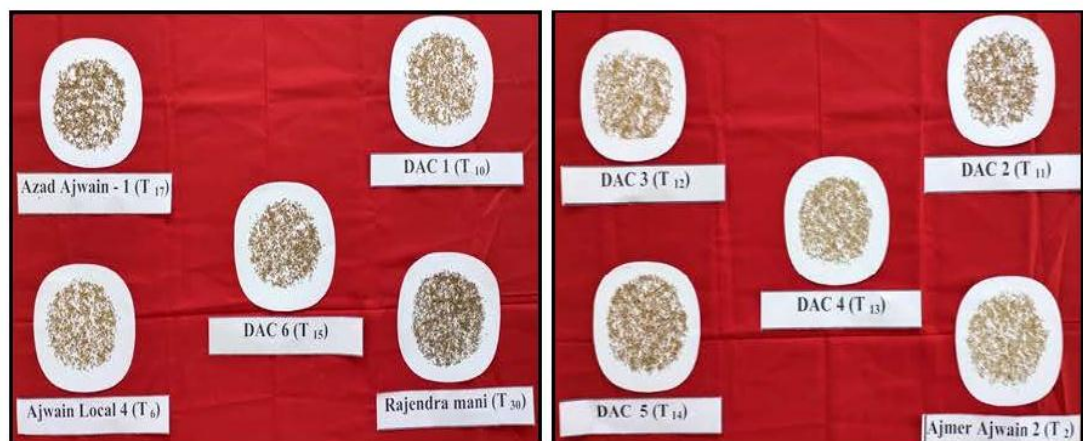


Plate 3. Variability of seeds among the ajwain genotypes

4.2.6 Harvest index (%)

The data pertaining to harvest index (%) of ajwain differed significantly among the genotypes.

In the season 2020-21, HUB-8 recorded maximum harvest index (%) of (38.19%), followed by AZ-1 (35.50%), AA-93 (29.60%) and RM (27.57%), whereas the harvest index (%) was recorded minimum in HUB-11 (14.00 %) (Table 14).

In the season 2021-22, AZ-1 recorded maximum harvest index (%) of (41.05 %), followed by AA-93 (36.50%), HUB-8 (36.20%) and AA-1 (31.81%), whereas the harvesting index was recorded minimum in HUB-9 (15.05%) (Table 14).

In pooled average over both the season, AZ-1 recorded maximum harvest index (%) of (38.27%), which was statistically on par with HUB-8 (37.19%), AA-93 (33.05%), whereas the harvest index (%) was recorded minimum in HUB-9 (14.70%) (Table 14).

4.2.7 Test weight (g)

Thousand seed weight differed considerably among the ajwain genotypes.

In the season 2020-21, the maximum test weight was observed in HUB-8 (1.83 g), followed by AZ-1 (1.60 g), AA-1 (1.56 g) and DAC-1 (1.56 g). The genotype RM showed least test weight of 0.97 g (Table 14).

In the season 2021-22, the maximum test weight was observed in HUB-8 (1.83 g), followed by AZ-1 (1.60 g), AA-1 (1.56 g) and DAC-1 (1.56 g). The genotype RM showed least test weight of 0.97 g (Table 14).

In pooled average over both the season, the maximum test weight was observed in HUB-8 (1.83 g) followed by AZ-1 (1.60 g), AA-1 (1.56 g) and DAC-1 (1.56 g). The genotype RM showed least test weight of 0.97 g (Table 14).

4.3 Quality parameters

4.3.1 Essential oil (%)

The genotypes chosen for study exhibited significant difference in respect of essential oil (%) content (Plate 4).

In the season 2020-21, the highest essential oil content was recorded in RM (2.25%), which was statistically on par with DAC-2 (2.25 %), AA-1 (2.15%), AA-93 (2.15%) and HUB-8 (2.15%), whereas lowest oil content was found in HUB-9 (0.85 %) (Table 15).

In the season 2021-22, the highest essential oil content was recorded in RM (2.35%), which was statistically on par with HUB-8 (2.25%), whereas lowest oil content was found in HUB-9 (0.85 %) (Table 15).

In pooled average over both the season, the highest essential oil content was recorded in RM (2.30%), which was statistically on par with HUB-8 (2.20%), AA-1 (2.15%), DAC-2 (2.15%) and AA-93 (2.15%). The lowest essential oil was found in HUB-9 (0.90%) (Table 15).

4.3.2 Oleoresin (%)

The genotypes chosen for study exhibited significant difference in respect to oleoresin (%) content

In the season 2020-21, the highest oleoresin content was recorded in DAC-5 (6.65%), followed by RM (6.35%) and DAC-4 (6.25%), whereas lowest oleoresin content was found in AL-3 (1.75%) (Table 15).

In the season 2021-22, the highest oleoresin content was recorded in DAC-5 (6.65%), followed by DAC-4 (6.35%) and RM (6.15%), whereas lowest oleoresin content was found in AL-3 (1.75%) (Table 15).

In pooled average over both the season, the highest oleoresin content was recorded in DAC-5 (6.65%), followed by DAC-4 (6.30%) and RM (6.25%), whereas lowest oleoresin content was found in AL-3 (1.75 %).



Plate 4. Variability of essential oil (%) content in ajwain genotypes

4.3.3 Thymol content (%)

The highest thymol content was recorded in DAC-5 (49.61%), which was statistically on par with DAC-3 (46.74%), whereas lowest oleoresin content was found in HUB-2 (41.10%) (Table 16) and (Fig. 2).

4.4 Disease and pest scoring

4.4.1 Powdery mildew

There was no occurrence of powdery mildew in the research plot, hence no observations were recorded.

4.4.2 Wilt

There was no occurrence of wilt in the research plot, hence no observations were recorded.

4.4.3 Aphids

Aphids incidence was not observed in the field, hence no observations were recorded.

4.4.4 Stem fly

Incidence of stem fly was seen on all the 28 genotypes (Plate 5).

In the season 2020-21, The genotype AA-2 showed less per cent incidence of stem fly (23.21%), which was statistically on par with GA-1 (24.34%), AA-93 (25.00%), AZ-1 (26.53%), HUB-2 (26.40%), HUB-1 (28.75%), whereas the maximum incidence of stem fly was noticed in HUB-10 (44.78%) (Table 17).

In the season 2021-22, HUB-8 showed less per cent incidence of stem fly (20.14%), which was statistically on par with HUB-2 (20.18 %), AA-93 (22.86), AZ -1 (22.86%) and HUB-1 (22.99%), whereas the maximum incidence of stem fly was noticed in HUB-10 (45.71%) (Table 17).

Table 12. Number of seeds per umbel and seed yield per plant (g) in ajwain genotypes

Treatment	Genotype	Number of seeds per umbel			Seed yield per plant (g)		
		2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T1	AA-1	206.30	208.27	207.29	10.61	11.28	10.95
T2	AA-2	199.00	193.91	196.46	9.75	10.29	10.02
T3	AA-93	261.30	278.30	269.80	10.75	11.30	11.03
T4	GA-1	179.10	164.53	171.81	9.73	10.18	9.96
T5	AL-3	109.25	114.60	111.93	5.99	6.79	6.39
T6	AL-4	116.50	114.09	115.30	6.04	6.23	6.14
T7	LS-1	94.45	102.30	98.38	5.33	6.85	6.09
T8	LS-2	126.30	111.80	119.05	6.00	6.52	6.26
T9	LTA 26	113.00	122.90	117.95	6.34	6.57	6.46
T10	DAC-1	163.10	149.10	156.10	6.63	7.23	6.93
T11	DAC-2	163.25	178.15	170.70	6.78	6.42	6.60
T12	DAC-3	191.15	149.15	170.15	8.09	6.89	7.49
T13	DAC-4	144.75	158.85	151.80	7.27	7.38	7.33
T14	DAC-5	136.55	146.20	141.38	7.51	6.81	7.16
T15	DAC-6	113.90	111.80	112.85	7.12	7.84	7.48
T16	AZ-1	266.40	269.50	267.95	11.45	12.47	11.96
T17	HUB-1	97.95	183.86	140.91	6.68	7.67	7.17
T18	HUB-2	86.85	189.70	138.28	5.75	8.04	6.90
T19	HUB-3	173.05	177.54	175.30	7.36	7.21	7.29
T20	HUB-4	135.05	110.90	122.98	6.39	5.81	6.10
T21	HUB-5	112.31	72.40	92.36	6.18	5.62	5.90
T22	HUB-6	125.32	97.78	111.55	6.72	5.90	6.31
T23	HUB-8	260.20	299.80	280.00	11.60	11.63	11.62
T24	HUB-9	66.05	69.35	67.70	4.84	5.01	4.93
T25	HUB-10	102.35	93.75	98.05	5.30	5.03	5.17
T26	HUB-11	80.35	74.20	77.28	4.81	5.11	4.96
T27	HUB-13	105.64	100.60	103.12	5.61	7.29	6.45
T28	RM	206.65	223.80	215.23	8.42	9.16	8.79
	S. Em ±	10.42	12.34	15.44	0.37	0.44	0.39
	C. D. (P = 0.05)	30.22	35.81	44.79	1.07	1.27	1.13

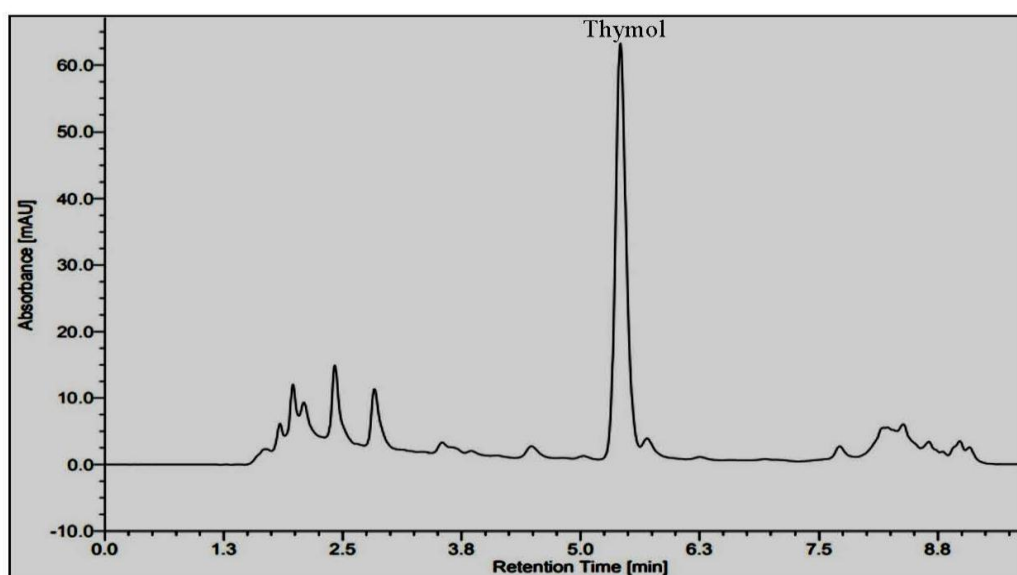


Fig 2a. Thymol content (%) in DAC-5 genotype estimated through HPLC

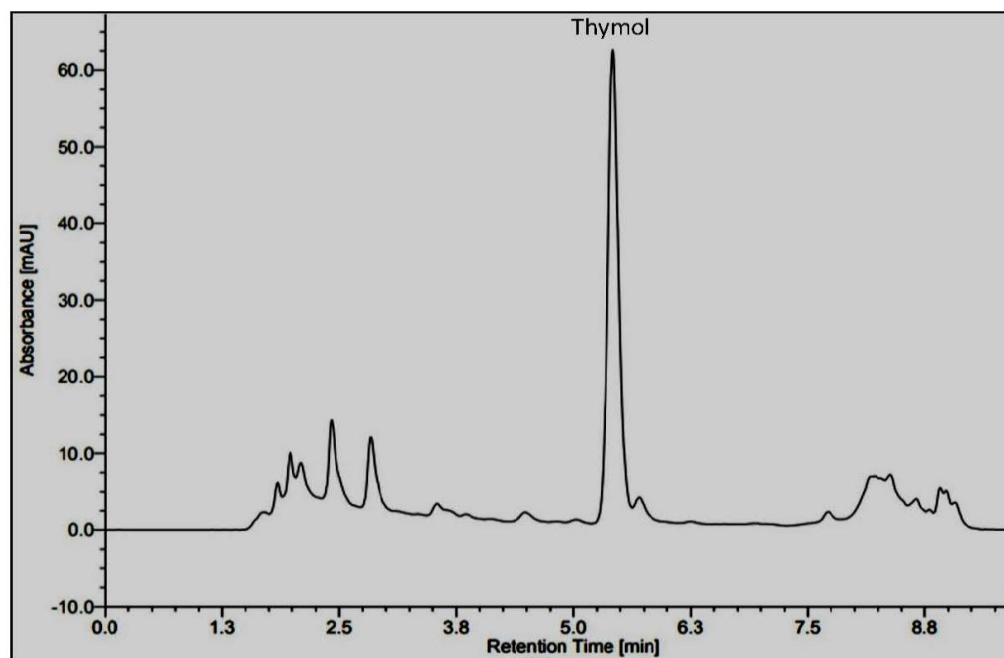


Fig 2b. Thymol content (%) in AA-93 genotype estimated through HPLC

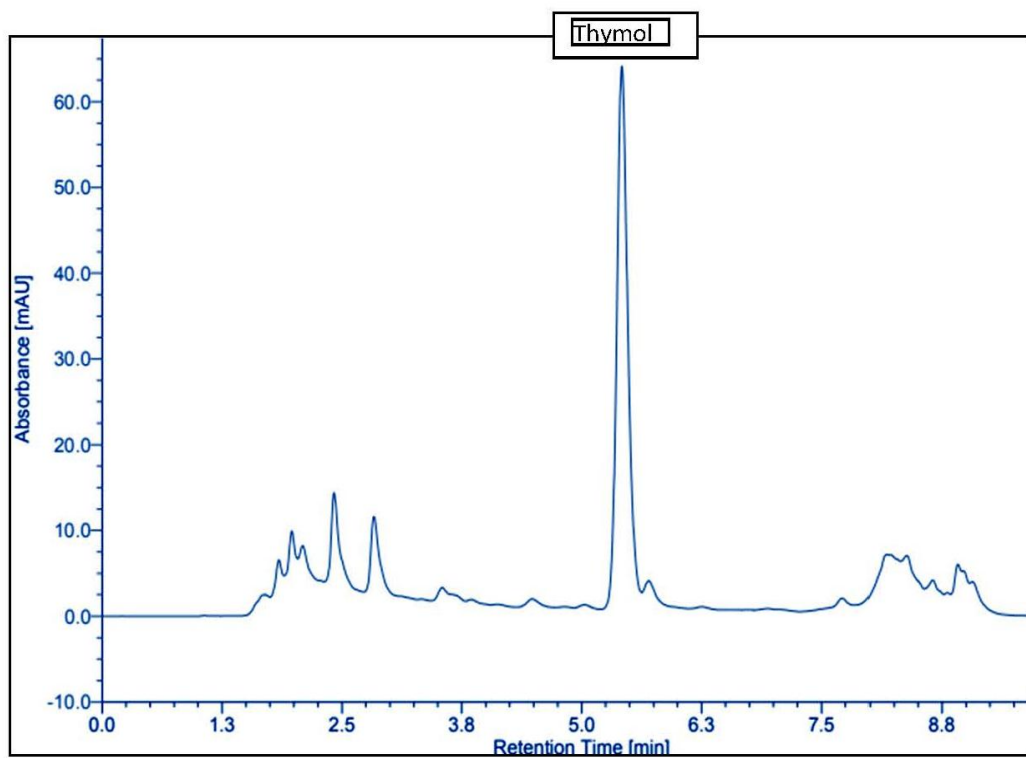


Fig 2c. Thymol content (%) in AA-2 genotype estimated through HPLC

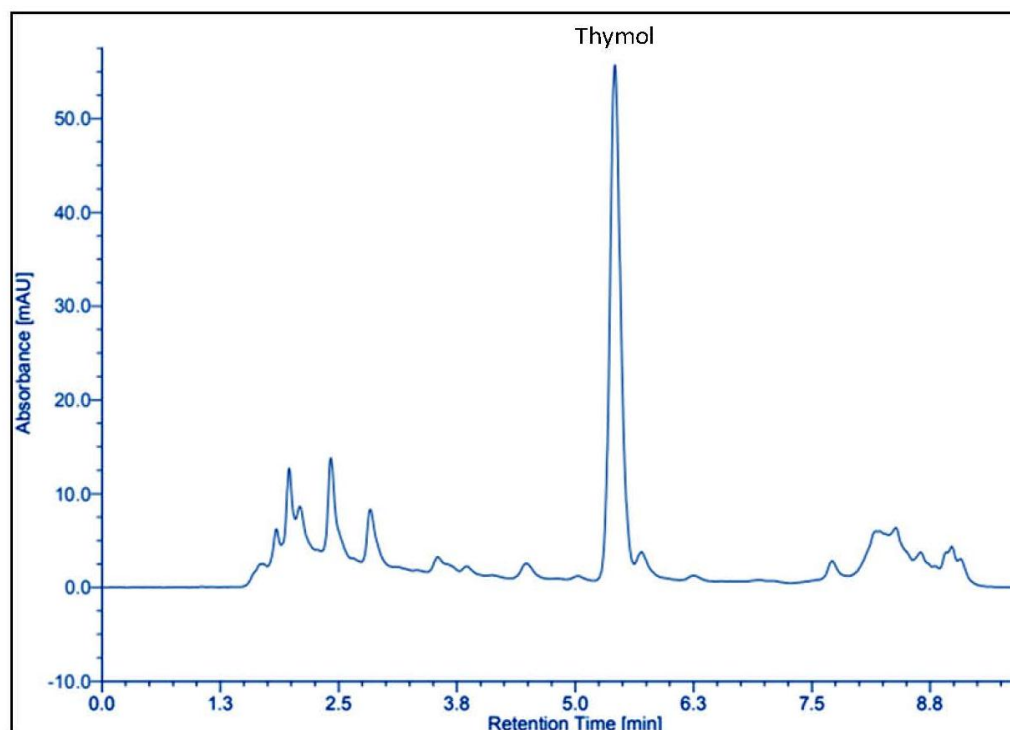


Fig 2d. Thymol content (%) in GA-1 genotype estimated through HPLC

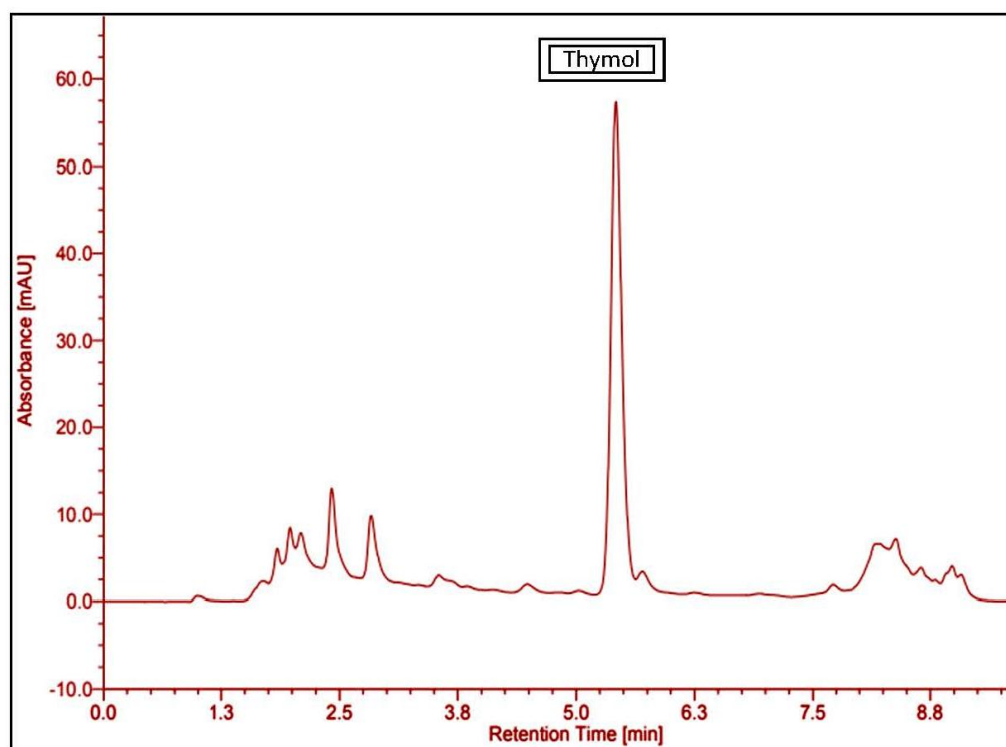


Fig 2e. Thymol content (%) in DAC-3 genotype estimated through HPLC

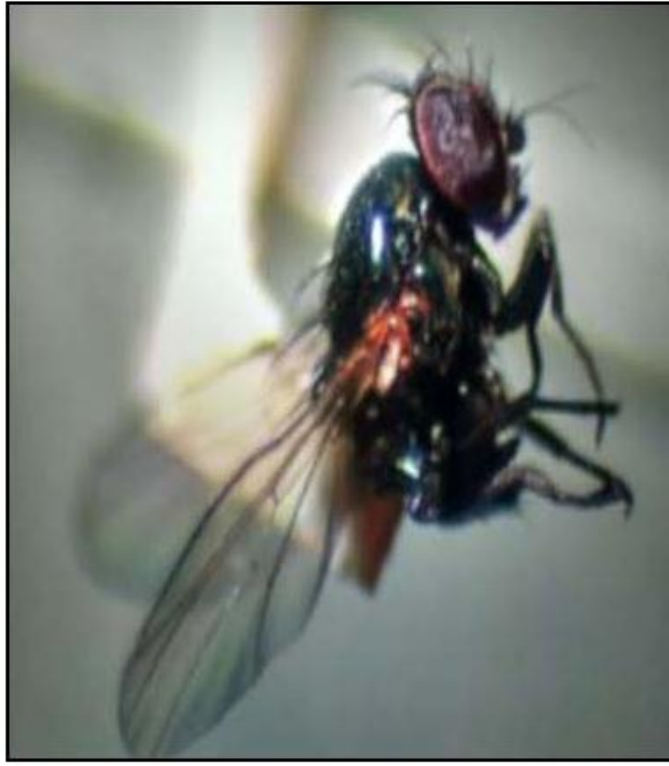


Plate 5. Infestation of stem fly (*Melanagromyza* sp.)

Table 13. Seed yield (g/plot) and (kg/ha) in ajwain genotypes

Treatment	Genotype	Seed yield (g/plot) and (kg/ha)					
		2020-21		2021-22		Pooled	
		g/plot	(kg/ha)	g/plot	(kg/ha)	g/plot	(kg/ha)
T1	AA-1	274.50	522.86	281.80	565.52	278.15	544.19
T2	AA-2	253.00	481.90	261.00	502.86	257.00	492.38
T3	AA-93	331.50	631.43	394.50	768.10	363.00	699.76
T4	GA-1	260.00	495.24	298.00	558.57	279.00	526.90
T5	AL-3	141.00	268.57	148.60	268.67	144.80	268.62
T6	AL-4	160.50	305.71	181.65	342.33	171.08	324.02
T7	LS-1	121.00	230.48	141.00	258.10	131.00	244.29
T8	LS-2	163.00	310.48	160.60	290.10	161.80	300.29
T9	LTA 26	142.50	271.43	175.00	344.76	158.75	308.10
T10	DAC-1	207.50	395.24	199.00	378.10	203.25	386.67
T11	DAC-2	220.00	419.05	229.50	418.10	224.75	418.57
T12	DAC-3	243.50	463.81	212.95	412.81	228.23	438.31
T13	DAC-4	199.00	379.05	192.50	361.43	195.75	370.24
T14	DAC-5	176.50	336.19	260.00	481.90	218.25	409.05
T15	DAC-6	176.00	335.24	236.15	496.33	206.08	415.79
T16	AZ-1	356.50	679.05	392.75	744.52	374.63	711.79
T17	HUB-1	149.00	283.81	256.20	488.19	202.60	386.00
T18	HUB-2	147.50	280.95	267.00	508.57	207.25	394.76
T19	HUB-3	220.00	419.05	244.10	474.57	232.05	446.81
T20	HUB-4	196.00	373.33	192.45	372.24	194.23	372.79
T21	HUB-5	189.00	360.00	149.25	269.29	169.13	314.64
T22	HUB-6	199.50	380.00	163.20	306.86	181.35	343.43
T23	HUB-8	375.00	714.29	371.75	694.05	373.38	704.17
T24	HUB-9	112.50	214.29	124.00	227.62	118.25	220.95
T25	HUB-10	145.00	276.19	122.00	239.52	133.50	257.86
T26	HUB-11	135.00	257.14	137.25	247.38	136.13	252.26
T27	HUB-13	146.00	278.10	198.90	399.90	172.45	339.00
T28	RM	263.00	500.95	341.30	654.19	302.15	577.57
	S. Em ±	12.77	24.32	15.74	14.99	20.48	41.47
	C. D. (P = 0.05)	37.05	70.57	45.67	43.50	59.42	120.34

Table 14. Harvest index (%) and test weight (g) in ajwain genotypes

Treatment	Genotype	Harvest index (%)			Test weight (g)		
		2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T1	AA-1	26.96	31.81	29.38	1.56	1.56	1.56
T2	AA-2	23.96	29.57	26.77	1.30	1.34	1.32
T3	AA-93	29.60	36.50	33.05	1.37	1.39	1.38
T4	GA-1	26.61	27.80	27.20	1.25	1.25	1.25
T5	AL-3	16.60	19.64	18.12	1.18	1.18	1.18
T6	AL-4	17.16	18.42	17.79	1.20	1.20	1.20
T7	LS-1	15.75	23.30	19.53	1.21	1.22	1.21
T8	LS-2	16.80	16.25	16.52	1.23	1.23	1.23
T9	LTA 26	18.45	17.13	17.79	1.42	1.42	1.42
T10	DAC-1	18.97	20.07	19.52	1.56	1.56	1.56
T11	DAC-2	19.25	15.95	17.60	1.21	1.21	1.21
T12	DAC-3	27.40	18.05	22.73	1.01	1.01	1.01
T13	DAC-4	24.90	24.19	24.54	1.42	1.42	1.42
T14	DAC-5	26.25	19.60	22.93	1.21	1.21	1.21
T15	DAC-6	23.83	28.38	26.10	1.55	1.55	1.55
T16	AZ-1	35.50	41.05	38.27	1.60	1.60	1.60
T17	HUB-1	20.10	25.91	23.00	1.41	1.41	1.41
T18	HUB-2	16.00	30.15	23.08	1.32	1.32	1.32
T19	HUB-3	25.11	24.61	24.86	1.18	1.18	1.18
T20	HUB-4	18.15	15.30	16.72	1.20	1.20	1.20
T21	HUB-5	17.90	15.93	16.92	1.22	1.22	1.22
T22	HUB-6	22.35	17.90	20.13	1.52	1.52	1.52
T23	HUB-8	38.19	36.20	37.19	1.83	1.83	1.83
T24	HUB-9	14.35	15.05	14.70	1.20	1.20	1.20
T25	HUB-10	15.50	15.65	15.58	1.31	1.31	1.31
T26	HUB-11	14.00	16.25	15.13	1.33	1.33	1.33
T27	HUB-13	15.45	24.15	19.80	1.10	1.10	1.10
T28	RM	27.57	28.55	28.06	0.97	0.97	0.97
	S. Em ±	0.81	0.95	2.46	0.01	0.02	0.01
	C. D. (P = 0.05)	2.35	2.74	7.14	0.03	0.05	0.03

Table 15. Essential oil (%) and oleoresin (%) content in ajwain genotypes

Treatment	Genotype	Essential oil (%)			Oleoresin (%)		
		2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T1	AA-1	2.15	2.15	2.15	3.30	3.25	3.28
T2	AA-2	1.85	1.95	1.90	3.30	3.15	3.23
T3	AA-93	2.15	2.15	2.15	5.25	5.23	5.24
T4	GA-1	1.15	1.25	1.20	4.10	4.15	4.13
T5	AL-3	1.25	1.20	1.23	1.75	1.75	1.75
T6	AL-4	1.15	1.15	1.15	3.85	3.95	3.90
T7	LS-1	1.75	1.65	1.70	3.75	3.75	3.75
T8	LS-2	1.35	1.35	1.35	4.15	4.05	4.10
T9	LTA 26	1.65	1.55	1.60	3.15	3.15	3.15
T10	DAC-1	2.05	2.05	2.05	2.45	2.55	2.50
T11	DAC-2	2.25	2.05	2.15	2.25	2.35	2.30
T12	DAC-3	2.00	2.10	2.05	2.65	2.55	2.60
T13	DAC-4	2.05	2.05	2.05	6.25	6.35	6.30
T14	DAC-5	1.15	1.25	1.20	6.65	6.65	6.65
T15	DAC-6	2.05	2.05	2.05	4.75	4.65	4.70
T16	AZ-1	2.00	2.15	2.08	5.65	5.75	5.70
T17	HUB-1	1.60	1.55	1.58	4.95	5.05	5.00
T18	HUB-2	1.65	1.45	1.55	5.15	5.20	5.18
T19	HUB-3	1.35	1.25	1.30	5.70	5.75	5.73
T20	HUB-4	1.35	1.40	1.38	5.50	5.45	5.48
T21	HUB-5	1.65	1.55	1.60	5.40	5.25	5.33
T22	HUB-6	1.85	1.65	1.75	5.85	5.95	5.90
T23	HUB-8	2.15	2.25	2.20	5.65	5.65	5.65
T24	HUB-9	0.85	0.95	0.90	2.65	2.60	2.63
T25	HUB-10	0.95	0.95	0.95	2.45	2.40	2.43
T26	HUB-11	0.85	0.95	0.90	2.85	2.95	2.90
T27	HUB-13	1.25	1.45	1.35	3.50	3.45	3.48
T28	RM	2.25	2.35	2.30	6.35	6.15	6.25
	S. Em ±	0.05	0.05	0.05	0.10	0.06	0.04
	C. D. (P = 0.05)	0.16	0.15	0.16	0.29	0.21	0.13

In pooled average over both the season, the genotype HUB-2 showed less per cent incidence of stem fly (23.29%), which was statistically on par with AA-2 (23.75%), AA-93 (23.93%), AZ-1 (24.69%), GA-1 (25.20%), HUB-8 (25.60%) and HUB-1 (25.87%), whereas maximum incidence of stem fly was noticed in HUB-10 (45.25%) (Table 17).

4.5 Analysis of variance

Mean sum of squares due to replication, genotypes and error of the experiment was calculated for the pooled data were presented in table 18. The analysis of variance showed highly significant differences among the genotypes for all the parameters (number of flowers per umbellates, days to flower initiation (10%), number of umbellates per umbel, number of umbels per plant, number of seeds per umbel, harvest index (%), seed yield per plant (g), essential oil (%), oleoresin (%), days to germination, plant height at 150 DAS, number of branches per plant at 150 DAS and days to 50 per cent flowering) which represents the existence of variability in the evaluated genotypes for all the traits. The results obtained with respect to different characters are described below.

4.6 Genetic, phenotypic, heritability and genetic advance in ajwain

Genetic variability factors like mean, range, phenotypic variance (PV), genotypic variance (GV), genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), genetic advance (GA), broad sense heritability (h^2 BS) and genetic advance as per cent of mean (GAM) was calculated for the pooled data and represented in Table 19. The results indicated that there was large amount of variability noticed for most of the characters.

4.6.1 Days to germination

Number of days to germination ranged between 9.75 and 15.50 with a grand mean of 12.43. The PV and GV were 2.08 and 1.67, respectively. The PCV (11.60%) and GCV (10.40%) were moderate. High heritability (80.30%) with moderate genetic advance over mean (19.20 %) was observed.

Table 16. Thymol content (%) in ajwain genotypes

SN	Genotype	Thymol content (%)
1	AA-1	46.37
2	AA-2	47.39
3	AA-93	48.50
4	GA-1	44.15
5	DAC-5	49.61
6	DAC-3	46.74
7	AZ-1	43.57
8	HUB-2	41.10
9	HUB-8	41.95
10	RM	41.47
	S. Em $\pm$	0.99
	C. D. (P = 0.05)	3.22

Table 17. Reaction of different genotypes of ajwain against stem fly infestation (%)

Treatment	Genotype	Incidence of stem fly (%)		
		2020-21	2021-22	Pooled
T1	AA-1	32.620	32.710	32.670
T2	AA-2	23.210	24.290	23.750
T3	AA-93	25.000	22.860	23.930
T4	GA-1	24.340	26.050	25.200
T5	AL-3	42.490	37.140	39.820
T6	AL-4	43.310	40.000	41.660
T7	LS-1	35.000	42.860	38.930
T8	LS-2	41.390	40.000	40.690
T9	LTA 26	41.210	45.710	43.460
T10	DAC-1	42.500	37.140	39.820
T11	DAC-2	42.060	42.860	42.460
T12	DAC-3	42.870	40.000	41.440
T13	DAC-4	35.620	31.430	33.530
T14	DAC-5	34.750	34.290	34.520
T15	DAC-6	36.810	31.430	34.120
T16	AZ-1	26.530	22.860	24.690
T17	HUB-1	28.750	22.990	25.870
T18	HUB-2	26.400	20.180	23.290
T19	HUB-3	39.630	34.290	36.960
T20	HUB-4	44.460	41.780	43.120
T21	HUB-5	43.890	37.140	40.520
T22	HUB-6	32.500	31.430	31.960
T23	HUB-8	31.070	20.140	25.600
T24	HUB-9	41.340	37.140	39.240
T25	HUB-10	44.780	45.710	45.250
T26	HUB-11	44.290	40.000	42.140
T27	HUB-13	44.130	38.640	41.380
T28	RM	36.020	33.390	34.700
	S. Em ±	2.12	1.25	2.04
	C. D. (P = 0.05)	6.15	3.63	5.91

Table 18. Analysis of variance (ANOVA) for growth, yield and quality parameters in ajwain genotype (Pooled)

SN	Source of variation/character	Replication	Genotype	Error
	Degree of freedom	1	27	27
1	Days to germination	9.446	4.156**	0.817
2	Plant height at 150 DAS	11402.872	104.752**	36.569
3	Number of branches per plant at 150 DAS	20.190	6.312**	1.024
4	Days to flower initiation (10%)	0.540	128.556**	19.198
5	Days to 50 per cent flowering	2.571	110.393**	23.340
6	Number of flowers per umbellates	9.364	22.450**	1.023
7	Number of umbels per plant	2411.719	8877.77**	58.569
8	Number of umbellates per umbel	2.122	3.167**	0.647
9	Number of seeds per umbel	306.704	6542.091**	476.551
10	Seed yield per plant (g)	1.605	8.167**	0.305
11	Harvest index (%)	37.294	77.454**	12.121
12	Test weight (g)	0.000	0.071	0.000
13	Essential oil (%)	0.000	0.386*	0.006
14	Oleoresin (%)	0.000	4.150**	0.004

**Significant at 1 (P=0.01)

*Significant at 5 (P=0.05)

DAS- Days after sowing

4.6.2 Plant height at 150 DAS

The plant height at 150 DAS ranged between 66.23 and 96.83 with a grand mean of 84.11. The PV and GV were 52.38 and 34.09, respectively. The PCV (8.60%) and GCV (6.94%) were low. High heritability (65.10%) with moderate genetic advance over mean (11.54 %) was observed.

4.6.3 Number of branches per plant at 150 DAS

The number of branches per plant at 150 DAS ranged between 10.25 and 18.18 with a grand mean of 14.86. The PV and GV were 3.16 and 2.64, respectively. The PCV (11.95%) and GCV (10.94%) were moderate for number of branches per plant at 150 DAS with high heritability (83.80%). The genetic advance over mean was high (20.63%) for this trait.

4.6.4 Days to flower initiation (10%)

Days to flower initiation (10%) ranged between 66.00 and 101.50 with a grand mean of 87.58. The PV and GV were 64.28 and 54.68, respectively. The low PCV (9.15%) and GCV (8.44%) were recorded. High heritability (85.10%) with moderate genetic advance over mean (16.04 %) was observed for days to flower initiation (10%).

4.6.5 Days to 50 per cent flowering

Days to 50 per cent flowering ranged between 77.25 and 109.75 with a grand mean of 96.36. The PV and GV were 55.20 and 43.53, respectively. The low PCV (7.71%) and GCV (6.85%) were recorded. High heritability (78.90%) with moderate genetic advance over mean (12.53%) was observed for days to 50 per cent flowering.

4.6.6 Number of flowers per umbellates

The number of flowers per umbellates ranged between 11.80 and 23.85 with a grand mean of 16.93. The PV and GV were 11.23 and 10.71, respectively. The PCV (19.79%) and GCV (19.33%) were moderate. High heritability (95.40%) with high genetic advance over mean (38.90%) was observed for number of flowers per umbellates.

4.6.7 Days to physiological maturity

Days to physiological maturity ranged between 129.75 and 156.00 with a grand mean of 138.56. The PV and GV were 48.82 and 38.08, respectively. The PCV (5.04%) and GCV (4.45%) were low. High heritability (78.00%) with low genetic advance over mean (8.10%) was observed for days to physiological maturity.

4.6.8 Number of umbels per plant

The number of umbels per plant ranged between 75.68 and 289.90 with a grand mean of 149.36. The PV and GV were 4438.89 and 4409.60, respectively. The PCV (44.61%) and GCV (44.46%) were high. High heritability (99.30%) with high genetic advance over mean (91.28%) was observed for this trait.

4.6.9 Number of umbellates per umbel

The number of umbellates per umbel ranged between 9.38 and 14.90 with a grand mean of 11.81. The PV and GV were 1.58 and 1.26, respectively. The PCV (10.65%) and GCV (9.50%) were low with high heritability (79.60%) and moderate genetic advance over mean (17.46%) was observed for this trait.

4.6.10 Number of seeds per umbel

The number of seeds per umbel ranged between 67.70 and 280.00 with a grand mean of 150.06. The PV and GV were 3271.05 and 3032.77, respectively. The PCV (38.11%) and GCV (36.70%) were high. High heritability (92.70%) with high genetic advance over mean (72.80%) was observed for number of seeds per umbel.

4.6.11 Seed yield per plant (g)

Seed yield per plant (g) ranged between 4.93 and 11.96 with a grand mean of 7.49. The PV and GV were 4.08 and 3.93, respectively. The PCV (26.97%) and GCV (26.46%) were high. High heritability (96.30%) with high genetic advance over mean (53.48%) was observed.

4.6.12 Seed yield (g/plot) and (kg/ha)

The seed yield (g/plot) ranged between 118.25 and 374.63 with a grand mean of 214.93. The PV and GV were 5144.21 and 4724.92, respectively. The PCV (33.37%) and GCV (31.98%) were high. High heritability (91.80%) with high genetic advance over mean (54.55%) was observed for this trait. Seed yield (kg/ha) ranged between 220.95 and 711.79 with a grand mean of 409.61. The PV and GV were 19047.67 and 17327.73, respectively. The PCV (33.69%) and GCV (32.13%) were high. High heritability (91.00%) with high genetic advance over mean (63.14%) was observed.

4.6.13 Harvest index (%)

The harvest index (%) ranged between 14.83 and 32.90 with a grand mean of 22.52. The PV and GV were 38.73 and 32.67, respectively. The PCV (27.64%) and GCV (25.38%) were high. High heritability (84.40%) with high genetic advance over mean (48.02%) was observed for harvest index (%).

4.6.14 Test weight (g)

Test weight (g) ranged between 0.97 and 1.83 with a grand mean of 1.31. The PV and GV were 0.04 and 0.04, respectively. The PCV (14.29%) and GCV (14.27%) were moderate. High heritability (99.70%) with high genetic advance over mean (29.34%) was observed for this trait.

4.6.15 Essential oil (%)

The essential oil (%) content ranged 0.90 and 2.30 with a grand mean of 1.64. The PV and GV were 0.19 and 0.19, respectively. The PCV (26.87%) and GCV (26.67%) were high. High heritability (98.50%) with high genetic advance over mean (54.52 %) was observed for essential oil (%).

4.6.16 Oleoresin (%)

Oleoresin content (%) ranged between 1.75 and 6.65 with a grand mean of 4.26. The PV and GV were 2.08 and 2.07, respectively. The PCV (33.84%) and GCV (33.83%) were high. High heritability (99.90%) with high genetic advance over mean (69.65%) was observed for this trait.

4.7 Correlation studies

4.7.1 Genotypic correlation

The genotypic association between dependent and independent traits in ajwain was estimated for pooled data and represented in table 20.

At genotypic level, total seed yield of plant (g) was positively and highly significantly associated with harvest index (%) (0.971), number of umbels per plant (0.965), number of seeds per umbel (0.950), number of flowers per umbellates (0.912), number of branches per plant at 150 DAS (0.892), number of umbellates per umbel (0.844), plant height at 150 DAS (0.842), essential oil (%) (0.650), test weight (g) (0.461) and oleoresin (%) (0.325). It was negatively and significantly associated with days to 50 per cent flowering (-0.907), days to flower initiation (10%) (-0.881) and days to germination (-0.809).

Days to germination was significant and positive correlation with days to 50 per cent flowering (0.858) and days to flower initiation (10%) (0.790). Days to germination was significant and had negative correlation with number of branches per plant at 150 DAS (-0.989), plant height at 150 DAS (-0.982), harvest index (%) (-0.914), number of seeds per umbel (-0.891), essential oil (%) (-0.844), seed yield per plant (g) (-0.809), number of umbellates per umbel (-0.789), number of umbels per plant (-0.779), number of flowers per umbellates (-0.756), oleoresin (%) (-0.627) and test weight (g) (-0.438).

Plant height at 150 DAS showed significant and positive correlation with number of branches per plant at 150 DAS (0.975), number of seeds per umbel (0.908), essential oil (%) (0.898), harvest index (%) (0.871), seed yield per plant (g) (0.842), number of flowers per umbellates (0.827), number of umbels per plant (0.805), number of umbellates per umbel (0.678) and oleoresin (%) (0.498). Plant height at 150 DAS was significant and negative correlation with days to flower initiation (10%) (-0.999) and days to 50 per cent flowering (-0.934).

Table 19. Estimates of genetic parameters for different characters in ajwain genotype (Pooled)

SN	Range	Mean	GV	PV	GCV (%)	PCV (%)	Heritability (%)	GA	GAM (%)
1	9.75-15.5	12.43	1.67	2.08	10.40	11.60	80.30	2.39	19.20
2	66.23-96.83	84.11	34.09	52.38	6.94	8.60	65.10	9.70	11.54
3	10.25-18.18	14.86	2.64	3.16	10.94	11.95	83.80	3.07	20.63
4	66.00-101.50	87.58	54.68	64.28	8.44	9.15	85.10	14.05	16.04
5	77.25-109.75	96.36	43.53	55.20	6.85	7.71	78.90	12.07	12.53
6	11.80-23.85	16.93	10.71	11.23	19.33	19.79	95.40	6.59	38.90
7	129.75-156.00	138.56	38.08	48.82	4.45	5.04	78.00	11.22	8.10
8	75.68-289.90	149.36	4409.60	4438.89	44.46	44.61	99.30	136.34	91.28
9	9.38-14.90	11.81	1.26	1.58	9.50	10.65	79.60	2.06	17.46
10	67.70-280.00	150.06	3032.77	3271.05	36.70	38.11	92.70	109.24	72.80
11	4.93-11.96	7.49	3.93	4.08	26.46	26.97	96.30	4.01	53.48
12	118.25-374.63	214.93	4724.92	5144.21	31.98	33.37	91.80	135.70	63.14
13	220.95-711.79	409.61	17327.73	19047.67	32.13	33.69	91.00	258.64	63.14
14	14.83-32.90	22.52	32.67	38.73	25.38	27.64	84.40	10.81	48.02
15	0.97-1.83	1.31	0.04	0.04	14.27	14.29	99.70	0.39	29.34
16	0.90-2.30	1.64	0.19	0.19	26.67	26.87	98.50	0.89	54.52
17	1.75-6.65	4.26	2.07	2.08	33.83	33.84	99.90	2.97	69.65

GCV- Genotypic coefficient of variation **PCV**- Phenotypic coefficient of variation **GA**- Genetic advance **GAM**- Genetic advance over mean

1. Days to germination
2. Plant height (cm) at 150 DAS
3. Number of branches per plant at 150 DAS
4. Days to flower initiation (10%)
5. Days to 50 per cent flowering
6. Number of flowers per umbellates
7. Days to physiological maturity

8. Number of umbels per plant
9. Number of umbellates per umbel
10. Number of seeds per umbel
11. Seed yield per plant (g)
12. Seed yield per plot (g)
13. Seed yield per plot (kg/ha)
14. Harvest index (%)

15. Test weight (g)
16. Essential oil (%)
17. Oleoresin (%)

Number of branches per plant at 150 DAS exhibited significant and positive correlation with seed yield per plant (g) (0.892), number of umbellates per umbel (0.867), number of seeds per umbel (0.863), harvest index (%) (0.863), number of umbels per plant (0.863), number of flowers per umbellates (0.841), essential oil (%) (0.841) and oleoresin (%) (0.420). Days to 50 per cent flowering (-0.959) and days to flower initiation (10%) (-0.890) was significant and negative correlation with number of branches per plant at 150 DAS.

Days to flower initiation (10%) was significant and positively correlated with days to 50 per cent flowering (0.956). Days to flower initiation (10%) showed significant and negative correlation with harvest index (%) (-0.988), number of umbels per plant (-0.929), number of seeds per umbel (-0.924), seed yield per plant (g) (-0.881), number of flowers per umbellates (-0.829), number of umbellates per umbel (-0.786), essential oil (%) (-0.624), oleoresin (%) (-0.541) and test weight (g) (-0.363).

Days to 50 per cent flowering owned significant and was negatively correlated with number of seeds per umbel (-0.960), number of umbels per plant (-0.938), seed yield per plant (g) (-0.907), number of flowers per umbellates (-0.855), harvest index (%) (-0.766), number of umbellates per umbel (-0.673), oleoresin (%) (-0.619), essential oil (%) (-0.610) and test weight (g) (-0.358).

Number of flowers per umbellates exhibited significant and was positively correlated with number of seeds per umbel (0.958), seed yield per plant (g) (0.912), number of umbels per plant (0.885), harvest index (%) (0.879), number of umbellates per umbel (0.798), essential oil (%) (0.641) oleoresin (%) (0.322) and test weight (g) (0.289).

Number of umbels per plant showed significant and positive correlation with seed yield per plant (g) (0.965), harvest index (%) (0.957), number of seeds per umbel (0.951), number of umbellates per umbel (0.940), essential oil (%) (0.641), test weight (g) (0.390) and oleoresin (%) (0.351).

Number of umbellates per umbel appeared significant and positive correlation with number of seeds per umbel (0.902), harvest index (%) (0.858), seed yield per plant (g) (0.844), essential oil (%) (0.780), oleoresin (%) (0.478) and test weight (g) (0.471).

Number of seeds per umbel was significant and positive correlation with seed yield per plant (g) (0.950), harvest index (%) (0.932), essential oil (%) (0.738), test weight (g) (0.383) and oleoresin % (0.359).

Harvest index (%) owned significant and positive correlation with seed yield per plant (g) (0.971), essential oil (%) (0.693), oleoresin (%) (0.518) and test weight (g) (0.467).

Test weight (g) was significant and positive correlation with seed yield per plant (g) (0.461) and essential oil (%) (0.370). It showed non-significant and positive correlation with oleoresin (0.162).

Essential oil (%) showed significant and positive correlation with seed yield per plant (g) (0.650) and showed non-significant and positive correlation with oleoresin (%) (0.251).

Oleoresin (%) exhibited significant and positive correlation with seed yield per plant (g) (0.325).

4.7.2 Phenotypic correlation

The phenotypic association between dependent and independent traits in ajwain was estimated for pooled data and represented in table 21.

At phenotypic level, total seed yield of plant (g) was positively and highly significantly associated with harvest index (%) (0.925), number of umbels per plant (0.922), number of seeds in an umbel (0.910), number of flowers per umbellates (0.879), number of umbellates per umbel (0.774), number of branches per plant at 150 DAS (0.755), essential oil (%) (0.618), plant height at 150 DAS (0.581), test weight (g) (0.441) and oleoresin (%) (0.314). It was negatively and significantly associated with days to flower initiation (10%) (-0.724), days to 50 per cent flowering (-0.685) and days to germination (-0.629).

Table 20. Genotypic correlation for yield and yield related traits in ajwain genotype (Pooled)

@	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
X1	1.000	-0.982**	-0.989**	0.790**	0.858**	-0.756**	-0.779**	-0.789**	-0.891**	-0.914**	-0.438**	-0.844**	-0.627**	-0.809**
X2		1.000	0.975**	-0.999**	-0.934**	0.827**	0.805**	0.678**	0.908**	0.871**	0.169	0.898**	0.498**	0.842**
X3			1.000	-0.890**	-0.959**	0.841**	0.863**	0.867**	0.863**	0.863**	0.205	0.841**	0.420**	0.892**
X4				1.000	0.956**	-0.829**	-0.929**	-0.786**	-0.924**	-0.988**	-0.363**	-0.624**	-0.541**	-0.881**
X5					1.000	-0.855**	-0.938**	-0.673**	-0.960**	-0.766**	-0.358**	-0.610**	-0.619**	-0.907**
X6						1.000	0.885**	0.798**	0.958**	0.879**	0.289*	0.641**	0.322*	0.912**
X7							1.000	0.940**	0.951**	0.957**	0.390**	0.641**	0.351**	0.965**
X8								1.000	0.902**	0.858**	0.471**	0.780**	0.478**	0.844**
X9									1.000	0.932**	0.383**	0.738**	0.359**	0.950**
X10										1.000	0.467**	0.693**	0.518**	0.971**
X11											1.000	0.370**	0.162	0.461**
X12												1.000	0.251	0.650**
X13													1.000	0.325*

Critical value of 'r' at 5%= .2631 and that at 1%= .3415

** Significant at 1 per cent level of probability

* Significant at 5 per cent level of probability

X1- Days to germination

X9 - Number of seeds per umbel

X2 - Plant height (cm) at 150 DAS

X10 - Harvest index (%)

X3 - Number of branches per plant at 150 DAS

X11- Test weight (g)

X4 - Days to flower initiation (10%)

X12- Essential oil (%)

X5 - Days to 50 per cent flowering

X13 - Oleoresin (%)

X6 - Number of flowers per umbellates

X14 - Seed yield of a plant (g)

X7 - Number of umbels per plant

X8 - Number of umbellates per umbel

Days to germination owned significant and was positively correlated with days to 50 per cent flowering (0.644) and days to flower initiation (10%) (0.642). Days to germination was significant and negative correlation with essential oil (%) (-0.711), number of umbellates per umbel (-0.651), seed yield per plant (g) (-0.629), number of seeds per umbel (-0.618), number of umbels per plant (-0.618), harvest index (%) (-0.612), number of branches per plant at 150 DAS (-0.599), number of flowers per umbellates (-0.581), oleoresin (%) (-0.514), plant height at 150 DAS (-0.505) and test weight (g) (-0.358).

Plant height at 150 DAS was significant and had positive correlation with number of seeds per umbel (0.649), number of flowers per umbellates (0.636), number of branches per plant at 150 DAS (0.768), number of umbellates per umbel (0.608), harvest index (%) (0.594), seed yield per plant (g) (0.581), number of umbels per plant (0.590), essential oil (%) (0.567) and oleoresin (%) (0.350). Plant height at 150 DAS showed significant and was negatively correlated with days to flower initiation (10%) (-0.645) and days to 50 per cent flowering (-0.644).

Number of branches per plant at 150 DAS showed significant and had positive correlation with number of seeds per umbel (0.775), number of umbels per plant (0.763), seed yield per plant (g) (0.755), number of flowers per umbellates (0.754), number of umbellates per umbel (0.689), essential oil (%) (0.688), harvest index (%) (0.675) and oleoresin (%) (0.354). Number of branches per plant at 150 DAS exhibited significant and negative correlation with days to flower initiation (10%) (-0.694) and days to 50 per cent flowering (-0.686).

Days to flower initiation (10%) owned significant and was positively correlated with days to 50 per cent flowering (0.971). Days to flower initiation 10% showed significant and negative correlation with number of umbels per plant (-0.798), seed yield per plant (g) (-0.724), number of seeds per umbel (-0.710), number of umbellates per umbel (-0.707), harvest index (%) (-0.674), number of flowers per umbellates (-0.666), essential oil (%) (-0.554), oleoresin (%) (-0.461) and test weight (g) (-0.313).

Days to 50 per cent flowering showed significant and negative correlation with number of umbels per plant (-0.755), number of umbellates per umbel (-0.696), seed

yield per plant (g) (-0.685), number of seeds per umbel (-0.677), harvest index (%) (-0.634), number of flowers per umbellates (-0.634), essential oil (%) (-0.524), oleoresin (%) (-0.492) and test weight (g) (-0.289).

Number of flowers per umbellates had exhibited significant and positive correlation with number of seeds per umbel (0.940), seed yield per plant (g) (0.879), number of umbels per plant (0.842), harvest index (%) (0.802), number of umbellates per umbel (0.717), essential oil (%) (0.588), oleoresin (%) (0.311) and test weight (g) (0.278).

Number of umbels per plant showed significant and positive correlation with seed yield per plant (g) (0.922), number of seeds per umbel (0.881), harvest index (%) (0.813), number of umbellates per umbel (0.767), essential oil (%) (0.630), test weight (0.387) and oleoresin (%) (0.348).

Number of umbellates per umbel exhibited significant and was positively correlated with number of seeds per umbel (0.847), harvest index (%) (0.791), seed yield per plant (g) (0.774), essential oil (%) (0.637), oleoresin (%) (0.391) and test weight (g) (0.371).

Number of seeds per umbel showed significant and was positively correlated with seed yield per plant (g) (0.910), harvest index (%) (0.864), essential oil (%) (0.660), test weight (g) (0.355) and oleoresin (%) (0.339).

Harvest index (%) revealed significant and positive correlation with seed yield per plant (g) (0.925), essential oil (%) (0.583), oleoresin (%) (0.444) and test weight (g) (0.403).

Test weight (g) showed significant and positive correlation with seed yield per plant (g) (0.441) and essential oil (0.360). It showed non-significant and positive correlation with oleoresin (0.160).

Essential oil (%) was significant and positively correlated with seed yield per plant (0.618) and showed non-significant and had positive correlation with oleoresin (%) (0.245).

Table 21. Phenotypic correlation for yield and yield related traits in ajwain genotype (Pooled)

@	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
X1	1.000	-0.505**	-0.599**	0.642**	0.644**	-0.581**	-0.618**	-0.651**	-0.618**	-0.612**	-0.358**	-0.711**	-0.514**	-0.629**
X2		1.000	0.768**	-0.645**	-0.644**	0.636**	0.590**	0.608**	0.649**	0.594**	0.120	0.567**	0.350**	0.581**
X3			1.000	-0.694**	-0.686**	0.754**	0.763**	0.689**	0.775**	0.675**	0.182	0.688**	0.354**	0.755**
X4				1.000	0.971**	-0.666**	-0.798**	-0.707**	-0.710**	-0.674**	-0.313*	-0.554**	-0.461**	-0.724**
X5					1.000	-0.634**	-0.755**	-0.696**	-0.677**	-0.634**	-0.289*	-0.524**	-0.492**	-0.685**
X6						1.000	0.842**	0.717**	0.940**	0.802**	0.278*	0.588**	0.311*	0.879**
X7							1.000	0.767**	0.881**	0.813**	0.387**	0.630**	0.348**	0.922**
X8								1.000	0.847**	0.791**	0.371**	0.637**	0.391**	0.774**
X9									1.000	0.864**	0.355**	0.660**	0.339*	0.910**
X10										1.000	0.403**	0.583**	0.444**	0.925**
X11											1.000	0.360**	0.160	0.441**
X12												1.000	0.245	0.618**
X13													1.000	0.314*

Critical value of 'r' at 5%= .2631 and that at 1%= .3415 ** Significant at 1 per cent level of probability * Significant at 5 per cent level of probability

X1- Days to germination

X2 - Plant height (cm) at 150 DAS

X3 - Number of branches per plant at 150 DAS

X4 - Days to flower initiation (10%)

X5 - Days to 50 per cent flowering

X6 - Number of flowers per umbellates

X7 - Number of umbels per plant

X8 - Number of umbellates per umbel

X9 - Number of seeds per umbel

X10- Harvest index (%)

X11- Test weight (g)

X12- Essential oil (%)

X13 -Oleoresin (%)

X14 -Seed yield of a plant (g)

Oleoresin (%) exhibited significant and positively correlated with seed yield per plant (0.314).

4.8 Path coefficient analysis

The direct and indirect effect of association of dependent and independent variables in ajwain was calculated for the pooled data. The path coefficient analysis gives information regarding to the relative contribution of different traits with respect to seed yield of a plant by dividing the correlation coefficient into indirect and direct effect of a selected character on seed yield of a plant were computed.

4.8.1 Genotypic path co-efficient

Genotypic path coefficients for yield per plant with 13 independent characters are presented in table 22 and fig 3.

For total seed yield per plant high positive direct effect was expressed by number of seeds per umbel (3.040) followed by number of branches at 150 DAS (2.033), test weight (g) (0.566), days to germination (0.531) and oleoresin (%) (0.056), whereas number of flowers per umbellates (-1.416), harvest index (%) (-1.035), number of umbellates per umbel (-0.976), days to 50 per cent flowering (-0.841), plant height at 150 DAS (-0.582), number of umbels per plant (-0.543), essential oil (%) (-0.442) and days to flower initiation (10%) (-0.171) had negative direct effect on total yield per plant (Fig 2).

Days to germination had positive indirect effect on seed yield per plant *via* number of flowers per umbellates (1.071), number of umbellates per umbel (1.033), harvest index (%) (0.946), plant height at 150 DAS (0.670), number of umbels per plant (0.423) and essential oil (%) (0.373). Number of seeds per umbel (-2.707), number of branches per plant at 150 DAS (-2.010), days to 50 per cent flowering (-0.721), test weight (%) (-0.248), days to flower initiation (10%) (-0.135) and oleoresin (%) (-0.035) had negative indirect effect on seed yield per plant.

Plant height at 150 DAS had positive indirect effect on seed yield per plant *via* number of seeds per umbel (2.759), number of branches per plant at 150 DAS (1.983), days to 50 per cent flowering (0.942), days to flower initiation (10%) (0.180), test

weight (g) (0.096) and oleoresin (%) (0.028). Number of umbellates per umbel (-1.047), harvest index (%) (-0.901), days to germination (-0.611), number of umbels per plant (-0.437) and number of flowers per umbellates (-0.171) had negative indirect effect on seed yield per plant.

Number of branches per plant at 150 DAS had indirect positive effect on seed yield per plant *via* number of seeds per umbel (2.622), days to 50 per cent flowering (0.806), days to flower initiation (10%) (0.152), test weight (g) (0.116) and oleoresin (%) (0.023). Number of flowers per umbellates (-1.190), harvest index (%) (-0.893), number of umbellates per umbel (-0.846), plant height at 150 DAS (-0.567), days to germination (-0.525), number of umbels per plant (-0.469) and essential oil (%) (-0.372) had negative indirect effect on seed yield per plant.

Days to flower initiation (10%) showed indirect positive effect on seed yield per plant *via* number of flowers per umbellates (1.174), harvest index (%) (1.022), number of umbellates per umbel (0.980), plant height at 150 DAS (0.615), number of umbels per plant (0.505), days to germination (0.420) and essential oil (%) (0.276). Number of seeds per umbel (-2.809), number of branches per plant at 150 DAS (-1.810), days to 50 per cent flowering (10%) (-0.847), test weight (g) (-0.205) and oleoresin (%) (-0.030) had negative indirect effect on seed yield per plant.

Days to 50 per cent flowering owned indirect positive effect on seed yield per plant *via* number of flowers per umbellates (1.210), number of umbellates per umbel (1.058), harvest index (%) (1.056), plant height at 150 DAS (0.652), number of umbels per plant (0.509), days to germination (0.455) and essential oil (%) (0.269). Number of seeds per umbel (-2.917), number of branches per plant at 150 DAS (-1.950), test weight (%) (-0.202), days to flower initiation (10%) (-0.172) and oleoresin (%) (0.035) had negative indirect effect on seed yield per plant.

Number of flowers per umbellates exhibited indirect positive effect on seed yield per plant *via* number of seeds per umbel (2.912), number of branches per plant at 150 DAS (1.709), days to 50 per cent flowering (0.719), test weight (g) (0.164), days to flower initiation (10%) (0.141) and oleoresin (%) (0.018). Harvest index (%) (-0.910), number of umbellates per umbel (-0.779), plant height at 150 DAS (-0.481), number of

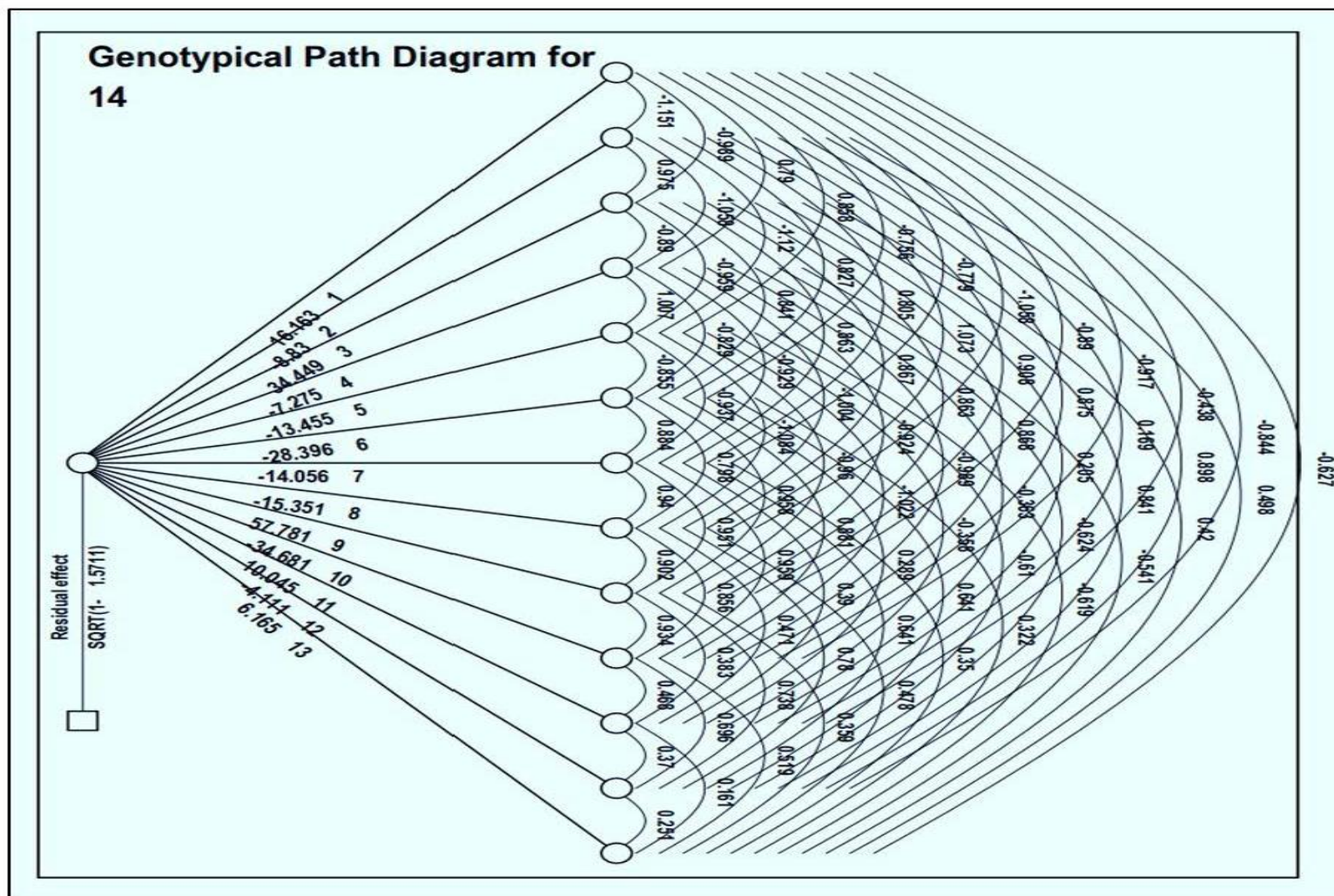


Fig. 3. Genotypic path diagram for total seed yield per plant in ajwain genotypes (Pooled)

umbels per plant (-0.480), days to germination (-0.401) and essential oil (%) (-0.283) had negative indirect effect on seed yield per plant.

Number of umbels per plant resulted indirect positive effect on seed yield per plant *via* number of seeds per umbel (2.892), number of branches per plant at 150 DAS (1.754), Days to 50 per cent flowering (0.788), test weight (g) (0.221), days to flower initiation (10%) (0.158) and oleoresin (%) (0.020). Number of flowers per umbellates (-1.252), harvest index (%) (-0.991), number of umbellates per umbel (-0.917), plant height at 150 DAS (-0.468), days to germination (0.413) and essential oil (%) (-0.283) had negative indirect effect on seed yield per plant.

Number of umbellates per umbel showed indirect positive effect on seed yield per plant *via* number of seeds per umbel (2.741), number of branches per plant at 150 DAS (1.762), days to 50 per cent flowering (0.911), days to flower initiation (10%) (0.717) test weight (g) (0.267), and oleoresin (%) (0.027). Number of flowers per umbellates (-1.130), harvest index (%) (-0.888), plant height at 150 DAS (-0.624), days to germination (-0.562), number of umbels per plant (-0.510) and essential oil (%) (-0.344) had negative indirect effect on seed yield per plant.

Number of seeds per umbel owned indirect positive effect on seed yield per plant *via* number of branches per plant at 150 DAS (1.754), days to 50 per cent flowering (0.807), test weight (g) (0.217), days to flower initiation (10%) (0.158) and oleoresin (%) (0.020). Number of flowers per umbellates (-1.356), harvest index (%) (-0.965), number of umbellates per umbel (-0.880), plant height at 150 DAS (-0.528), number of umbels per plant (-0.517), days to germination (-0.473) and essential oil (%) (-0.326) had negative indirect effect on seed yield per plant.

Harvest index (%) resulted indirect positive effect on seed yield per plant *via* number of seeds per umbel (2.833), number of branches per plant at 150 DAS (1.754), days to 50 per cent flowering (0.857), test weight (g) (0.264), days to flower initiation (10%) (0.168) and oleoresin (%) (0.029). Number of flowers per umbellates (-1.245), number of umbellates per umbel (-0.837), number of umbels per plant (-0.520), plant height at 150 DAS (-0.485), days to germination (0.149) and essential oil (%) (-0.306) had negative indirect effect on seed yield per plant.

Table 22. Genotypic path for yield and yield related traits in ajwain genotype (Pooled)

@	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	rG
X1	0.531	0.670	-2.010	-0.135	-0.721	1.071	0.423	1.033	-2.707	0.946	-0.248	0.373	-0.035	-0.809**
X2	-0.611	-0.582	1.983	0.180	0.942	-1.171	-0.437	-1.047	2.759	-0.901	0.096	-0.397	0.028	0.842**
X3	-0.525	-0.567	2.033	0.152	0.806	-1.190	-0.469	-0.846	2.622	-0.893	0.116	-0.372	0.023	0.892**
X4	0.420	0.615	-1.810	-0.171	-0.847	1.174	0.505	0.980	-2.809	1.022	-0.205	0.276	-0.030	-0.881**
X5	0.455	0.652	-1.950	-0.172	-0.841	1.210	0.509	1.058	-2.917	1.056	-0.202	0.269	-0.035	-0.907**
X6	-0.401	-0.481	1.709	0.141	0.719	-1.416	-0.480	-0.779	2.912	-0.910	0.164	-0.283	0.018	0.912**
X7	-0.413	-0.468	1.754	0.158	0.788	-1.252	-0.543	-0.917	2.892	-0.991	0.221	-0.283	0.020	0.965**
X8	-0.562	-0.624	1.762	0.171	0.911	-1.130	-0.510	-0.976	2.741	-0.888	0.267	-0.344	0.027	0.844**
X9	-0.473	-0.528	1.754	0.158	0.807	-1.356	-0.517	-0.880	3.040	-0.965	0.217	-0.326	0.020	0.950**
X10	-0.485	-0.506	1.754	0.168	0.857	-1.245	-0.520	-0.837	2.833	-1.035	0.264	-0.306	0.029	0.971**
X11	-0.232	-0.098	0.418	0.062	0.301	-0.410	-0.212	-0.460	1.165	-0.483	0.566	-0.163	0.009	0.461**
X12	-0.448	-0.522	1.710	0.106	0.513	-0.907	-0.348	-0.761	2.244	-0.717	0.209	-0.442	0.014	0.650**
X13	-0.333	-0.289	0.854	0.092	0.521	-0.455	-0.190	-0.467	1.092	-0.536	0.091	-0.111	0.056	0.325*

rG- Genotypic correlation value of seed yield/plant

** Significant at 1 per cent level of probability * Significant at 5 per cent level of probability

X1- Days to germination

X2 - Plant height (cm) at 150 DAS

X3 - Number of branches per plant at 150 DAS

X4 - Days to flower initiation (10%)

X5 - Days to 50 per cent flowering

X6 - Number of flowers per umbellates

X7 - Number of umbels per plant

X8 - Number of umbellates per umbel

X9 - Number of seeds per umbel

X10 - Harvest index (%)

X11- Test weight (g)

X12- Essential oil (%)

X13 - Oleoresin (%)

X14 - Seed yield of a plant (g)

Test weight (g) exhibited indirect positive effect on seed yield per plant *via* number of seeds per umbel (1.165), number of branches per plant at 150 DAS (0.418), days to 50 per cent flowering (0.301), days to flower initiation (10%) (0.062) and oleoresin (%) (0.009). Harvest index (%) (-0.483), number of umbellates per umbel (-0.460), number of flowers per umbellates (-0.410), days to germination (-0.232), number of umbels per plant (-0.212), essential oil (%) (-0.163) and plant height at 150 DAS (-0.098) had negative indirect effect on seed yield per plant.

Essential oil (%) had indirect positive effect on seed yield per plant *via* number of seeds per umbel (2.244), number of branches per plant at 150 DAS (1.710), days to 50 per cent flowering (0.513), test weight (g) (0.209), days to flower initiation (10%) (0.106) and oleoresin (%) (0.014). Number of flowers per umbellates (-0.907), number of umbellates per umbel (-0.761), harvest index (%) (-0.717), plant height at 150 DAS (-0.522), days to germination (-0.448) and number of umbels per plant (-0.348) had negative indirect effect on seed yield per plant.

Oleoresin (%) showed indirect positive effect on seed yield per plant *via* number of seeds per umbel (1.092), number of branches per plant at 150 DAS (0.854), days to 50 per cent flowering (0.521), days to flower initiation (10%) (0.092) and test weight (g) (0.091). Harvest index (%) (-0.536), number of umbellates per umbel (-0.467), number of flowers per umbellates (-0.455), days to germination (-0.333), plant height at 150 DAS (-0.289), number of umbels per plant (-0.190) and essential oil (%) (-0.011) had negative indirect effect on seed yield per plant.

4.8.2 Phenotypic path co-efficient

Phenotypic path coefficients for yield per plant with 13 independent characters are presented in table 23 and fig 4.

For total seed yield per plant had highest positive direct effect was expressed by harvest index (%) (0.542), number of umbels per plant (0.366), number of flowers per umbellates (0.149), number of branches per plant at 150 DAS (0.141), days to flower initiation (10%) (0.124), test weight (g) (0.070) and number of seeds per umbel (0.008). Oleoresin (%) (-0.133), days to 50 per cent flowering (-0.128), plant height at 150 DAS

(-0.083), number of umbellates per umbel (-0.077), days to germination (-0.074) and essential oil (%) (-0.067) had negative direct effect for seed yield per plant (Fig 3).

Days to germination had positive indirect effect on seed yield per plant *via* days to flower initiation (10%) (0.080), oleoresin (%) (0.068), number of umbellates per umbel (0.050), essential oil (%) (0.048) and plant height at 150 DAS (0.042). Harvest index (%) (-0.332), number of umbels per plant (-0.226), number of flowers per umbellates (-0.087), number of branches per plant at 150 DAS (-0.085), days to 50 per cent flowering (-0.082), test weight (g) (-0.025) and number of seeds per umbel (-0.005) had negative indirect effect on seed yield per plant.

Plant height at 150 DAS showed positive indirect effect on seed yield per plant *via* harvest index (%) (0.322), number of umbels per plant (0.216), number of branches per plant at 150 DAS (0.109), number of flowers per umbellates (0.095), days to 50 per cent flowering (0.082), days to germination (0.038), test weight (g) (0.008) and number of seeds per umbel (0.006). Days to flower initiation (10%) (-0.080), number of umbellates per umbel (-0.047), oleoresin (%) (-0.046) and essential oil (%) (-0.038) had negative indirect effect on seed yield per plant.

Number of branches per plant at 150 DAS possess indirect positive effect on seed yield per plant *via* harvest index (%) (0.366), number of umbels per plant (0.279), number of flowers per umbellates (0.112), days to 50 per cent flowering (0.088), days to germination (0.045), test weight (g) (0.013) and number of seeds per umbel (0.007). Days to flower initiation (10%) (-0.086), plant height at 150 DAS (-0.064), number of umbellates per umbel (-0.053), oleoresin (%) (-0.047) and essential oil (%) (-0.046) had negative indirect effect on seed yield per plant.

Days to flower initiation (10%) exhibited positive indirect effect on seed yield per plant *via* oleoresin (%) (0.061), number of umbellates per umbel (0.054), plant height at 150 DAS (0.053) and essential oil (%) (0.037). Harvest index (%) (-0.365), number of umbels per plant (-0.292), days to 50 per cent flowering (-0.124), number of flowers per umbellates (-0.099), number of branches per plant at 150 DAS (-0.098), days to germination (-0.048), test weight (g) (-0.022) and number of seeds per umbel (-0.006) had negative indirect effect on seed yield per plant.

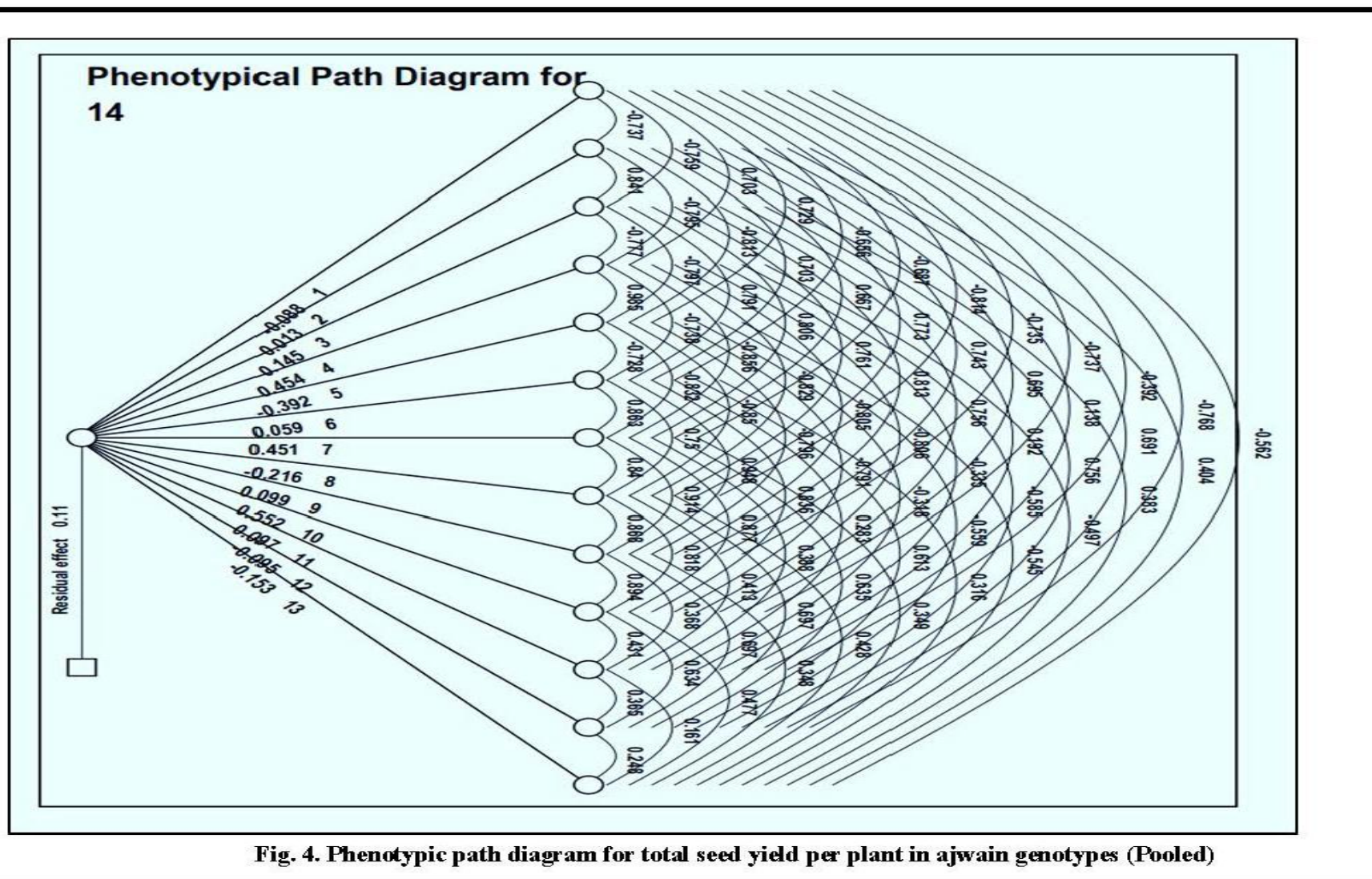


Fig. 4. Phenotypic path diagram for total seed yield per plant in ajwain genotypes (Pooled)

Days to 50 per cent flowering exhibited indirect positive effect on seed yield per plant *via* days to flower initiation (10%) (0.121), oleoresin (%) (0.065), number of umbellates per umbel (-0.054), essential oil (%) (0.035) and plant height at 150 DAS (0.053). Harvest index (%) (-0.344), number of umbels per plant (-0.276), number of branches per plant at 150 DAS (-0.097), number of flowers per umbellates (-0.095), days to germination (-0.048), test weight (g) (-0.020) and number of seeds per umbel (-0.006) had negative indirect effect on seed yield per plant.

Number of flowers per umbellates resulted indirect positive effect on seed yield per plant *via* harvest index (%) (0.435), number of umbels per plant (0.309), number of branches per plant at 150 DAS (0.107), days to 50 per cent flowering (0.081), days to germination (0.043), test weight (g) (0.020) and number of seeds per umbel (0.008). Days to flower initiation (10%) (-0.083), number of umbellates per umbel (-0.055), plant height at 150 DAS (-0.053), oleoresin (%) (-0.041) and essential oil (%) (-0.039) had negative indirect effect on seed yield per plant.

Number of umbels per plant appeared indirect positive effect on seed yield per plant *via* harvest index (%) (0.441), number of flowers per umbellates (0.126), number of branches per plant at 150 DAS (0.108), days to 50 per cent flowering (0.096), days to germination (0.046), test weight (g) (0.027) and number of seeds per umbel (0.007). Days to flower initiation (10%) (-0.099), number of umbellates per umbel (-0.059), plant height at 150 DAS (-0.049), oleoresin (%) (-0.046) and essential oil (%) (-0.042) had negative indirect effect on seed yield per plant.

Number of umbellates per umbel possess indirect positive effect on seed yield per plant *via* harvest index (%) (0.429), number of umbels per plant (0.281), number of flowers per umbellates (0.107), number of branches per plant at 150 DAS (0.097), days to 50 per cent flowering (0.089), days to germination (0.048), test weight (g) (0.026) and number of seeds per umbel (0.007). Days to flower initiation (10%) (-0.088), oleoresin (%) (-0.052), plant height at 150 DAS (-0.050) and essential oil (%) (-0.043) had negative indirect effect on seed yield per plant.

Table 23. Phenotypic path for yield and yield related traits in ajwain genotype (Pooled)

@	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	rG
X1	-0.074	0.042	-0.085	0.080	-0.082	-0.087	-0.226	0.050	-0.005	-0.332	-0.025	0.048	0.068	-0.629**
X2	0.038	-0.083	0.109	-0.080	0.082	0.095	0.216	-0.047	0.006	0.322	0.008	-0.038	-0.046	0.581**
X3	0.045	-0.064	0.141	-0.086	0.088	0.112	0.279	-0.053	0.007	0.366	0.013	-0.046	-0.047	0.755**
X4	-0.048	0.053	-0.098	0.124	-0.124	-0.099	-0.292	0.054	-0.006	-0.365	-0.022	0.037	0.061	-0.724**
X5	-0.048	0.053	-0.097	0.121	-0.128	-0.095	-0.276	0.054	-0.006	-0.344	-0.020	0.035	0.065	-0.685**
X6	0.043	-0.053	0.107	-0.083	0.081	0.149	0.309	-0.055	0.008	0.435	0.020	-0.039	-0.041	0.879**
X7	0.046	-0.049	0.108	-0.099	0.096	0.126	0.366	-0.059	0.007	0.441	0.027	-0.042	-0.046	0.922**
X8	0.048	-0.050	0.097	-0.088	0.089	0.107	0.281	-0.077	0.007	0.429	0.026	-0.043	-0.052	0.774**
X9	0.046	-0.054	0.110	-0.088	0.086	0.140	0.323	-0.065	0.008	0.468	0.025	-0.044	-0.045	0.910**
X10	0.046	-0.049	0.095	-0.084	0.081	0.120	0.298	-0.061	0.007	0.542	0.028	-0.039	-0.059	0.925**
X11	0.027	-0.010	0.026	-0.039	0.037	0.041	0.142	-0.029	0.003	0.218	0.070	-0.024	-0.021	0.441**
X12	0.053	-0.047	0.097	-0.069	0.067	0.088	0.231	-0.049	0.006	0.316	0.025	-0.067	-0.033	0.618**
X13	0.038	-0.029	0.050	-0.057	0.063	0.046	0.127	-0.030	0.003	0.240	0.011	-0.016	-0.133	0.314*

rG- Genotypic correlation value of seed yield/plant

** Significant at 1 per cent level of probability

* Significant at 5 per cent level of probability

X1- Days to germination

X2 - Plant height (cm) at 150 DAS

X3 - Number of branches per plant at 150 DAS

X4 - Days to flower initiation (10%)

X5 - Days to 50 per cent flowering

X6 - Number of flowers per umbellates

X7 - Number of umbels per plant

X8 - Number of umbellates per umbel

X9 - Number of seeds per umbel

X10 - Harvest index (%)

X11- Test weight (g)

X12- Essential oil (%)

X13 -Oleoresin (%)

X14 -Seed yield of a plant (g)

Number of seeds per umbel had indirect positive effect on seed yield per plant *via* harvest index (%) (0.468), number of umbels per plant (0.323), number of flowers per umbellates (0.140), number of branches per plant at 150 DAS (0.110), days 50 per cent flowering (0.086), days to germination (0.046), test weight (g) (0.025) and number of seeds per umbel (0.008). Days to flower initiation (10%) (-0.088), number of umbellates per umbel (-0.065), plant height at 150 DAS (-0.054), oleoresin (%) (-0.045) and essential oil (%) (-0.044) had negative indirect effect on seed yield per plant.

Harvest index (%) showed indirect positive effect on seed yield per plant *via* number of umbels per plant (0.298), number of flowers per umbellates (0.120), number of branches per plant at 150 DAS (0.095), days to 50 per cent flowering (0.081), days to germination (0.046), test weight (g) (0.028) and number of seeds per umbel (0.007). Days to flower initiation (10%) (-0.084), number of umbellates per umbel (-0.061), oleoresin (%) (-0.059), plant height at 150 DAS (-0.049) and essential oil (%) (-0.039) negative indirect effect on seed yield per plant.

Test weight (g) exhibited indirect positive effect on seed yield per plant *via* harvest index (%) (0.218), number of umbels per plant (0.142), number of flowers per umbellates (0.041), days to 50 per cent flowering (0.037), days to germination (0.027), number of branches per plant at 150 DAS (0.026) and number of seeds per umbel (0.003). Days to flower initiation (10%) (-0.039), number of umbellates per umbel (-0.029), essential oil (%) (-0.024), oleoresin (%) (-0.021) and plant height at 150 DAS (-0.010) had negative indirect effect on seed yield per plant.

Essential oil (%) exhibited indirect positive effect on seed yield per plant *via* harvest index (%) (0.316), number of umbels per plant (0.231), number of branches per plant at 150 DAS (0.097), number of flowers per umbellates (0.088), days to 50 per cent flowering (0.067), days to germination (0.053), test weight (g) (0.025) and number of seeds per umbel (0.006). Days to flower initiation (10%) (-0.069), number of umbellates per umbel (-0.049), plant height at 150 DAS (-0.047) and oleoresin (%) (-0.033) had negative indirect effect on seed yield per plant.

Oleoresin (%) had indirect positive effect on seed yield per plant *via* harvest index (%) (0.240), number of umbels per plant (0.127), days to 50 per cent flowering (0.063), number of branches per plant at 150 DAS (0.050), number of flowers per umbellates (0.046), days to germination (0.038), essential oil (%) (0.013), test weight (g) (0.011) and number of seeds per umbel (0.003). Number of umbellates per umbel (-0.030), days to flower initiation (10%) (-0.057), plant height at 150 DAS (-0.029) and essential oil (%) (-0.016) had negative indirect effect on seed yield per plant.

4.9 Genetic divergence

Genetic diversity in 28 ajwain genotypes on different characters was estimated using D^2 statistic for pooled data.

4.9.1 Relative contribution of different characters towards divergence

Among the all characters studied, the maximum contribution to the total divergence was by oleoresin (%) (69.58%) followed by test weight (g) (12.17%), seed yield per plant (g) (10.32%), number of umbels per plant (5.03%), essential oil (%) (2.65%), number of flowers per umbellates (0.26). However, the traits like harvest index (%), days to flower initiation (10%), number of umbellates per umbel, number of seeds per umbel, days to germination, plant height at 150 DAS, number of branches per plant at 150 DAS, days to 50 per cent flowering had no substantial contribution to total genetic divergence (Table 24).

4.9.2 Crop constellations

By using the estimated D^2 values, 28 genotypes were grouped into 12 clusters (Fig. 5) following the method suggested by Tocher (Rao, 1952). The distribution pattern of genotypes into various clusters was shown in table 25.

Cluster I found to be largest with 6 genotypes followed by cluster IV, V, VII and VIII with 5, 3, 4 and 3 genotypes. The clusters II, III, VI, IX, X, XI and XII were solitary clusters.

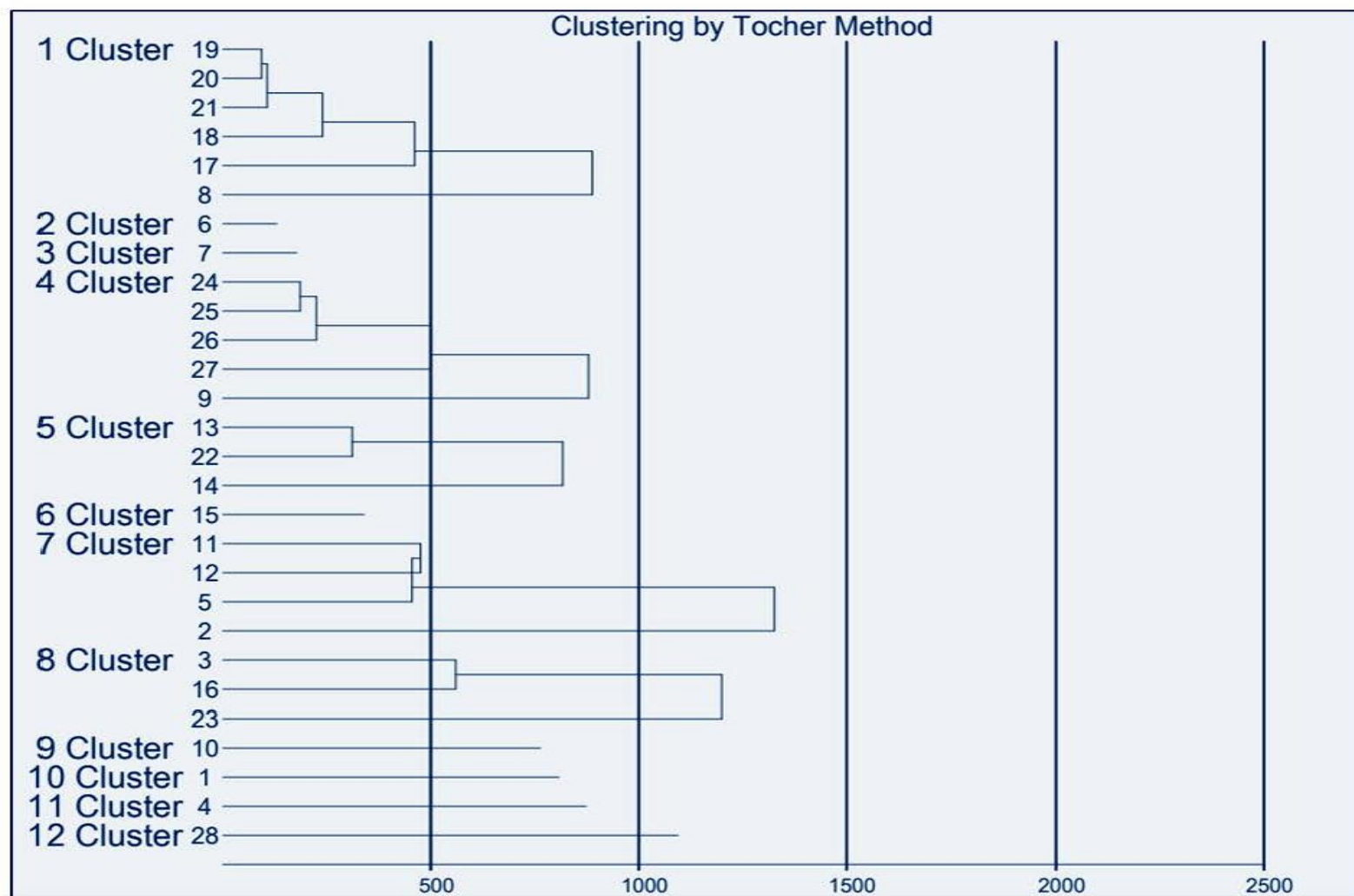


Fig 5. Dendrogram showing the diversity among the 28 genotypes of ajwain (Pooled)

4.9.3 Intra-cluster distance

Data pertaining to intra-cluster distance of different characters are presented in table 26. The highest intra cluster distance was noticed in the cluster VIII with D^2 value of 37.24 followed by cluster VII (34.51), cluster V (30.35), cluster IV (26.94) and cluster II (24.51). The clusters II, III, VI, IX, X, XI and XII had no intra cluster distance as they were represented by single genotype (Table 26).

4.9.4 Inter-cluster distance

Data pertaining to inter-cluster distance of different characters are presented in table 26. The highest inter cluster distance was noticed between the cluster VII and V (114.42) followed by cluster IX and V (99.34), cluster VIII and VII (96.59) and cluster X and V (95.06). Cluster III and II (13.51) had lowest inter cluster distance.

4.9.5 Cluster means of different characters

Data pertaining to cluster mean for 14 characters are summarized in table 27.

4.9.5.1 Days to germination

The minimum cluster mean for days to germination was observed in a cluster VIII (10.42) followed by cluster X (11.00) and cluster XII (11.50). The maximum cluster mean for days to germination was observed in a cluster II (14.25) followed by cluster IV (14.20), cluster VII (12.63) cluster XI (12.50) and cluster III (12.50).

4.9.5.2 Plant height at 150 DAS

Plant height at 150 DAS was maximum in a cluster XII (96.82) followed by VIII (93.11), cluster VI (89.55) and cluster VII (87.10). Minimum cluster mean for plant height at 150 DAS in cluster IV (73.07).

4.9.5.3 Number of branches per plant at 150 DAS

Cluster VIII (17.47) was found to have highest cluster mean for number of branches per plant at 150 DAS followed by cluster XII (17.38), cluster X (16.65) and cluster VII (15.61). Lowest cluster mean was recorded in cluster IV (12.40).

4.9.5.4 Days to flower initiation (10%)

Days to flower initiation (10%) showed the minimum cluster mean in VIII (71.00) and cluster X (75.50). The maximum days to flower initiation (10%) was observed in cluster IV (97.55) followed by cluster V (90.25), cluster II (89.75) and cluster III (89.25).

4.9.5.5 Days to 50 per cent flowering

Cluster mean for days to 50 per cent flowering was found minimum in cluster VIII (81.67). The maximum cluster mean for days to 50 per cent flowering was observed in cluster IV (105.95), followed by cluster III (98.75) and cluster V (98.58) and minimum in cluster VIII (81.67).

4.9.5.6 Number of flowers per umbellates

Maximum cluster mean for number of flowers per umbellates was noticed in cluster VIII (23.16) followed by cluster XII (21.02) and cluster X (20.00) and minimum cluster mean was observed in cluster III (12.88).

4.9.5.7 Number of umbels per plant

For number of umbels per plant, cluster mean was highest in cluster VIII (285.63) followed by cluster XII (249.00) and cluster X (230.25). The lowest cluster mean was recorded in cluster IV (91.51).

4.9.5.8 Number of umbellates per umbel

Maximum mean for number of umbellates per umbel was noted in cluster VIII (14.10), followed by cluster XII (13.27) and cluster IX (12.55) and minimum mean was observed in cluster IV (10.38).

4.9.5.9 Number of seeds per umbel

Cluster VIII (272.58) was found to have maximum number of seeds per umbel, followed by cluster XII (215.23) and cluster X (207.29). Cluster IV (92.82) was recorded minimum number of seeds per umbel.

Table 24. Relative per cent contribution of different characters to the total divergence in ajwain genotype (Pooled)

SN	Character	No. of times ranked first	Per cent contribution
1	Days to germination	0	0.00 %
2	Plant height at 150 DAS	0	0.00 %
3	Number of branches per plant at 150 DAS	0	0.00 %
4	Days to flower initiation (10%)	0	0.00 %
5	Days to 50 per cent flowering	0	0.00 %
6	Number of flowers per umbellates	1	0.26%
7	Number of umbels per plant	19	5.03%
8	Number of umbellates per umbel	0	0.00 %
9	Number of seeds per umbel	0	0.00 %
10	Seed yield per plant (g)	39	10.32 %
11	Harvest index (%)	0	0.00 %
12	Test weight (g)	46	12.17%
13	Essential oil (%)	10	2.65
14	Oleoresin (%)	263	69.58%
	Total	378	100

Table 25. Categorization of ajwain genotypes into different clusters based on D² values (Pooled)

Cluster number	Number of genotype	Genotype included
I	6	HUB-3, HUB-4, HUB-5, HUB-2, HUB-1, LS-2
II	1	AL-4
III	1	LS-1
IV	5	HUB-9, HUB-10, HUB-11, HUB-13, LTA-26
V	3	DAC-4, HUB-6, DAC-5
VI	1	DAC-6
VII	4	DAC-2, DAC-3, AL-3, AA-2
VIII	3	AA-93, AZ-1, HUB-8
IX	1	DAC-1
X	1	AA-1
XI	1	GA-1
XII	1	RM

Table 27. Cluster mean for 14 traits from D² analysis (Pooled)

SN	Characters	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI	Cluster VII	Cluster VIII	Cluster IX	Cluster X	Cluster XI	Cluster XII
1	Days to germination	12.42	14.25	12.50	14.20	11.67	11.75	12.63	10.42	12.25	11.00	12.50	11.50
2	Plant height at 150 DAS	84.47	86.45	83.10	73.07	82.23	89.55	87.10	93.11	83.97	85.10	83.60	96.82
3	Number of branches per plant at 150 DAS	14.47	15.14	14.30	12.40	14.89	14.57	15.61	17.47	14.40	16.65	15.43	17.38
4	Days to flower initiation (10%)	87.46	89.75	89.25	97.55	90.25	87.75	88.25	71.00	87.75	87.75	85.25	75.50
5	Days to 50 per cent flowering	95.00	97.00	98.75	105.95	98.58	97.25	97.94	81.67	97.50	96.25	93.50	85.50
6	Number of flowers per umbellates	15.45	15.80	12.88	13.91	16.55	14.30	17.99	23.16	17.17	20.00	19.65	21.02
7	Number of umbels per plant	120.95	102.25	106.05	91.51	126.90	120.00	150.29	285.63	146.40	230.25	206.20	249.00
8	Number of umbellates per umbel	11.85	10.60	11.00	10.38	11.51	12.05	11.82	14.10	12.55	12.45	11.70	13.27
9	Number of seeds per umbel	131.48	115.29	98.38	92.82	134.91	112.85	162.31	272.58	156.10	207.29	171.81	215.23
10	Seed yield per plant (g)	6.60	6.14	6.09	5.59	6.93	7.48	7.63	11.53	6.93	10.94	9.95	8.79
11	Harvest index (%)	20.16	17.79	19.52	16.62	22.53	26.10	21.30	35.34	19.52	29.39	27.20	28.06
12	Test weight (g)	1.26	1.20	1.21	1.27	1.38	1.54	1.18	1.58	1.55	1.56	1.25	0.96
13	Essential oil (%)	1.46	1.15	1.70	1.14	1.67	2.05	1.83	2.14	2.05	2.15	1.20	2.30
14	Oleoresin (%)	5.13	3.90	3.75	2.91	6.28	4.70	2.47	5.53	2.50	3.28	4.13	6.25

4.9.5.10 Seed yield per plant (g)

The highest cluster mean for seed yield per plant (g) was observed in cluster VIII (11.53), followed by cluster X (10.94) and cluster XI (9.95). The lowest cluster mean was noticed in cluster IV (5.59).

4.9.5.11 Harvest index (%)

Maximum harvest index (%) was found in cluster VIII (35.34), followed by cluster X (29.39) and cluster XII (28.06) and minimum in cluster IV (16.62).

4.9.5.12 Test weight (g)

In a cluster VIII (1.58) maximum test weight, followed by cluster X (1.56) and cluster IX (1.55) with a minimum test weight in cluster XII (0.96).

4.9.5.13 Essential oil (%)

The maximum essential oil (%) was found in a cluster XII (2.30), followed by cluster X (2.15) and cluster VIII (2.14) with a minimum in cluster IV (1.14).

4.9.5.14 Oleoresin (%)

In cluster V (6.28) the highest oleoresin (%) content was observed, followed by cluster XII (6.25) and cluster VIII (5.53) with a minimum in cluster VII (2.47).

4.10 Molecular marker profiling

Genetic variability assessment is the pre requisite for classification of germplasm into heterotic pools for downstream breeding applications. Molecular markers that detect the variation at the DNA level have been the prime choice for genetic variability assessment. The genetic variability is commonly assessed by estimating genetic distance or genetic similarity from DNA fingerprinting data of genotypes. Simple sequence repeat (SSR) markers, being co-dominant are preferred for estimating the heterozygosity. This study was intended to assess the genetic variability among the collected genotypes of ajwain.

The DNA fingerprinting of 28 genotypes of ajwain was carried out by using 25 SSR markers (Plate 6). Out of 25 SSR markers, 24 markers were amplified and rest 1 SSR markers could not be amplified in ajwain. Among 24 markers amplified, 10 markers showed polymorphism (Table 28) among 28 genotypes of ajwain (Fig. 6) and remaining 14 markers showed monomorphism. With 10 SSRs, a total of 24 alleles across were obtained by screening 28 genotypes.

The basic parameters viz., number of alleles (N), number of different alleles (Na), effective number of alleles (Ne), Shannon's information index (I), Observed Heterozygosity (Ho), Expected Heterozygosity (He), Unbiased Expected Heterozygosity (uHe), Fixation index (F) and Polymorphic Information Content (PIC) of 10 SSR markers are represented in (Table 29).

The allele number ranged from 2 to 4 with mean value of 2.40. Maximum numbers of alleles was denoted in GSSR_17 (4), followed by GSSR_44 (3) and GSSR_63 (3) and minimum number of alleles was noticed in CuminSSR_7 (2), CuminSSR_12 (2), GSSR_4 (2), GSSR_6 (2), GSSR_14 (2), GSSR_16 (2) and GSSR_19 (2).

The number of effective alleles ranged from 1.600 to 2.575 with mean 1.806. The number of effective alleles were maximum in GSSR_63 (2.575), followed by GSSR_17 (1.903) and GSSR_16 (1.849). Minimum number of effective alleles was noticed in GSSR_6 (1.600) and GSSR_14 (1.600). The information ranged from 0.562 to 1.003 with mean 1.806. Maximum information index was noticed in GSSR_63 (1.003), followed by GSSR_17 (0.848) and GSSR_16 (0.652). Minimum information index was observed in GSSR_6 (0.562) and GSSR_14 (0.562).

The observed heterozygosity ranged from 0.000 to 0.393 with mean 0.071. Maximum observed heterozygosity was highest in GSSR_63 (0.393), followed by GSSR_14 (0.143) and GSSR_17 (0.071) and minimum observed heterozygosity was noticed in CuminSSR_7 (0.000) and CuminSSR_12 (0.000). The expected heterozygosity ranged from 0.375 to 0.612 with mean value of 0.436. The expected heterozygosity was highest in GSSR_63 (0.612) followed by GSSR_17 (0.474) and GSSR_16 (0.459). Lowest expected heterozygosity was observed in GSSR_6 (0.375) and GSSR_14 (0.375).

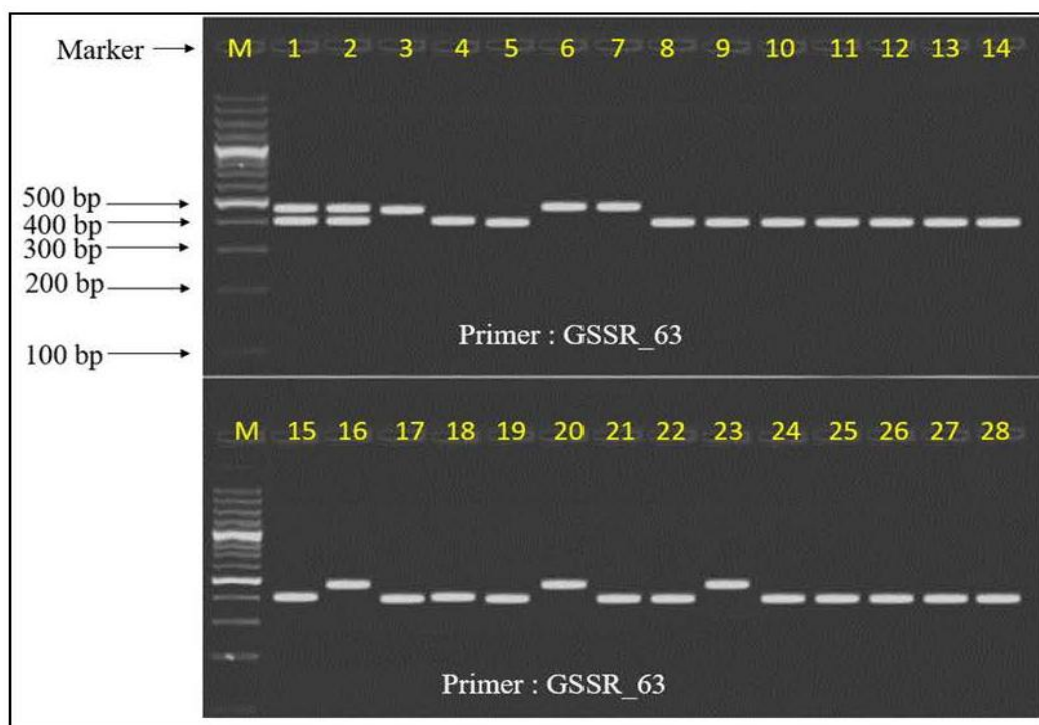


Plate 6a. Gel photograph showing different genotypes of ajwain
Lane M: 100bp ladder

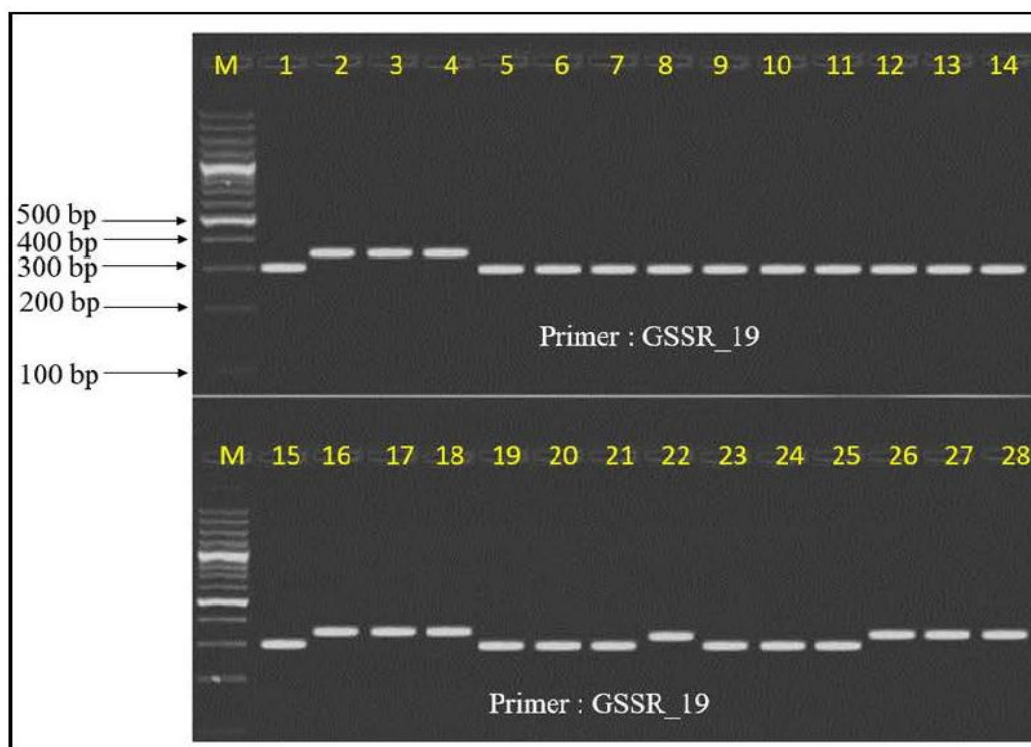


Plate 6b. Gel photograph showing different genotypes of ajwain
Lane M: 100bp ladder

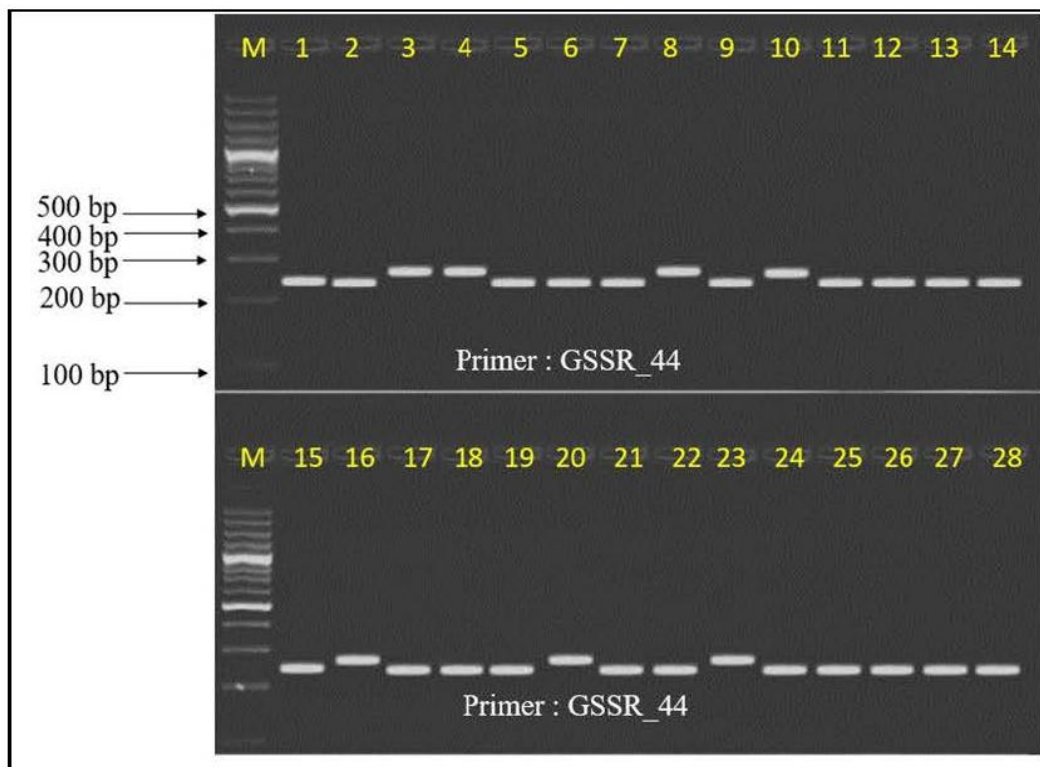


Plate 6c. Gel photograph showing different genotypes of ajwain
Lane M: 100bp ladder

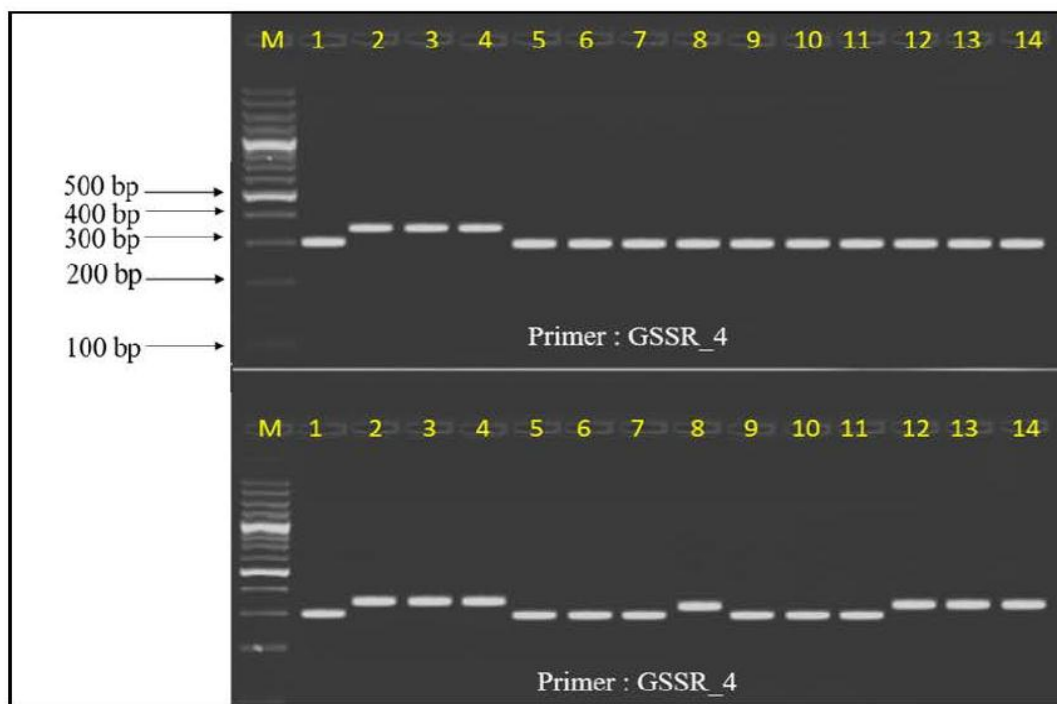
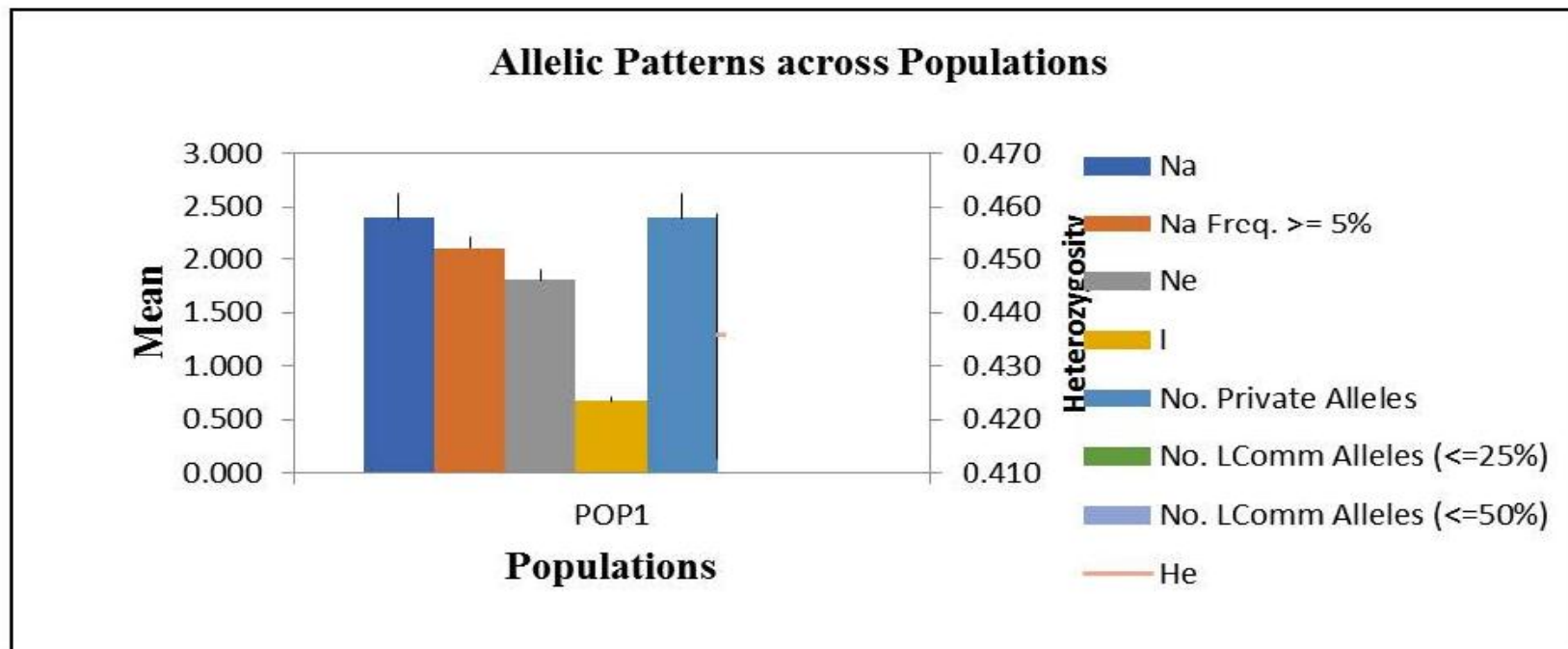


Plate 6d. Gel photograph showing different genotypes of ajwain
Lane M: 100bp ladder



Totals for Allelic Patterns by Populations

Population	POP1
Na	24
Na Freq. >= 5%	21.000
Ne	24.000
No. LComm Alleles (<=25%)	0.000
No. LComm Alleles (<=50%)	0.000

Fig 6. Allelic patterns across populations of 10 SSR markers

The fixation index ranged from 0.358 to 1.000 with mean 0.854. The fixation index was maximum in CuminSSR_7 (1.000) followed by CuminSSR_12 (1.000) and GSSR_19 (1.000). Minimum fixation index was recorded in GSSR_63 (0.358) and GSSR_14 (0.619).

The PIC value ranged from 0.304 to 0.529 with a mean value of 0.355. Highest PIC values were noticed in marker GSSR_63 (0.529) and lowest PIC value was noticed in marker CuminSSR_12 (0.304), GSSR_6 (0.304) and GSSR_14 (0.304).

4.10.1 Diversity analysis of ajwain using SSR marker

Cluster analysis of SSR marker data grouped 28 genotypes of ajwain into 3 cluster (Fig. 7). Cluster I contain 15 genotypes, Cluster II with 13 genotypes and cluster 3 with solitary.

Cluster 1 contains LTA-26, AL-3, LS-1, DAC-3, DAC-2, AL-4, DAC-5, DAC-4, DAC-1, LS-2, HUB-4, HUB-5, HUB-10, HUB-9, HUB-3 genotypes. Cluster 2 contains GA-1, AA-93, AA-2, AZ-1, HUB-2, HUB-1, AA-1, HUB-8, RM, HUB-13, HUB-11, DAC-6 genotypes. Cluster III with HUB-6 genotype.

Table 28. Standardized SSR marker amplification data in ajwain genotypes

SN	Markers	Annealing temperature (°C)
1	CuminSSR_7	55
2	CuminSSR_12	55
3	GSSR_4	55
4	GSSR_6	55
5	GSSR_14	55
6	GSSR_16	57
7	GSSR_17	54
8	GSSR_19	58
9	GSSR_44	58
10	GSSR_63	55

Table 29. Heterozygosity, F-statistics and Polymorphism Information Content (PIC) of ten SSR markers

SN	Markers	N	Na	Ne	I	Ho	He	uHe	F	PIC
1	CuminSSR_7	28	2.000	1.690	0.598	0.000	0.408	0.416	1.000	0.324
2	CuminSSR_12	28	2.000	1.600	0.562	0.000	0.375	0.382	1.000	0.304
3	GSSR_4	28	2.000	1.849	0.652	0.000	0.459	0.468	1.000	0.353
4	GSSR_6	28	2.000	1.600	0.562	0.071	0.375	0.382	0.810	0.304
5	GSSR_14	28	2.000	1.600	0.562	0.143	0.375	0.382	0.619	0.304
6	GSSR_16	28	2.000	1.849	0.652	0.000	0.459	0.468	1.000	0.353
7	GSSR_17	28	4.000	1.903	0.848	0.071	0.474	0.483	0.849	0.414
8	GSSR_19	28	2.000	1.774	0.628	0.000	0.436	0.444	1.000	0.341
9	GSSR_44	28	3.000	1.622	0.627	0.036	0.383	0.390	0.907	0.322
10	GSSR_63	28	3.000	2.575	1.003	0.393	0.612	0.623	0.358	0.529
	Mean	28	2.400	1.806	0.669	0.071	0.436	0.444	0.854	0.355

N-Number of alleles

Na- Number of different alleles

Ne- Effective number of alleles

I-Shannon's information index

Ho- Observed Heterozygosity

He- Expected Heterozygosity

uHe-Unbiased Expected Heterozygosity

F- Fixation index

PIC- Polymorphic Information Content

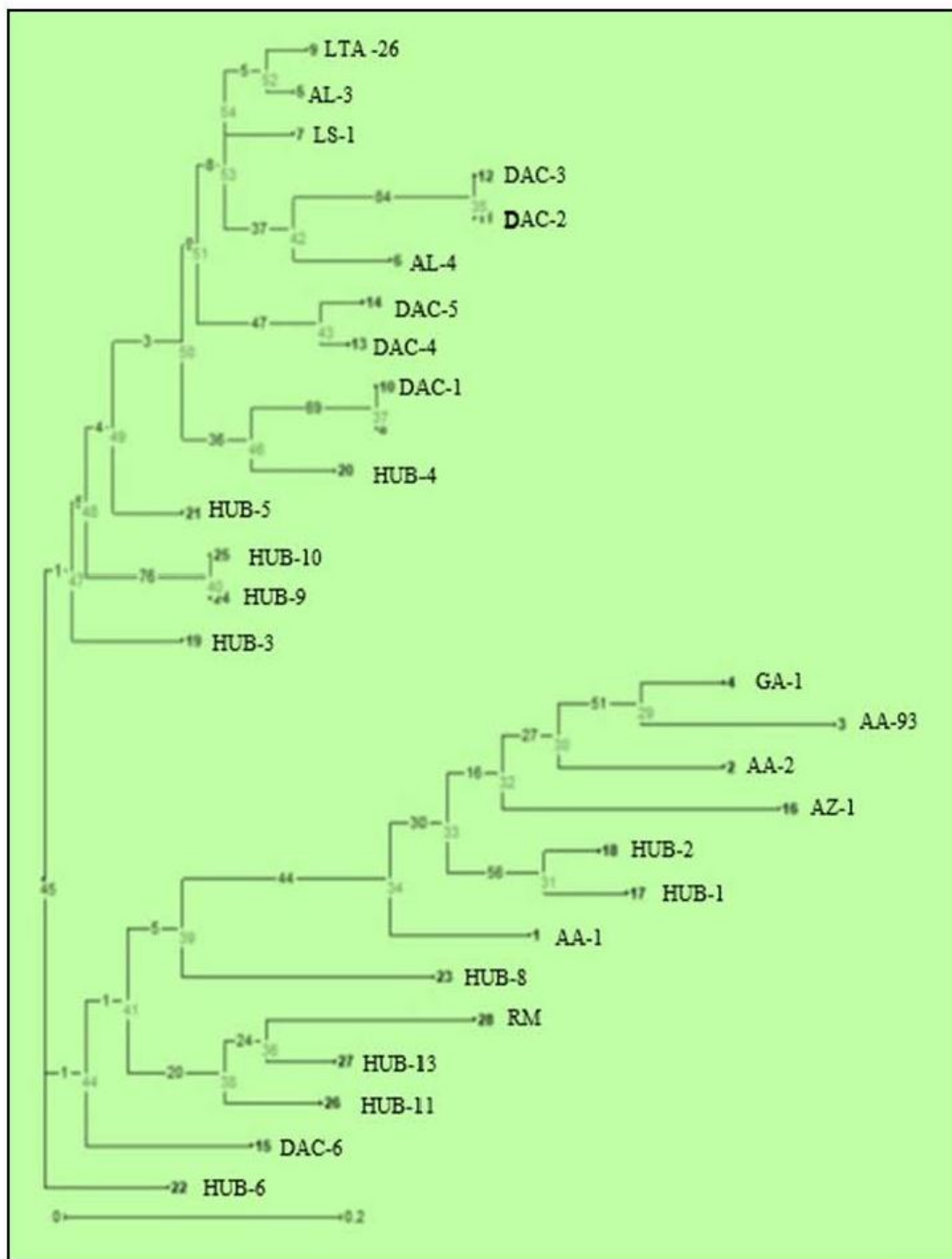


Fig 7. Cluster analysis showing the diversity among 28 genotypes of ajwain produced by 25 SSR marker through Darwin software.

5. DISCUSSION

In the world, India is referred to be the "land of spices" because no other country produces a wide range of spices. India ranks first in production, consumption and foreign exchange of spices. India produces more than the 17 seed spices and these spices are categorized into major and minor seed spices. Ajwain is one among the important minor seed spices, which is used as spice and has medicinal properties. Ajwain is extensively produced in northern dry zone of Karnataka. The investigation was conducted to evaluate the performance of ajwain genotypes for growth, yield and quality traits during 2020-201 and 2021-22 *rabi* season in the Department of Plantation, Spices, Medicinal and Aromatic Crops (PMA), College of Horticulture, Bagalkot.

The basic objectives of each breeding programme is the utilization of existing germplasm or populations and to choose superior genotypes on the basis of performance and character association to yield and quality. The performance of genotypes highly depends on the genetic constitution and its adaptability to the local environment, selection of these superior genotypes is a key factor in order to get a maximum yield and superior quality and the results obtained in this study are discussed in this chapter.

5.1 Performance of ajwain cultivars for growth, yield and quality parameters

All the ajwain characteristics are mainly depended upon the genetic material of the varieties. The significant variation in crop is directly correlated with the planting material used. Even though the genotypes were grown under similar condition the morphological variation depend on the genetic factor of ajwain genotypes.

5.1.1 Growth parameters

In the current investigation significant variation was observed for all the growth parameters in ajwain cultivars during the crop growth.

5.1.1.1 Days to germination

The variety AZ-1 (9.75) was germinated early when compared with the other genotypes evaluated and the cultivars such as HUB-8 (10.00), AA-1 (11.00), DAC-3 (11.00), DAC-5 (11.00), AA-93 (11.50), DAC-4 (11.50) and RM (11.50) were

statistically similar to the cultivar AZ-1, whereas HUB-10 (15.50) has taken maximum days to germinate. This difference in germination is due to the genetic makeup as well as the genotype interaction with the environment. Faster germination of some genotypes was mainly due to the quicker imbibitions of water by the seed tissues, but other ajwain genotypes observed late germination as a result of insufficient water intake. The results obtained on germination of genotypes are in concordance with works of Meena *et al.* (2012), Giridhar *et al.* (2017) and Chaitanya *et al.* (2020).

5.1.1.2 Plant height

Considerable amount of variation were noted for plant height at 150 DAS. Higher plant height was recorded in the genotype RM (96.83 cm). The cultivars such as HUB-8 (94.38 cm), AZ-1 (93.43 cm), HUB-1 (93.30 cm), AA-93 (91.53 cm), DAC-6 (89.55 cm), DAC-3 (88.68 cm), DAC-2 (88.33 cm), AA-2 (87.40 cm), AL-4 (86.45 cm), AA-1 (85.10 cm) and HUB-3 (84.80 cm) were statistically at par with the genotype RM, whereas HUB-11 (66.23 cm) showed relatively lower plant height when compared with the other genotypes evaluated (Fig. 8). The difference in the plant height among the ajwain genotypes were observed because of the genotype variation and its interaction with favourable agroclimatic and soil conditions. Shridhar *et al.* (1990), Rajgopalan *et al.* (1996), Datta *et al.* (2001), Selvarajan *et al.* (2002), Singh *et al.* (2003), Velayudham (2004), Saxena *et al.* (2005), Sarada *et al.* (2009), Arif (2012), Meena (2012), Subramaniyan *et al.* (2019), Meena *et al.* (2020) and Chaitanya *et al.* (2020) were also reported difference in the plant height among the genotypes in their respective study material.

5.1.1.3 Number of branches per plant

Remarkable differences were observed among ajwain genotypes for the total number of branches produced by each plant after 150 days of sowing. Highest number of branches per plant (18.18) were noted in the genotype AA-93 and the genotypes AZ-1 (17.38), RM (17.38), AA-2 (17.25), HUB-8 (16.85) and AA-1 (16.65) were statistically at par with the genotype AA-93. The lowest number of branches per plant was noticed in HUB-10 (10.25) (Fig. 9). The difference in the production of branches among the genotypes was mainly due to the genetic constitution of genotypes and its interaction with the environment on which it is grown. Increased production of branches

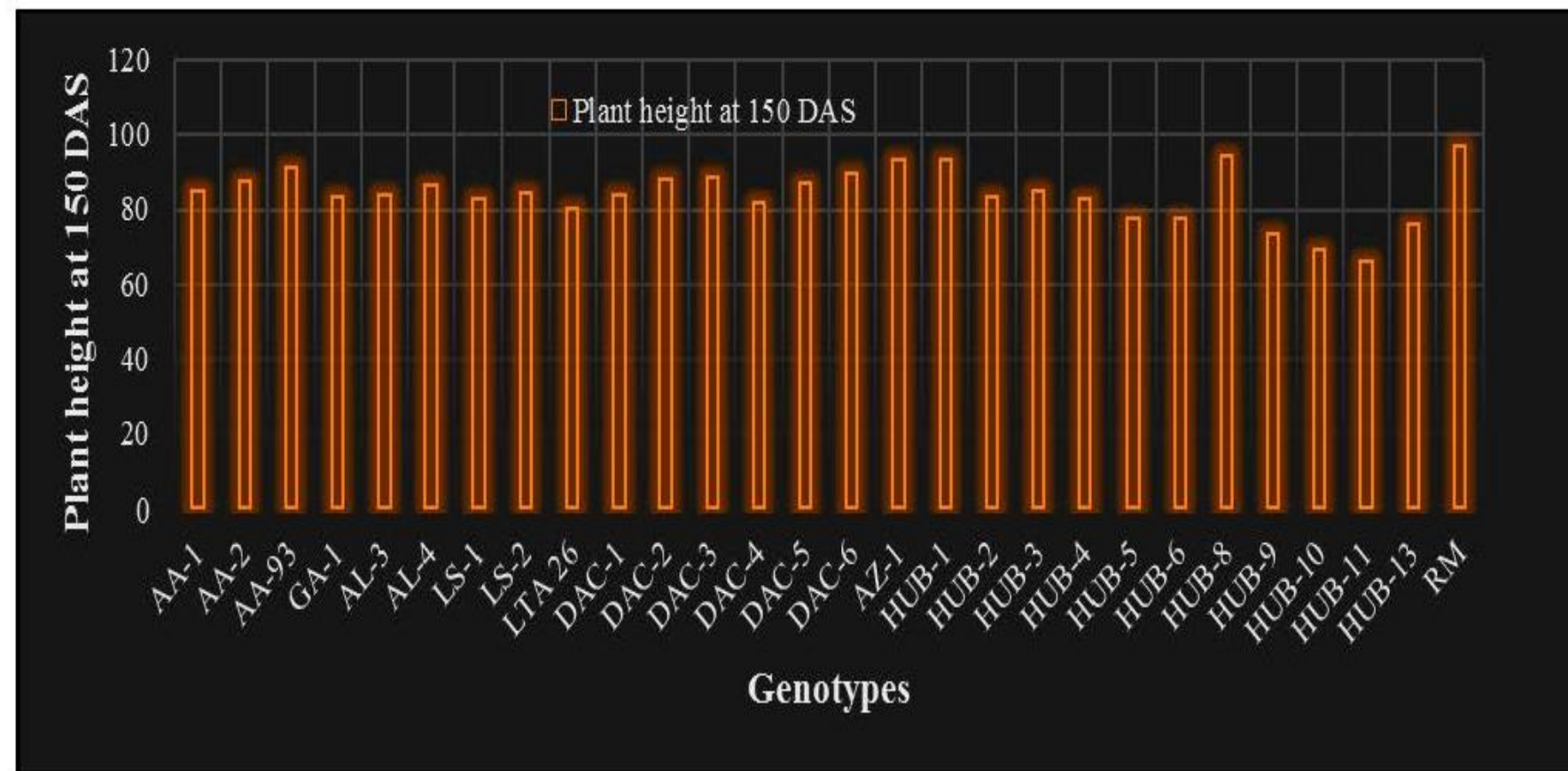


Fig 8. Plant height in ajwain genotypes at 150 DAS (Pooled)

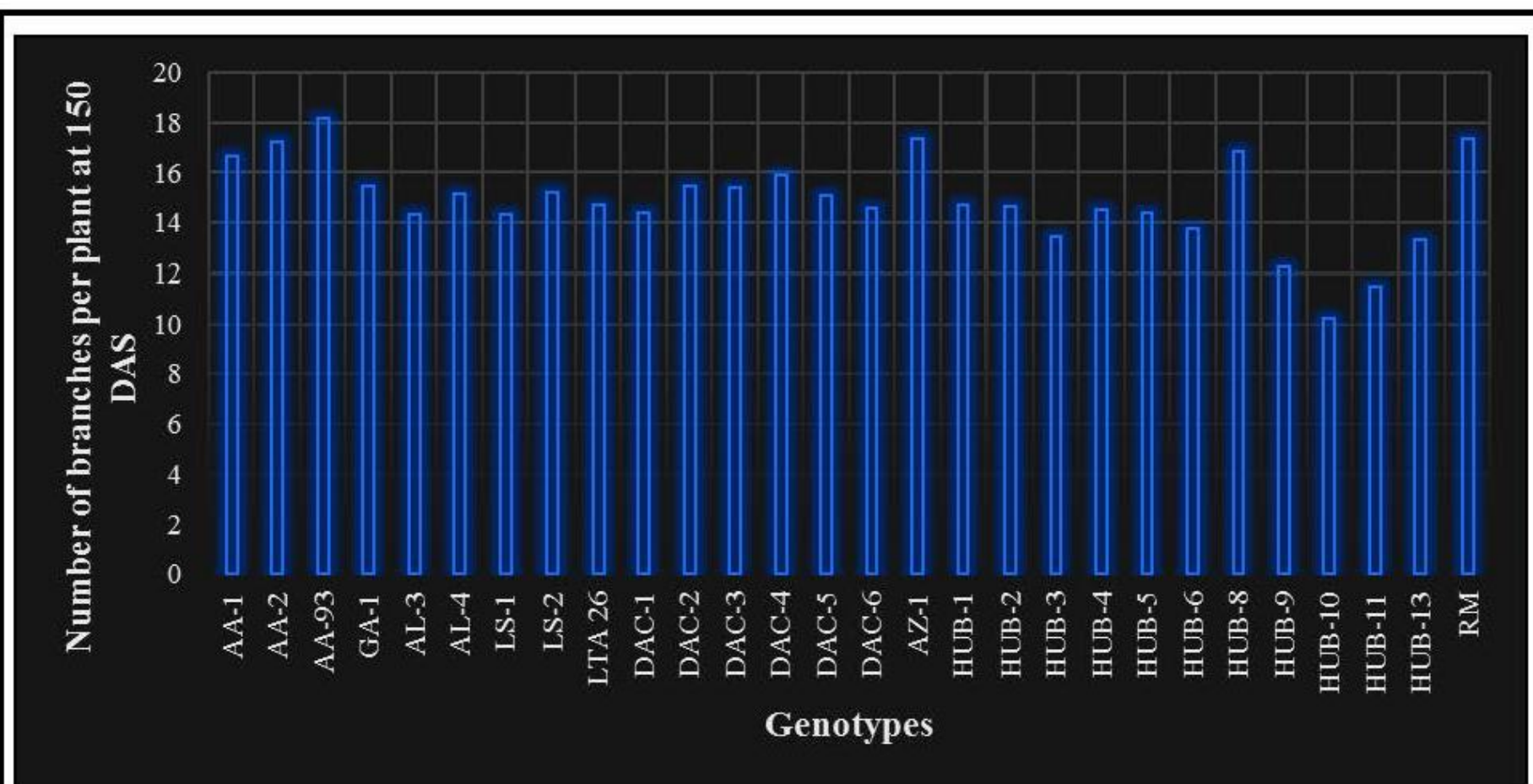


Fig9. Number of branches per plant at 150 DAS in ajwain genotypes (Pooled)

resulted in the increased number of leaves and there by increases the photosynthetic activity which in turn increases the total yield. Datta *et al.* (2001), Meena (2012), Subramaniyan *et al.* (2019), Chaitanya *et al.* (2020) and Meena *et al.* (2020) were also noticed variation in the primary branches produced by a plant among the ajwain genotypes used in their investigation. Venkatareddy *et al.* (1986), Shridhar *et al.* (1990), Selvarajan *et al.* (2002), Velayudham (2004), Giridhar and Sharada (2005), Datta and Choudhuri (2006) and Arif (2012) reported variation with respect to number of branches among the coriander genotypes.

5.1.1.4 Days to flower initiation (10%)

The genotype AZ-1 has taken minimum days (66.00) for commencement of 10% flower initiation, HUB-8 (70.00) was statistically similar to the genotype AZ-1, whereas maximum days (101.50) for the production 10% flower was noticed in the cultivar HUB-11. The variation among the ajwain genotypes for the initiation of 10% flower was due to the genetic constitution of the cultivars, shifting towards the reproductive stage from the vegetative stage might vary across the genotypes. The current results are in consonance with Chaitanya *et al.* (2020). Similar variations for days to flower initiation (10%) were also noted by earlier researchers Selvarajan *et al.* (2002), Velayadhum, (2004) and Sarada and Giridhar (2005) in coriander genotypes.

5.1.1.5 Days to 50 per cent flowering

The minimum days taken for commencement of 50 per cent flowering was observed in AZ-1 (77.25), which was statistically on par with HUB-8 (81.25), RM (85.50) and AA-93 (86.50), whereas maximum days for commencement of 50 per cent flowering was recorded in HUB-11 (109.75). The variations in days to first flower appearance and 50 per cent flowering was attributed to the genetic constitution of the genotype combined with environmental interaction. Also, quick growth and accumulation of more amount of carbohydrates have resulted in early flowering. Similar reports were also reported earlier by several workers by Meena *et al.* (2014), Meena *et al.* (2017) and Chaitanya *et al.* (2020) in ajwain genotypes. Moniruzzaman *et al.* (2013), Phurailatpam *et al.* (2016) and Hongal *et al.* (2018) in coriander genotypes and Telugu *et al.* (2019) in fennel genotypes.

5.1.1.6 Number of flowers per umbellates

Total number of flowers in an umbellates is important seed yielding component. The highest number of flowers per umbellates was observed in HUB-8 (23.85), which was statistically on par with AZ-1 (23.43) and AA-93 (22.20), whereas lowest number of flowers per umbellates was registered in HUB-9 (11.67). Similar variation with regards to number of flowers in an umbellates was reported by Subramaniyan *et al.* (2019), Chaitanya *et al.* (2020) and Ranjeetha *et al.* (2020).

5.1.1.7 Days to physiological maturity

The minimum days taken for harvest was recorded in AZ-1 (128.50), which was statistically on par with AA-93 (129.75), AA-1 (129.75), AA-2 (130.00), HUB-8 (130.75), GA-1 (133.50), RM (134.25), DAC-1 (136.00), HUB-5 (137.25), DAC-3 (137.25), LTA 26 (137.50), DAC-2 (137.75) and HUB-1 (138.00) and the maximum days taken for harvest was observed in HUB-10 (156.00). This is because of the genetic makeup and short or long-life cycle of a specific genotype and due to the interaction of the genotype with environmental factors (temperature, day length, humidity, *etc.*,) prevailed during the experiment. Also, the interaction of these factors with endogenous phytoharmones have resulted in early maturity following early flowering. Similar variations were reported reported by Moniruzzaman *et al.* (2013) and Hongal *et al.* (2018) in coriander genotypes and differences in crop duration in ajwain was described by Meena (2012), Meena *et al.* (2014), Chaitanya *et al.* (2020) and Ranjeetha *et al.* (2020)

5.1.2 Yield parameters

Ajwain genotypes showed differences in the seed yield. Seed yield mainly depends on variations in yield traits viz., number of umbellates per umbel, number of umbels per plant, number of seeds in an umbel and test weight (g).

5.1.2.1 Number of umbels per plant

The total number of umbels per plant differed significantly among the ajwain genotypes. AZ-1 showed the highest number of umbels in an individual plant is 302.25, which was statistically on par with HUB-8 (289.90). The lowest number of umbels in an

individual plant was recorded in HUB-11 (75.68) (Fig. 10). The variation in production of umbels per plant is due to genetic makeup and response of specific genotype to environmental factors. However, increase in umbels per plant results in more number of flowers and this accompanied by higher seed set will result in higher yields. Such increase in umbels per plant may be attributed to the higher growth parameters like plant height, number of primary branches and similar results were reported by Johnny and Ravindran (2006), Singhanian *et al.* (2006), Moniruzzaman *et al.* (2013), Phurailatpam *et al.* (2016) and Hongal *et al.* (2018) in coriander genotypes, Sarada *et al.* (2009), Meena (2012), Meena *et al.* (2017), Subramaniyan *et al.* (2019), Chaitanya *et al.* (2020) and Meena *et al.* (2020) in ajwain genotypes and Telugu *et al.* (2019) in fennel genotypes.

5.1.2.2 Number of umbellates per umbel

This experiment showed significant differences in number of umbellates per umbel. AZ-1 showed the highest number of umbellates per umbel (14.90), which was statistically on par with HUB-8 (13.85), AA-93 (13.55) and RM (13.28). The lowest number of umbellates per umbel was recorded in HUB-9 (9.38). The variation among the genotypes was due to good vegetative growth, its genotypic interaction with local environmental condition and due to better growth of primary and secondary branches as well as response of a specific genotype to a particular environment. The results are in close confirmation with the reports of Sarada *et al.* (2009), Sunilkumar (2010), Meena (2012), Meena *et al.* (2017), Chaitanya *et al.* (2020) and Meena *et al.* (2020) in ajwain genotypes, Shirdhar *et al.* (1990), Pan *et al.* (2003), Velayudham (2004), Datta and Choudhuri (2006) and Rajamanickam *et al.* (2012), Moniruzzaman *et al.* (2013) and Hongal *et al.* (2018) in coriander genotypes and Telugu *et al.* (2019) in fennel genotypes.

5.1.2.3 Number of seeds per umbel

The findings from the experiment showed existence of variation for the number of seeds per umbel. HUB-8 showed the highest number of seeds per umbel (280.00), which was statistically on par with AA-93 (269.80) and AZ-1 (267.95). Minimum number of seeds per umbel was recorded in HUB -9 (67.70) (Fig. 11). Among the yield components, number of seeds per umbel seems to be the most important component

closely associated with the seed yield (Shirdhar *et al.*, 1990). The greater number of seeds in an umbel was mainly because of good pollination, more number of fertilized ovules with the retention of zygote and the response of a specific genotype to a particular environment have resulted in variations in seeds per umbel. Similar results were reported by Datta *et al.* (2001), Singh *et al.* (2003), Saxena *et al.* (2005), Datta and Choudhuri (2006), Meena (2012), Meena *et al.* (2017), Subramaniyan *et al.* (2019), Chaitanya *et al.* (2020) and Meena *et al.* (2020) in ajwain genotypes, Moniruzzaman *et al.* (2013) and Hongal *et al.* (2018) in coriander genotypes and Telugu *et al.* (2019) in fennel genotypes.

5.1.2.4 Seed yield per plant (g)

Seed yield per plant differed significantly among different genotypes. The genotype AZ-1 showed the highest seed yield per plant (11.96 g), which was statistically on par with HUB-8 (11.62 g), AA-93 (11.03 g) and AA-1 (10.95 g), whereas HUB-9 noted less for its seed yield of a single plant (4.93 g) (Fig. 12). Seed yield is a complex biometric trait and considerable variations in seed yield are attributed to genetic character and response of a genotype to agro-climatic conditions. Increase in seed yield among ajwain genotypes could be attributed to better growth parameters which positively correlated to yield. Seed yield mainly depends on total number of branches in a plant, number of umbels in a plant, number of flowers in an umbel, number of umbellates in an umbel, number of seeds in an umbel and thousand seed weight. It is also associated with better accumulation of dry matter and storage of photosynthates. Significant differences among ajwain genotypes was reported by Sarada *et al.* (2009), Meena *et al.* (2014), Awas *et al.* (2015), Bajad *et al.* (2017) and Chaitanya *et al.* (2020) in ajwain genotypes, Moniruzzaman *et al.* (2013), Phurailatpam *et al.* (2016) and Hongal *et al.* (2018) in coriander genotypes and Telugu *et al.* (2019) in fennel genotypes. The factors mainly responsible for the differences in the seed yield among the genotypes were due to the differences in the yield attributes like umbels per plant, umbellates per umbel, seeds per umbellates, number of seeds per umbel and thousand seed weight was reported by Ali *et al.* (1993), Godhra (1995), Singh *et al.* (2005) and Fikreselassie *et al.* (2012). Considerable variation in the seed yield among the genotypes of the coriander were also reported earlier by several workers by Shridhar (1989), Giridhar and Sharda (2005), Saxena *et al.*

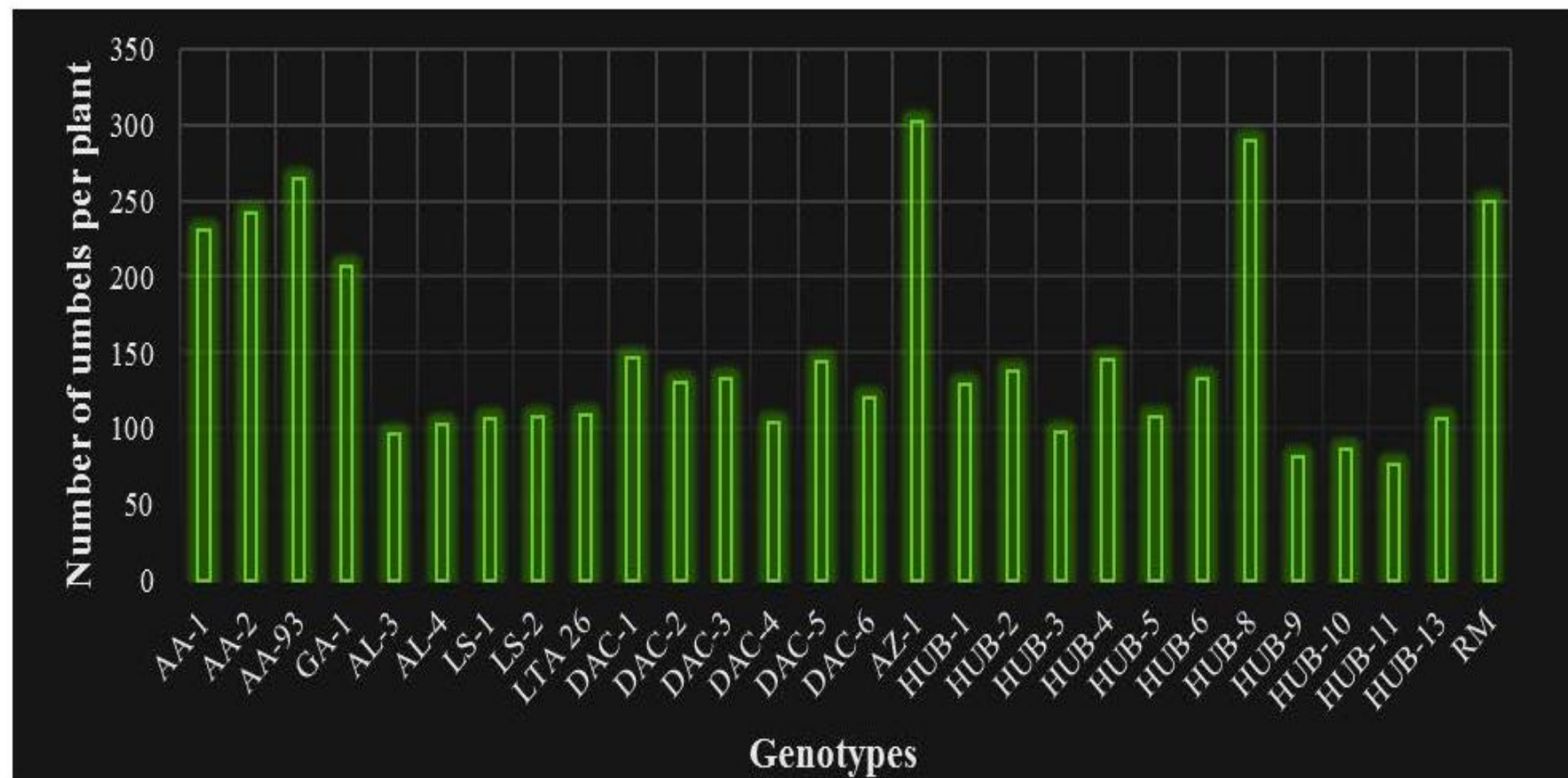


Fig 10. Number of umbels per plant in ajwain genotypes (Pooled)

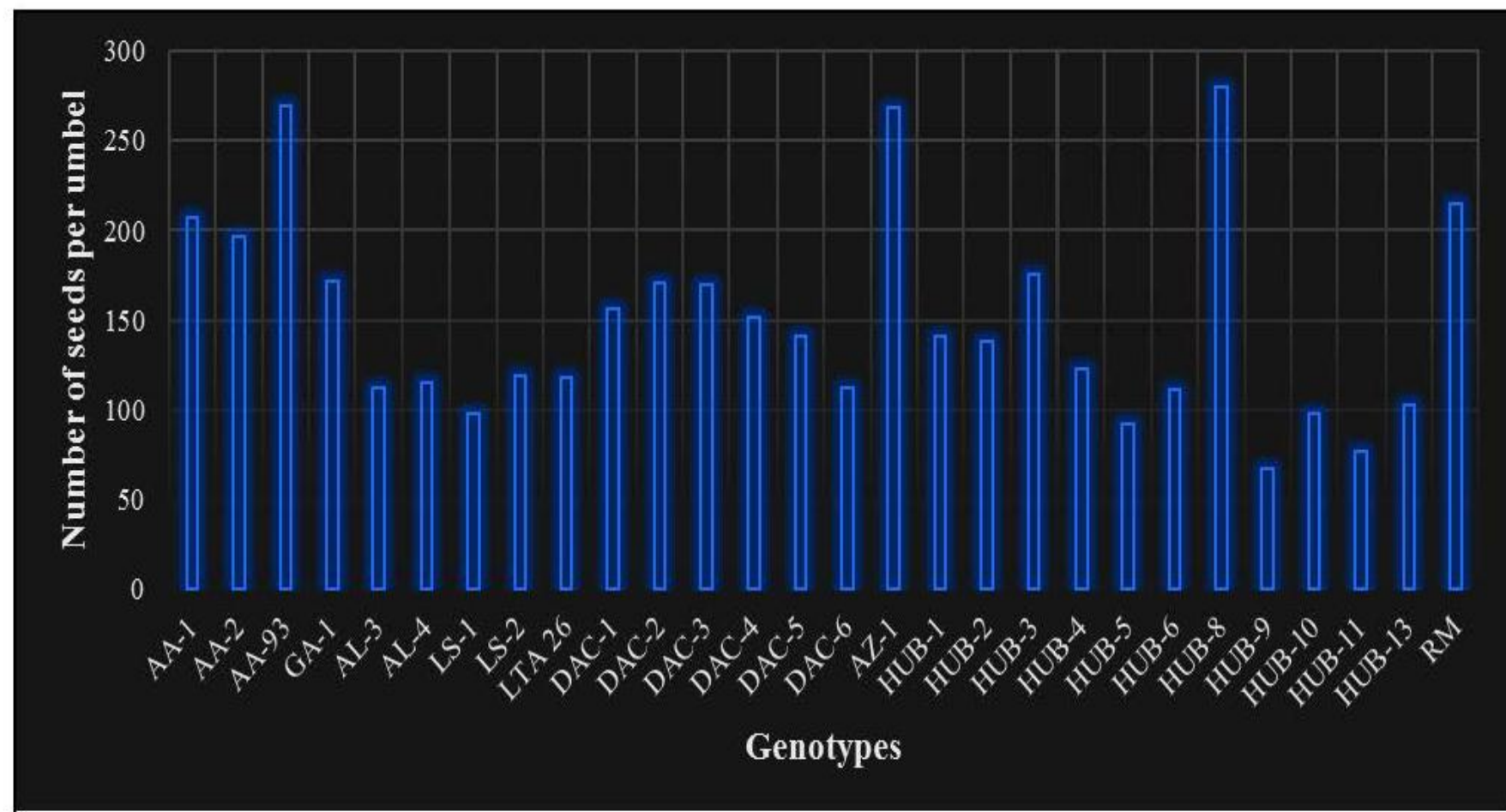


Fig 11. Number of seeds per umbel in ajwain genotypes (Pooled)

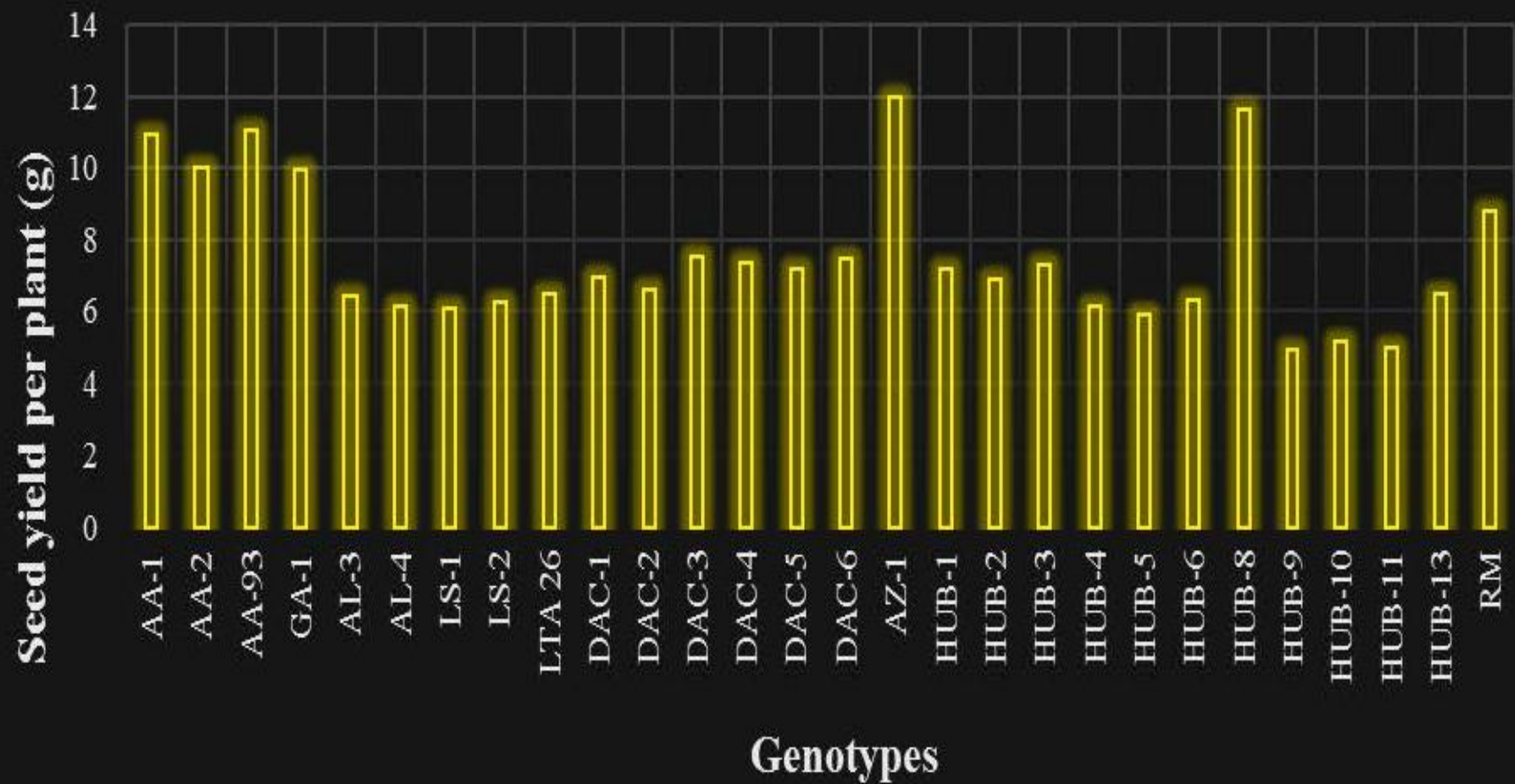


Fig 12. Seed yield per plant (g) in ajwain genotypes (Pooled)

(2005), Prabhu and Balakrishnamurthy (2005), Singh and Prasad (2006), Velayudham *et al.* (2006), Arif (2012) and Palanikumar *et al.* (2012) in coriander.

5.1.2.5 Seed yield (g/plot) and (kg/plot)

The genotypes exhibited remarkable differences for most of the traits including seed yield. AZ-1 recorded the highest seed yield of 374.63 g per plot, which was statistically on par with HUB-8 (373.38 g/plot) and AA-93 (363.00 g/plot), while lowest was noted in HUB-9 (118.25 g). AZ-1 recorded the highest seed yield of 711.79 kg per ha, which was statistically on par with HUB-8 (704.17 kg/ha) and AA-93 (699.76 kg/ha), while lowest was noted in HUB-9 (220.95 kg/ha). The variation in seed yield may be because of variation in growth and yield traits viz., number of umbels in a plant, number of flowers in an umbel, number of umbellates per umbel, number of seeds in an umbel and test weight (g). In this experiment seed yield was less due to the stem fly incidence. Remarkable differences in seed yield among ajwain genotypes were reported prior by several researchers such as Datta *et al.* (2001), Sarada *et al.* (2009), Meena (2012), Giridhar *et al.* (2014), Giridhar *et al.* (2017) and Chaitanya *et al.* (2020).

5.1.2.7 Harvest index (%)

The substantial results with respect to harvest index was observed. AZ-1 recorded maximum harvest index (%) of (38.27%), which was statistically on par with HUB-8 (37.19%), AA-93 (33.05%), whereas the harvest index (%) was recorded minimum in HUB-9 (14.70%). Maximum harvest index (%) was noticed as a result of highest seed yield in a plant with less biological yield per plant. Similar findings was reported by Singh and Choudhary (2008), Meena *et al.* (2020) and Chaitanya *et al.* (2020). The variations could be attributed to production of more seed yield and dry matter. The findings of Hongal *et al.* (2018) in coriander genotypes and Telugu *et al.* (2019) in fennel genotypes provides support to the present results.

5.1.2.8 Test weight (g)

Test weight (g) varied considerably among the various genotypes of ajwain. the maximum test weight was observed in HUB-8 (1.83 g) followed by AZ-1 (1.60g), AA-1 (1.56g) and DAC-1 (1.56 g). The genotype RM showed least test weight of 0.97 g. The

boldness of the seeds contributed maximum test weight in ajwain. The findings are in conformity with earlier workers by Meena (2012), Chaitanya *et al.* (2020) and Meena *et al.* (2020) in ajwain, Sharma and Bhati (1988), Agarwal *et al.* (1990), Shirdhar *et al.* (1990), Gurbuz (2001) and Rajamanickam *et al.* (2012) in coriander.

5.1.3 Quality Parameters

5.1.3.1 Essential oil (%)

The quality of ajwain seeds is a prime factor which determines its premium cost in the market. There was a significant difference noticed for essential oil content in ajwain.

The data on the essential oil content showed significant variation among the different genotypes. The highest essential oil content was recorded in RM (2.30%), which was statistically on par with HUB-8 (2.20%), AA-1 (2.15%), DAC-2 (2.15%) and AA-93 (2.15%). The lowest essential oil was found in HUB-9 (0.90%) (Fig. 13). This might be because of the genotypic interaction with the environment and maturity of the crop also determines the essential oil content. Present experimental results were in correspondence with the earlier studies by Agrawal *et al.* (2003), Saxena *et al.* (2012), Saxena *et al.* (2016), Subramaniyan *et al.* (2019) and Chaitanya *et al.* (2020). Starch being a primary metabolite, may affect the accumulation of secondary metabolites like essential oil there for the genotypes with bigger seed will have low essential oil content mostly because of high starch content. The reasons for the difference in essential oil among the genotypes is directly related to the essential oil content and the seed yield per hectare and those with higher oil content and higher seed yield have yielded higher essential oil yield per hectare. The results are in conformity with the earlier workers by Agarwal *et al.* (1990), Rajagopalan *et al.* (1996), Singh *et al.* (2002), Prabhu and Balakrishnamurty (2005), Velayudham *et al.* (2004) and Meena *et al.* (2013) in coriander.

5.1.3.2 Oleoresin

The data on the oleoresin content showed significant variation among the different genotypes.

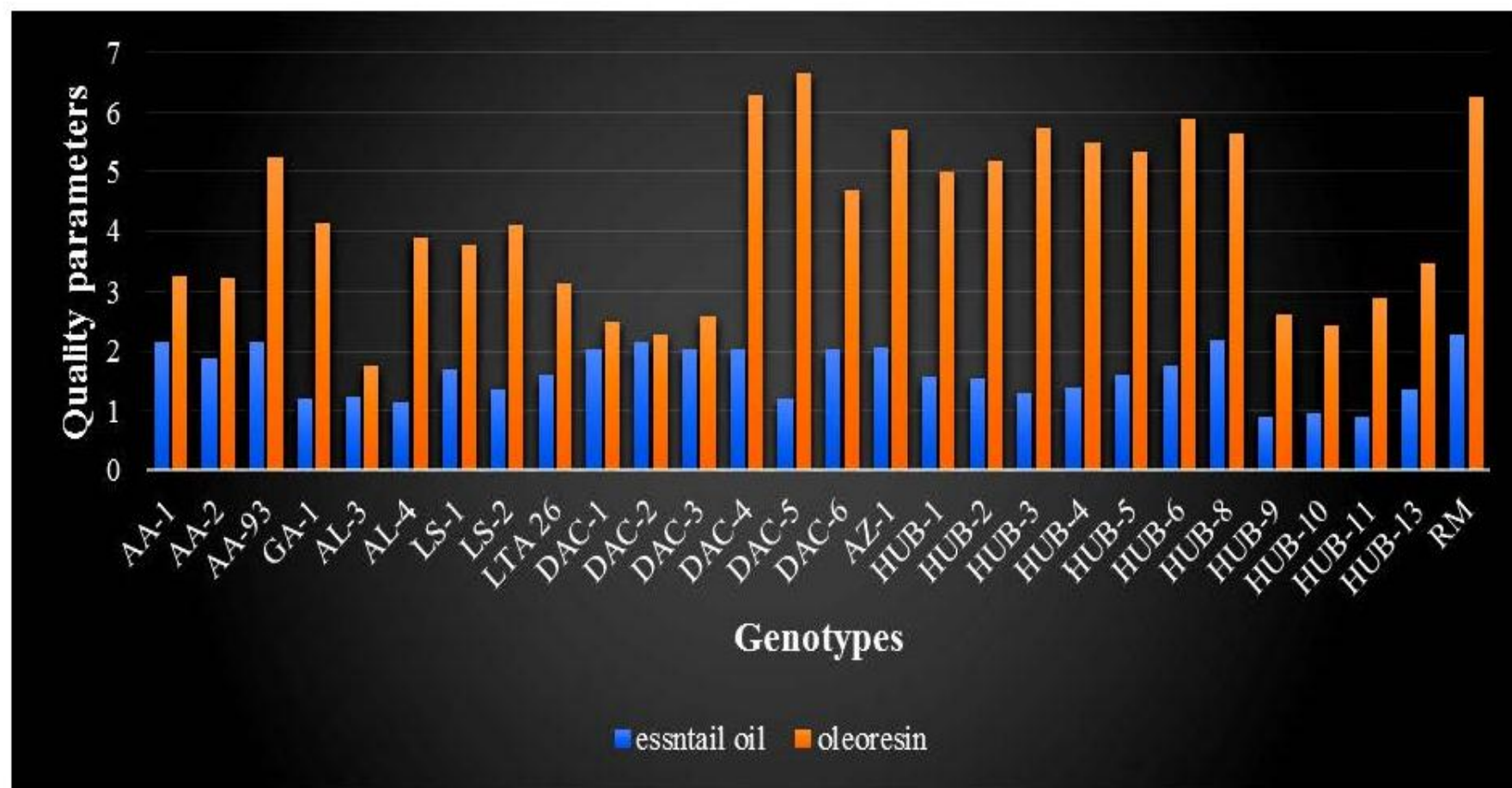


Fig 13. Essential oil and oleoresin content (%) in in ajwain genotypes (Pooled)

Significant difference was noticed for essential oil content in ajwain. The highest oleoresin content was recorded in DAC-5 (6.65%), followed by DAC-4 (6.30%) and RM (6.25%), whereas lowest oleoresin content was found in AL-3 (1.75 %) (Fig.12). This might be because of the genotypic interaction with the environment and maturity of the crop also determines the oleoresin and essential oil content. Present experimental results were in correspondence with the earlier studies by Agrawal *et al.* (2003), Saxena *et al.* (2012), Saxena *et al.* (2016) and Subramaniyan *et al.* (2019) and Chaitanya *et al.* (2020).

5.1.3.3 Thymol content (%)

Significant difference was noticed for thymol content (%) in ajwain (Fig. 8). The highest thymol content was recorded in DAC-5 (49.61%), which was statistically on par with DAC-3 (46.74%), whereas lowest oleoresin content was found in HUB-2 (41.10%) (Fig.14). Similar findings were reported by Chialva *et al.* (1993), Raina *et al.* (2004) and Subramaniyan *et al.* (2019).

5.2 Disease and pest scoring

A study on evaluation of twenty-eight genotypes were undertaken for their reaction to stem fly, *Melanagromyza* species the genotype HUB-2 showed less per cent incidence of stem fly (23.29%), which was statistically on par with AA-2 (23.75%), AA-93 (23.93%), AZ-1 (24.69%), GA-1 (25.20%), HUB-8 (25.60%) and HUB-1 (25.87%), whereas maximum incidence of stem fly was noticed in HUB-10 (45.25%) (Fig. 15). HUB-2, AA-2, AA-93, AZ-1, GA-1, HUB-8 and HUB-1 genotype were found resistance to stem fly incidence and the genotypes GA-1, HUB-8 and HUB-1 were found moderate resistance to stem fly incidence. Hence, resistance genotypes identified during present study needs further investigation at different seasons and location to develop the host plant resistance (HPR) against stem fly of ajwain. Similar outcomes were reported by Upadhyay (2017), Azmi and Sharma (2020) and Chaitanya *et al.* (2020).

5.3 Analysis of variance

Analysis of variance revealed significant differences among the genotypes for different characters studied indicating presence of sufficient variability. A wide range of

variation was noticed. Hence, there was a scope for improvement in ajwain through characters studied such as number of flowers per umbellates, days to flower initiation (10%), number of umbellates per umbel, number of umbels per plant, number of seeds per umbel, harvest index (%), seed yield per plant (g), essential oil (%), oleoresin (%), days to germination, plant height at 150 DAS, number of branches per plant at 150 DAS, days to flower initiation (10%) and days to 50 per cent flowering. Mean sum of square due to treatment was found highly significant for all the characters, indicated the presence of high magnitude of variability present among the genotypes (Singh *et al.*, 2019). The variation among the genotypes was a result of genotype and environment interaction. This specifies the magnitude of variability exhibited among the genotypes for the characters studied and also indicates that extensive scope for improvement among the genotypes. The present results are in conformity with earlier reports of Tripathi *et al.* (2000), Singh and Mittal (2002), Meena *et al.* (2014), Ghanshyam *et al.* (2015), Singh *et al.* (2017), Nagar *et al.* (2019) and Chaitanya *et al.* (2020).

5.4 Genetic variability, heritability and genetic advance

Genetic variability is the basic knowledge to define the effective breeding programme and information about the occurrence of genetic variability for yield and yield related characteristics. Superior genotypes can be isolated by determination, if significant genetic variability exists within the population. The genetic variability along with heritability gives a reliable picture of the genetic advance to be expected for choices, whereas the heritability along with genetic advance helps in predicting the important conclusion for effective selection based on phenotypic occurrence of genotype.

The coefficient of genotypic and phenotypic variability is helpful to measure the extent of variability present in particular trait. They also provide a helpful measure to compare the variability present among various quantitative traits. The estimates of coefficient of variances revealed that magnitude of phenotypic coefficient of variation for all the traits were higher than the magnitude of genotypic coefficient of variation that indicated the role of environment in expression of traits. In general, PCV values were relatively higher than respective GCV values indicating influence of environment

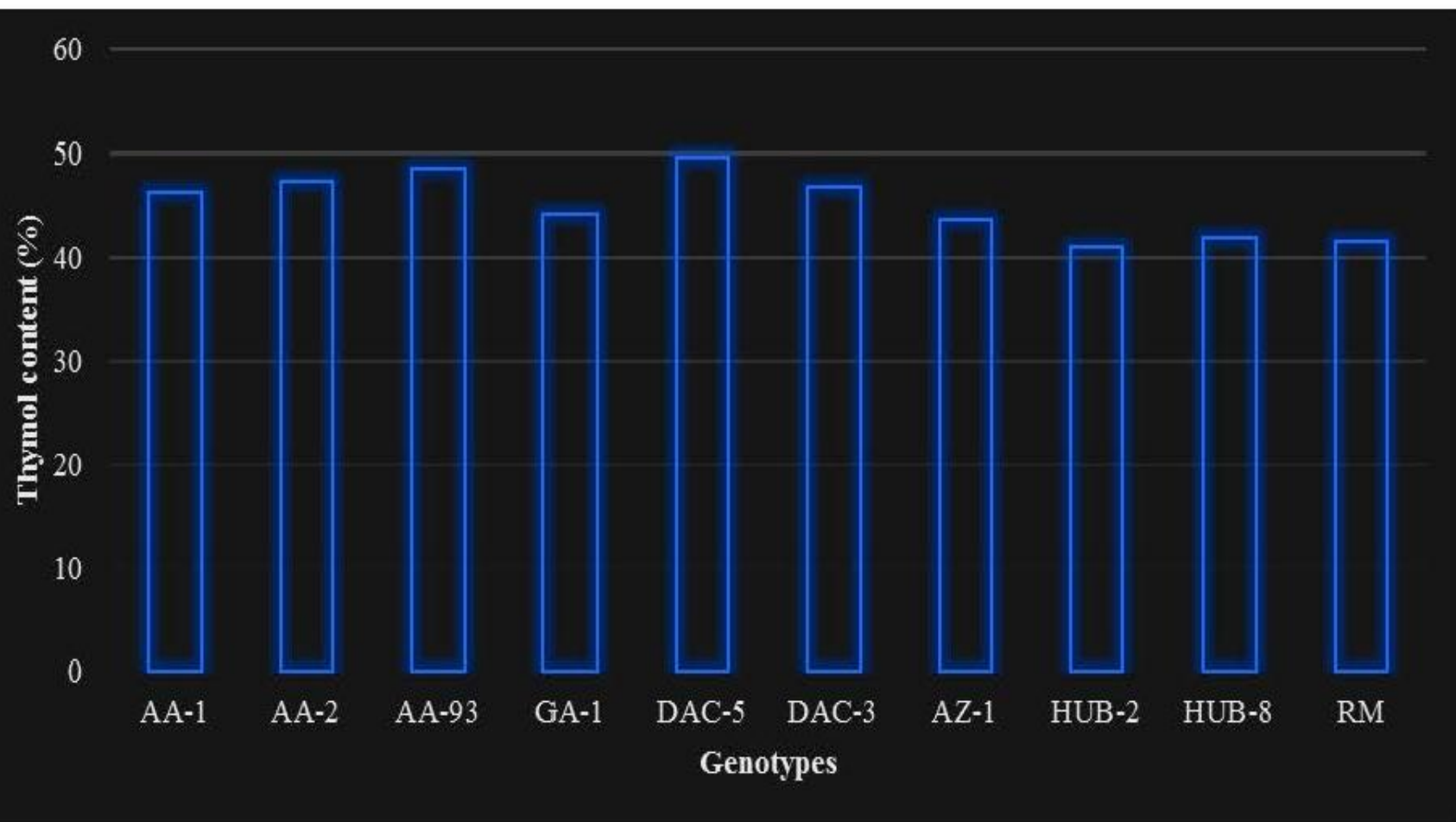


Fig 14. Thymol content (%) in ajwain genotypes

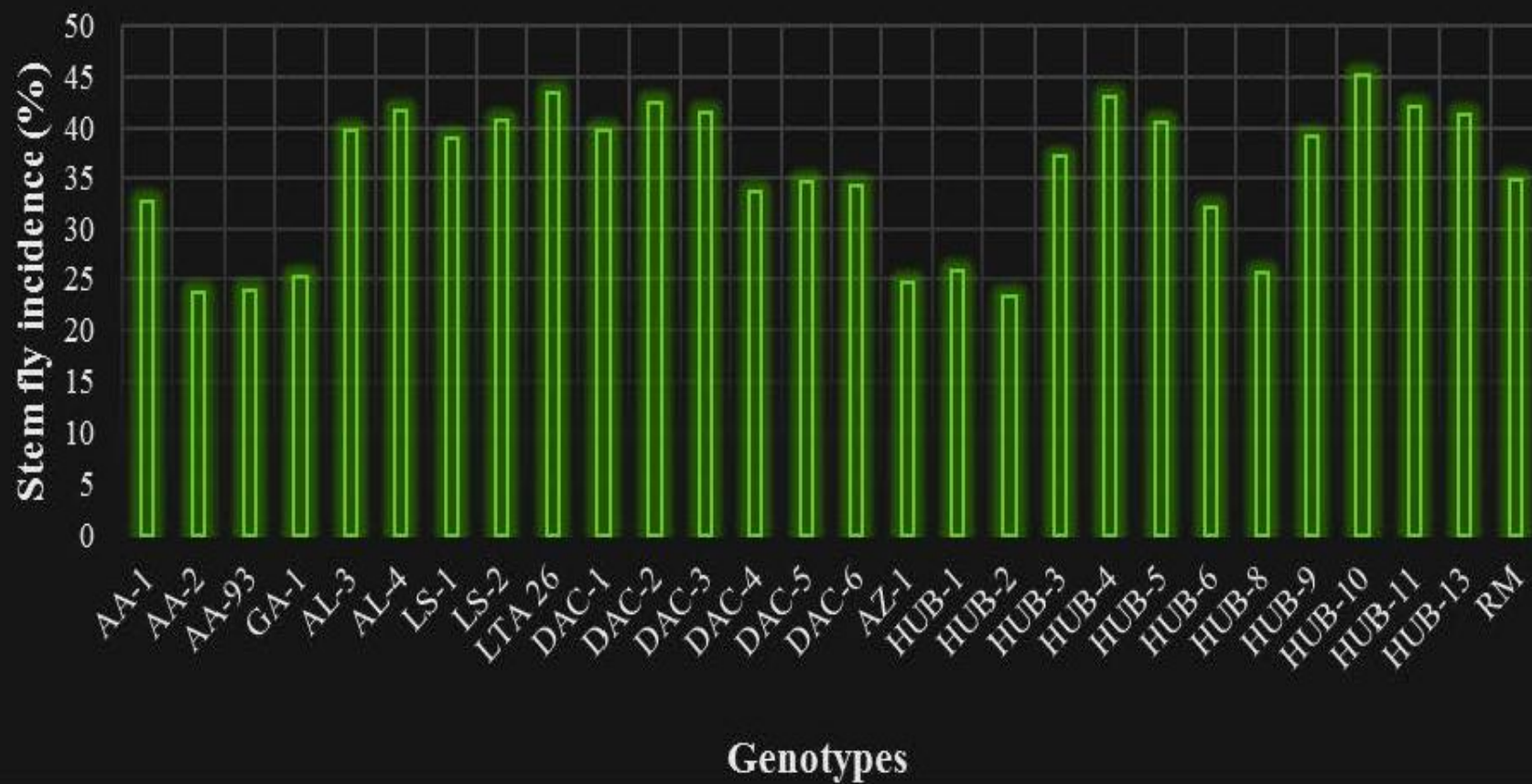


Fig 15. Reaction of ajwain genotypes against stem fly incidence (*Melanagromyza sp.*) (Pooled)

on the expression of character. The estimated of PCV and GCV indicated the existence of high degree of variability (Chaudhary *et al.*, 1987).

5.4.1 Genotypic and phenotypic coefficient of variation

High GCV and PCV was showed for number of umbels per plant, number of seeds per umbel, seed yield per plant (g), seed yield per plot (g) and (kg/ha), harvest index (%), essential oil (%), oleoresin (%). Ghanshyam *et al.* (2015) reported highest values of GCV and PCV for seed yield per plant, oil content (%), number of umbels per plant and harvest index (%) and the traits like seed yield per plant, essential oil (%) and number of umbels per plant exhibited high GCV indicating preponderance of additive gene effect for these traits. High magnitude of PCV and GCV was also observed for seed yield per plant by Singh and Choudhary (2008), Dalkani *et al.* (2012), Singh and Mittal (2002) in fennel and Rajput and Dhirendra (2003) in coriander. The highest genotypic coefficient of variation (GCV) was observed for umbels per plant followed by seed yield per plant, oil content and biological yield per plant and the phenotypic coefficients of variation (PCV) was observed highest for seed yield per plant followed by umbels per plant, biological yield per plant and oil content in ajwain was observed by Nagar *et al.* (2019). This indicates that the character can be easily heritable and selection is effective. The present results are in conformity with earlier reports of Tripahti *et al.* (2000), Ravindrababu *et al.* (2012), Meena *et al.* (2014), Meena and Dhakar (2017), Verma *et al.* (2018), Singh *et al.* (2019) and Chaitanya *et al.* (2020).

Moderate GCV and PCV was observed for days to germination, test weight (g), number of branches per plant at 150 DAS and number of flowers per umbellates. Singh *et al.* (2019) observed moderate GCV and PCV for test weight (g), umbellates per umbel and number of branches per plant. Similar results were reported by Tripahti *et al.* (2000), Singh and Mittal (2002), Rajput and Dhirendra (2003), Singh and Choudhary (2008), Dalkani *et al.* (2012), Ravindrababu *et al.* (2012), Meena *et al.* (2014), Ghanshyam *et al.* (2015), Meena and Dhakar (2017), Verma *et al.* (2018), Nagar *et al.* (2019) and Chaitanya *et al.* (2020).

Low GCV and PCV was observed for plant height at 150 DAS, days to flower initiation (10%), days to 50 per cent flowering, number of umbellates per umbel and days to physiological maturity. Tripahti *et al.*, (2000), Sharma *et al.* (2004), Shrivastava

et al. (2004), Singh *et al.* (2006), Ghanshyam *et al.* (2015) and Chaitanya *et al.* (2020) reported the low GCV and PCV for plant height at 150 DAS, number of umbellates per umbel, days to flower initiation (10%), days to 50 per cent flowering DAS and physiological maturity. Lower values of GCV and PCV was recorded for number of umbellates per umbel indicating the important role of environment in the expression of the character and there was a least chance of improving these traits by direct visual selection. Other parameters like physiological maturity and days to 50 percent flowering exhibited low PCV and GCV indicating the narrow genetic base among the genotypes for a particular trait (Ghanshyam *et al.*, 2015).

5.4.2 Heritability and genetic advance over mean

Heritability is important to the plant breeders primarily as a measure of the value of selection for the particular character in various types of progeny and as an index of transmissibility of characters from parent to offspring. Hence, the concept of heritability is important to evaluate the relative magnitude of the effect of genes and environments on total phenotypic variability. For this reason, Burton (1952) suggested that genetic variability along with heritability should be considered for assessing the maximum and accurate effect of selection.

High heritability was noticed for days to germination, number of branches per plant at 150 DAS, days to flower initiation (10%), days to 50 per cent flowering, number of flowers per umbellates, number of umbels per plant, number of seeds per umbel, seed yield per plant (g), plant height at 150 DAS, days to physiological maturity, number of umbellates per umbel, seed yield per plot (g) and (kg/ha), harvest index (%), test weight (g), essential oil (%) and oleoresin (%). High genetic advance was noticed for number of branches per plant at 150 DAS, number of flowers per umbellates, number of umbels per plant, number of seeds per umbel, seed yield per plant (g), seed yield per plot (g) and (kg/ha), harvest index (%), test weight (g), essential oil (%) and oleoresin (%). The heritability in broad sense estimates were quite high for the characters viz., test weight, plant height at 60 DAS, days to 50 per cent flowering, number of branches per plant are according to the studies by Meena *et al.* (2015) and Dalkani *et al.* (2012). The results indicates that, high heritability accompanied with high genetic advance as per cent of mean indicates that most likely the heritability is due to

additive gene effects and selection may be effective. However, it is not necessary that a character showing high heritability will also exhibit high genetic advance (Johnson *et al.*, 1955). High heritability coupled with high genetic advance as per cent of mean was observed for the characters days to germination, plant height at 150 DAS, days to flower initiation (10%), days to 50 per cent flowering, number of flowers per umbellates, number of umbels per plant, number of branches per plant at 150 DAS, number of seeds per umbel, seed yield per plant (g), number of umbellates per umbel seed yield per plot (g), essential oil (%), oleoresin (%), harvest index (%) and test weight (g), indicating that these characters were also controlled by the additive action of polygene (Panse, 1957) and would be considered for selection criteria. These findings are in support from the previous studies of Dyulgerov and Dyulgerova (2013), Meena *et al.* (2015), Nagar *et al.* (2019), Subramaniyan *et al.* (2019) recorded high heritability for seed oil content, umbels per plant, seed yield per plant followed by biological yield per plant. High heritability coupled with high genetic advance as per cent of mean was reported for umbels per plant, seed yield per plant, seeds per umbel and plant height by Singh and Singh (2013), Dhakad *et al.* (2017) and Verma *et al.* (2018), 1000 - seed weight by Gauhar *et al.* (2018) and Anilkumar *et al.* (2018). The present results are in conformity with earlier reports of Krishnamoorthy and Madalageri (2002), Singh and Choudhary (2008), Meena and Dhakar (2017), Patel *et al.* (2018), Nagar *et al.* (2019) and Chaitanya *et al.* (2020).

Moderate genetic advance over mean noticed for days to germination, plant height at 150 DAS, days to flower initiation (10%), days to 50 per cent flowering and number of umbellates per umbel. Dhakad *et al.* (2017) reported that moderate genetic advance over mean was observed for number of umbellates per umbel and days to flower initiation (10%). The variability in these traits was due to both additive and non-additive gene action. Selection based on these traits was less effective in breeding programme. Prior research has reported by Singh and Choudhary (2008), Meena *et al.* (2013), Sharma *et al.* (2015), Meena and Dhakar (2017), Patel *et al.* (2018), Nagar *et al.* (2019) and Chaitanya *et al.* (2020).

Low genetic advance over mean was noticed for days to physiological maturity. Alie *et al.* (2005), Singh *et al.* (2005), Meena *et al.* (2014) and Dhakad *et al.* (2017) reported the low genetic advance over mean for days to physiological maturity. These

characters were governed by non-additive gene action and selection based on these parameters found not effective. Prior research have reported by Singh and Choudhary (2008), Meena *et al.* (2013), Sharma *et al.* (2015), Meena and Dhakar (2017), Patel *et al.* (2018), Nagar *et al.* (2019), Ranjeetha *et al.* (2020) and Chaitanya *et al.* (2020).

5.5 Correlation analysis

Correlation analysis in ajwain provides information about the magnitude and direction of genetic association between two traits. Phenotypic association coefficients were slightly more than the genotypic association coefficients, this may be because of the effect of environment modify the expression of genotypes, thus altering the genotypic expression. Phenotypic correlation was found higher than the genotypic correlation. The genotypic correlation values were observed low due to masking or modifying effects of environment on genetic association between the parameters.

Both at genotypic and phenotypic level, seed yield of plant was positively and highly significantly associated with harvest index (%), number of umbels per plant, number of seeds per umbel, number of branches per plant at 150 DAS, number of flowers per umbellates, number of umbellates per umbel, essential oil (%), plant height at 150 DAS, oleoresin (%) and test weight (g). This indicates that seed yield per plant will be increased with the increase of harvest index (%), number of umbels per plant, number of seeds in an umbel, number of branches per plant at 150 DAS, number of flowers per umbellates, number of umbellates per umbel, essential oil (%), plant height at 150 DAS, oleoresin (%) and test weight (g). Most of studied characters showed positive and significant correlations with single plant yield. It was negatively and significantly associated with days to flower initiation (10%), days to 50 per cent flowering and days to germination. These findings are in line with the reports of Vijayalatha and Chezhiyan (2004), Singh *et al.* (2006), Singh and Prasad (2006) in coriander, Dalkani *et al.* (2011), Sharma *et al.* (2015), Meena and Dhakar (2017), Shivaprasad *et al.* (2018), Chaitanya *et al.* (2020), Ranjeetha *et al.* (2020), Rawat *et al.* (2020) and Singh *et al.* (2020).

Days to germination was significant and positive correlation with days to 50 per cent flowering and days to flower initiation (10%). Days to germination was significant and negatively correlated with number of branches per plant at 150 DAS, plant height at

150 DAS, harvest index (%), number of seeds per umbel, seed yield per plant (g), essential oil (%), number of umbellates per umbel, number of umbels per plant, number of flowers per umbellates, oleoresin (%) and test weight (g).

Plant height at 150 DAS showed significant and positive correlation with number of branches per plant at 150 DAS, number of seeds per umbel, essential oil (%), harvest index (%), seed yield per plant (g), number of flowers per umbellates, number of umbels per plant (g), number of umbellates per umbel and oleoresin (%). Plant height at 150 DAS was significant and negative correlation with days to flower initiation (10%) and days to 50 per cent flowering. These results are in conformity with findings of Rawat *et al.* (2020) and Chaitanya *et al.* (2020).

Number of branches per plant at 150 DAS exhibited significant and positive correlation with seed yield per plant (g), number of umbellates per umbel, number of seeds per umbel, harvest index (%), number of umbels per plant, number of flowers per umbellates, essential oil (%) and oleoresin (%). Days to 50 per cent flowering and days to flower initiation (10%) was significant and negative correlation with number of branches per plant at 150 DAS. Ravindrababu *et al.* (2012) and Chaitanya *et al.* (2020) obtained the similar findings in ajwain.

Days to flower initiation (10%) showed significant and positive correlation with days to 50 per cent flowering. Days to flower initiation 10% showed significant and negative correlation with harvest index (%), number of umbels per plant, number of seeds per umbel, seed yield per plant (g), number of flowers per umbellates, number of umbellates per umbel, essential oil (%), oleoresin (%) and test weight (g). These results are in conformity with the results of Meena, (2012), Giridhare *et al.* (2017) and Chaitanya *et al.* (2020).

Days to 50 per cent flowering owned significant and negative correlation with number of seeds per umbel, number of umbels per plant, seed yield per plant (g), number of flowers per umbellates, harvest index (%), number of umbellates per umbel, oleoresin (%), essential oil (%) and test weight (g). Similar results were obtained by Yadav (1999) in coriander, Shivaprasad *et al.* (2018) in fennel and Chaitanya *et al.* (2020).

Number of flowers per umbellates showed significant and positive correlation with number of seeds per umbel, seed yield per plant (g), number of umbels per plant, harvest index (%), number of umbellates per umbel, essential oil (%) and oleoresin (%) and test weight (g). More number of flowers in a plant produces more yield and aromatic seeds. This was in accordance with the findings of Verma *et al.* (2018) and Chaitanya *et al.* (2020).

Number of umbels per plant exhibited significant and positive correlation with seed yield per plant (g), harvest index (%), number of seeds per umbel, number of umbellates per umbel, essential oil (%), test weight (g) and oleoresin (%). Hence, more number of umbel per plant had positive impact on yield. These results in conformity with the results of Saxena *et al.* (2016), Singh and Chaudhari (2008) in fennel and Chaitanya *et al.* (2020) in ajwain.

Number of umbellates per umbel appeared significant and positive correlation with number of seeds per umbel, harvest index (%), seed yield per plant (g), essential oil (%), oleoresin (%) and test weight (g). Similar results were reported by Shivaprasad *et al.* (2018) in fennel and Chaitanya *et al.* (2020) in ajwain. Hence, less number of umbellate per umbel results in less yield whereas, quality in terms of essential oil is good if the number of umbellate per umbel is more.

Number of seeds per umbel was significant and positive correlation with seed yield per plant (g), harvest index (%), essential oil (%), test weight (g) and oleoresin (%). Harvest index (%) owned significant and positive correlation with seed yield per plant (g), essential oil (%), oleoresin (%) and test weight (g). Test weight (g) was significant and positive correlation with seed yield per plant (g) and essential oil (%). It showed non-significant and positive correlation with oleoresin (%). Essential oil showed significant and positive correlation with seed yield per plant (g) and showed non-significant and positive correlation with oleoresin (%). Oleoresin exhibited significant and positive correlation with seed yield per plant (g). These findings are in line with the reports of Meena and Dhakar (2017), Rawat *et al.* (2020), Singh *et al.* (2020) and Chaitanya *et al.* (2020).

Selection of parameters that are positively associated with yield helps in crop improvement by enhancing the yield of the genotypes. Selection with greater efficiency

was practiced through these positively correlated traits on yield. Negatively related traits with yield influence other parameters that are positively correlated with yield factor.

The residual effect was low which indicates that much of variation in seed yield has been considered and selection of the traits were accurate and needs additional consideration. Similar reports were obtained by Ghanshyam *et al.* (2015) and Rawat *et al.* (2020).

5.6 Path analysis

The path analysis is a statistical analysis, which take into consider the cause and impact relationship between the traits and then divided into indirect and direct effect which is compared with other independent variables. Correlation only measures the association between two traits, while the path coefficient analysis gives source and estimates their relative importance (Dewey and Lu, 1959).

At genotypic path level, for total seed yield per plant (g) had high positive direct effect was expressed by number of seeds in an umbel, followed by number of branches at 150 DAS, test weight (g), days to germination and oleoresin (%), whereas number of flowers per umbellates, harvest index (%), number of umbellates per umbel, days to 50 per cent flowering, plant height at 150 DAS, number of umbels per plant, essential oil (%) and days to flower initiation (10%) had negative direct effect on total yield per plant (Fig. 10). The present findings are supported by Gulpuz (2001), Garg *et al.* (2003), Lal *et al.* (2007), Sharma *et al.* (2008), Ghanshyam *et al.* (2015) and Chaitanya *et al.* (2020).

Days to germination had positive indirect effect on seed yield per plant via number of flowers per umbellates, number of umbellates per umbel, harvest index (%), plant height at 150 DAS, number of umbels per plant and essential oil (%). Number of seeds per umbel, number of branches per plant at 150 DAS, days to 50 per cent flowering, test weight (%), days to flower initiation (10%) and oleoresin (%) had negative indirect effect on seed yield per plant. Similar results were found by Chaitanya *et al.* (2020).

Number of branches per plant at 150 DAS had indirect positive effect on seed yield per plant *via* number of seeds per umbel, days to 50 per cent flowering, days to flower initiation (10%), test weight (g) and oleoresin (%). Number of flowers per umbellates, harvest index (%), number of umbellates per umbel, plant height at 150 DAS, days to germination, number of umbels per plant and essential oil (%) had negative indirect effect on seed yield per plant. The similar results were reported by Jain *et al.* (2013), Meena *et al.* (2014), Meena *et al.* (2016), Singh *et al.* (2016), Ranjeetha *et al.* (2020) and Chaitanya *et al.* (2020).

Number of seeds per umbel owned indirect positive effect on seed yield per plant *via* number of branches per plant at 150 DAS, days to 50 per cent flowering, test weight (g), days to flower initiation (10%) and oleoresin (%). Number of flowers per umbellates, harvest index (%), number of umbellates per umbel, plant height at 150 DAS, number of umbels per plant, days to germination and essential oil had negative indirect effect on seed yield per plant. The results are in confirmity previous reports of Bahraminejad *et al.* (2011), Kassaun *et al.* (2013), Meena *et al.* (2014), Ranjeetha *et al.* (2020) and Rawat *et al.* (2020).

Test weight exhibited indirect and positive effect on seed yield per plant *via* number of seeds per umbel, number of branches per plant at 150 DAS, days to 50 per cent flowering, days to flower initiation (10%) and oleoresin (%). Harvest index (%), number of umbellates per umbel, number of flowers per umbellates, days to germination, number of umbels per plant, essential oil (%) and plant height at 150 DAS had negative indirect effect on seed yield per plant. The results obtained are in the agreement with previous reports of Jain *et al.* (2013), Kassaun *et al.* (2013), Singh *et al.* (2016), Meena and Dhakar (2017), Singh *et al.* (2020), Ranjeetha *et al.* (2020), Rawat *et al.* (2020), Singh *et al.* (2020) and Chaitanya *et al.* (2020).

Oleoresin (%) content had indirect positive effect on seed yield per plant *via* number of seeds per umbel, number of branches per plant at 150 DAS, days to 50 per cent flowering, days to flower initiation (10%) and test weight (g). Harvest index (%), number of umbellates per umbel, number of flowers per umbellates, days to germination, plant height at 150 DAS, number of umbels per plant and essential oil (%) had negative indirect effect on seed yield per plant.

At phenotypic path level, total yield per plant had highest positive direct effect was expressed by harvest index (%), number of umbels per plant, number of flowers per umbellates, number of branches per plant at 150 DAS, days to flower initiation (10%), test weight (g) and number of seeds per umbel. Oleoresin (%), days to 50 per cent, plant height at 150 DAS, number of umbellates per umbel, days to germination and essential oil (%) had negative direct effect for seed yield per plant. The present findings are supported by Bahraminejad *et al.* (2011), Meena *et al.* (2014), Ghanshyam *et al.* (2015), Meena and Dhakar (2017), Ranjeetha *et al.* (2020), Rawat *et al.* (2020), Singh *et al.* (2020) and Chaitanya *et al.* (2020).

Number of branches per plant at 150 DAS possess indirect effect in positive manner on seed yield per plant *via* harvest index (%), number of umbels per plant, number of flowers per umbellates, days to 50 per cent flowering, days to germination, test weight (g) and number of seeds per umbel. Days to flower initiation (10%), plant height at 150 DAS, number of umbellates per umbel, oleoresin (%) and essential oil (%) had negative and indirect effect on seed yield per plant. Similar findings were reported in studies by Jain *et al.* (2013), Meena *et al.* (2016), Singh *et al.* (2016), Ranjeetha *et al.* (2020) and Chaitanya *et al.* (2020).

Days taken for flower initiation (10%) expressed positive with indirect effect on seed yield per plant *via* oleoresin (%), number of umbellates per umbel, plant height at 150 DAS and essential oil (%). Harvest index (%), number of umbels per plant, days to 50 per cent flowering, number of flowers per umbellates, number of branches per plant at 150 DAS, days to germination, test weight (g) and number of seeds per umbel had negative indirect effect on seed yield per plant. The obtained results are in conformity with findings of Chaitanya *et al.* (2020).

Number of flowers per umbellates had indirect and positive effect on seed yield per plant *via* harvest index (%), number of umbels per plant, number of branches per plant at 150 DAS, days to 50 per cent flowering, days to germination, test weight (g), and number of seeds per umbel. Days to flower initiation (10%), number of umbellates per umbel, plant height at 150 DAS, oleoresin (%) and essential oil (%) showed negative and indirect effect for seed yield per plant. Similar results were reported by the study conducted by Chaitanya *et al.* (2020).

Number of umbels per plant had indirect with positive effect for seed yield per plant *via* harvest index (%), number of flowers per umbellates, number of branches per plant at 150 DAS, days to 50 per cent flowering, days to germination, test weight (g), and number of seeds per umbel. Days taken for flower initiation (10%), number of umbellates per umbel, plant height at 150 DAS, oleoresin (%) and essential oil (%) showed negative with indirect effect on seed yield per plant. This result was in similarity with studies of Bahraminejad *et al.* (2011), Ghanshyam *et al.* (2015), Meena and Dhakar (2017), Ranjeetha *et al.* (2020) and Singh *et al.* (2020).

Number of seeds present in an umbel had indirect with positive effect on seed yield per plant *via* harvest index (%), number of umbels present in a plant, number of flowers per umbellates, number of branches per plant at 150 DAS, days 50 per cent flowering, days to germination, test weight (g) and number of seeds per umbel. Days to flower initiation (10%), number of umbellates per umbel, plant height at 150 DAS, oleoresin (%) and essential oil (%) had negative and indirect effect on seed yield per plant. Similar reports were reported by Bahraminejad *et al.* (2011), Meena *et al.* (2014), Meena *et al.* (2016) and Ranjeetha *et al.* (2020)

Harvest index (%) had indirect effect in positive for trait seed yield per plant *via* number of umbels per plant, number of flowers per umbellates, number of branches per plant at 150 DAS, days to 50 per cent flowering, days to germination, test weight (g) and number of seeds per umbel. Days to flower initiation (10%), number of umbellates per umbel, oleoresin (%), plant height at 150 DAS and essential oil (%) had negative indirect effect on seed yield per plant. This observation was in line with the findings of Gurjar *et al.* (2016), Singh *et al.* (2016), Ranjeetha *et al.* (2020) and Chaitanya *et al.* (2020).

Test weight (g) exhibited indirect effect in positive direction on the trait seed yield per plant *via* harvest index (%), number of umbels per plant, number of flowers per umbellates, days to 50 per cent flowering, days to germination, number of branches per plant at 150 DAS and number of seeds per umbel. Days to flower initiation (10%), number of umbellates per umbel, essential oil (%), oleoresin (%) and plant height at 150 DAS showed negative with indirect effect on seed yield per plant. Similar results were

found in the studies by Jain *et al.* (2013), Kassaun *et al.* (2013), Gurjar *et al.* (2016), Singh *et al.* (2016), Ranjeetha *et al.* (2020), Rawat *et al.* (2020) and Singh *et al.* (2020).

5.7 Genetic diversity analysis

Genetic diversity is regarded as important factor and it is an necessary pre-requisite for hybridization programme for obtaining high yielding ability progenies in the crop improvement programme. The most desirable genes are combined to obtain desirable recombinants by including divergent parents in hybridization programme. Genetic diversity measured quantitatively was more beneficial in evaluation of the genotypes under study.

Twenty-eight genotypes were grouped into 12 clusters based on D^2 values. Cluster I was found to be largest containing 6 genotypes followed by cluster IV, V, VII and VIII with 5, 3, 4 and 3 genotypes. The solitary clusters were II, III, VI, IX, X, XI and XII. The clustering of genotypes into different cluster was due to different genetic architecture. Studies by Sirohi and Dar (2009) reported that changing of genetic material, artificial selection genetic drift and natural variation and other than geographical and ecological and diversifications are the causes of genetic divergence. The varietal distribution pattern in different clusters, it appeared that geographical distance noticed between the varieties showed no relation with genetic divergence as the varieties from same source had fallen into different clusters along with the same cluster contained varieties from different sources. These findings are in close proximity with the previous reports by Mathur (1992), Patel *et al.* (2000), Banerjee *et al.* (2004), Singh *et al.* (2005), Jain *et al.* (2006), Kole and Saha (2009) in fenugreek, Palanikumar *et al.* (2012), Meena *et al.* (2014) studies in coriander, Singh *et al.* (2017) and Nagar *et al.* (2019).

The value of intra-cluster D^2 ranged from 24.51 to 37.24 in pooled average over both the season. Maximum intra cluster distance was noticed in cluster VIII followed by VII, V, IV and II. The clusters II, III, VI, IX, X, XI and XII had showed no intra cluster distance as they were represented by single genotypes. The genotypes categorized in cluster with highest intra cluster distance were more diversified from each other than the genotypes in the other clusters, whereas cluster with minimum intra cluster distance were comparatively less diverse from each other. The intra-cluster values are lesser than

the inter- cluster values which indicates the homogenous and heterogenous nature of the genotypes within and between the clusters, respectively. Similar results in coriander crop was reported by several scholars such as Patel *et al.* (2000), Srivastava *et al.* (2000), Palanikumar *et al.* (2012), Dyulgerov and Dyulgerova (2013), Meena *et al.* (2014), Singh *et al.* (2017) and Nagar *et al.* (2019).

The inter cluster D^2 values showed a wide range of cluster distance varying from 13.51 to 114.42, respectively. Maximum inter cluster distance was noticed between the cluster VII and V and was followed by cluster IX and V, cluster VIII and VII and cluster X and V. Lowest inter cluster distance was noticed in cluster III and II. This result suggests more variability in genetic make up of the accessions included in these clusters. The accessions under the clusters separated by high statistical distance could be used in hybridization programme for generating a wide variation among the segregates (Mengesha *et al.*, 2011). The genotypes in clusters separated by maximum inter cluster distance were genetically more divergent. Thus, it would be logical to include these genotypes under these clusters in future breeding programmes. The lowest inter cluster distance indicated close genetic association among the genotypes under the clusters. This suggests more variability in genetic make-up of the accessions included in these clusters. The results are in agreement with the findings of Patel *et al.* (2000), Banerjee *et al.* (2004), Palanikumar *et al.* (2012), Swami *et al.* (2012), Dyulgerov and Dyulgerova (2013) and Meena *et al.* (2014) in coriander, Singh *et al.* (2017) and Nagar *et al.* (2019). Hence, inter mating between the genotypes included in these clusters could be expected to give transgressive segregates in the advanced generation as suggested by Kalloo *et al.* (1980).

Among all the characters under the study, the greatest contribution to the total divergence was by oleoresin (%) content which was followed by test weight (g), seed yield per plant (g), number of umbels per plant, essential oil (%), number of flowers per umbellates. However, the traits like harvest index (%), days to flower initiation (10%), number of umbellates per umbel, number of seeds per umbel, days to germination, plant height at 150 DAS, number of branches per plant at 150 DAS, days to 50 per cent flowering did not show any substantial contribution to total divergence in pooled over two seasons. The contribution of different characters towards the genetic divergence expression must be taken in to account as a criteria for selection of parents for crossing

programme was reported by Subrahmanyam *et al.* (2003). Therefore, among the different characters, oleoresin (%), test weight (g), essential oil (%) and was followed by number of seeds per umbellates and number of umbels in each plant must be considered as a criterion for selection of parents for crossing programme. The results are in line with of Patel *et al.* (2000), Kole *et al.* (2002), Banerjee *et al.* (2004), Palanikumar *et al.* (2012), Meena *et al.* (2014), Pathak *et al.* (2014), Singh *et al.* (2017) and Nagar *et al.* (2019).

Highest cluster mean was noticed in cluster VIII for traits days taken for germination, number of branches per plant at 150 DAS, test weight (g), days to flower initiation (10%), number of seeds per umbel, number of flowers per umbellates, number of umbels per plant, days to 50 per cent flowering, number of umbellates per umbel, seed yield per plant (g) and harvest index (%). The characters such as plant height and essential oil (%) had maximum cluster mean in cluster XII. The oleoresin content was reported maximum in cluster V. The genotypes under these cluster can be utilized in further breeding programmes in improving the yield and its attributing characters, quality and also in developing early varieties. Hence, from the present study it can be said that a high yielding early flowering types with high quality can be bred by taking account the genotypes from cluster V, VIII and XII as parental genotypes in the future breeding programme. The genotypes of these cluster showed greater variation for many of the traits evaluated. Similar observations on clustering were also reported by Bhandari and Gupta (1993), Srivastava *et al.* (2000), Singh *et al.* (2012), Dyulgerov and Dyulgerova (2013) and Meena *et al.* (2014) in coriander.

5.8. Molecular marker profiling

Diversity assessment or germplasm characterization based on morphological or taxonomical descriptors is one of the common method which results in overlapping complex results. These methods are greatly influenced by the environment; hence there is a chance for occurrence of variation at phenotypic expression level. Therefore, it is much needed to support morphological variability with molecular variability studies for selecting better performing genotypes.

Out of 25 primers used in present study, 10 primers showed considerable per cent polymorphism. These primers can be used suitably to assess genetic diversity in

local types. Similar results were reported by the earlier studies done by Cholin *et al.* (2018) and Bharti *et al.* (2018). Variation in polymorphism among the different ajwain genotypes are due to wide genetic base of the ajwain genotypes and this variation were effectively identified by the SSR markers.

Maximum allele number was observed in GSSR_17 (4) and minimum allele number was observed in CuminSSR_7 (2). The number of effective alleles were found maximum in GSSR_63 (2.575) and minimum in GSSR_6 (1.600). Maximum information index was noticed in GSSR_63 (1.003) and minimum in GSSR_6 (0.562).

Maximum heterozygosity was highest in GSSR_63 (0.393) and minimum heterozygosity was noticed in CuminSSR_7 (0.000), whereas the expected heterozygosity was highest in GSSR_63 (0.612) and lowest in GSSR_6 (0.375). Fixation index was found maximum in CuminSSR_7 (1.000) and minimum in GSSR_63 (0.358). Highest PIC values were noticed in GSSR_63 (0.529) and lowest PIC value was noticed in CuminSSR_12 (0.304).

Diversity analysis done for twenty-eight ajwain genotypes collected from various geographical regions was carried using SSR marker and cluster analysis was analyzed for construction of dendogram. It revealed 3 cluster, cluster I contains 15 genotypes, cluster II with 13 and third cluster with solitary cluster. The clustering of genotypes was due to different genetic architecture, which is in line with previous worker cholin *et al.* (2018) in ajwian. The present study also shows that SSR markers as a useful tool for the assessment of genetic variability among ajwain genotypes.

6. SUMMARY AND CONCLUSION

Evaluation of genetic variability was the important feature in germplasm conservation studies and hence, it was essential to evaluate the genetic diversity of ajwain for employing effective preservation strategies. Isolation and protection of genetic resources were essential for the maintenance of diversity, to study local germplasm and to select genotypes with high growth, yield and quality parameters. The present investigation was carried out in 2020-21 and 2021-22 seasons during the year 2020-22 experimental plot laid out in randomized complete block design with two replications. 28 genotypes in ajwain germplasm collection were studied in both the seasons with the following objectives to evaluate the ajwain genotypes for morpho-physico characters and seed yield, the ajwain genotypes for seed quality traits, genetic variability among the ajwain genotypes, assessing the diversity and association between growth, yield and seed quality traits and molecular characterization of ajwain genotypes. The results obtained from the present investigations are summarized and concluded in this chapter.

1. Minimum days to germination was noticed in AZ-1 (9.75), whereas maximum days taken for germination were observed in HUB-10 (15.50).
2. Higher plant height at 150 DAS was recorded in RM (96.83 cm), whereas HUB-11 (66.23 cm) recorded the lowest plant height.
3. AA-93 recorded the highest number of branches per plant (18.18), whereas lowest number of branches per plant was recorded in HUB-10 (10.25).
4. The minimum days taken for commencement of flower initiation (10%) was observed in AZ-1 (66.00), whereas the maximum days for commencement of flower initiation (10%) was noticed in HUB-11 (101.50).
5. Minimum days taken for commencement of 50 per cent flowering was observed in AZ-1 (77.25), whereas maximum days for commencement of 50 per cent flowering was recorded in HUB-11 (109.75).
6. The highest number of flowers per umbellates was observed in HUB-8 (23.85), whereas lowest number of flowers per umbellates was registered in HUB-9 (11.67).

7. The minimum days taken for harvest was recorded in AZ-1 (128.50). The maximum days taken for harvest was observed in HUB-10 (156.00)
8. AZ-1 showed the highest number of umbels in an individual plant is 302.25. The lowest number of umbels in an individual plant was recorded in HUB-11 (75.68).
9. AZ-1 showed the highest number of umbellates per umbel (14.90). The lowest number of umbellates per umbel was recorded in HUB-9 (9.38).
10. HUB-8 showed the highest number of seeds per umbel (280.00). Minimum number of seeds per umbel was recorded in HUB -9 (67.70).
11. The genotype AZ-1 showed the highest seed yield per plant (11.96 g), whereas HUB-9 noted less for its seed yield of a single plant (4.93 g).
12. AZ-1 recorded the highest seed yield of 374.63 g per plot, while lowest was noted in HUB-9 (118.25 g). AZ-1 recorded the highest seed yield of 711.79 kg per ha, while lowest was noted in HUB-9 (220.95 kg/ha).
13. AZ-1 recorded maximum harvest index (%) of (38.27%), whereas the harvest index (%) was recorded minimum in HUB-9 (14.70%).
14. The maximum test weigh was observed in HUB-8 (1.83 g). The genotype RM showed least test weight of 0.97 g.
15. The highest essential oil content was recorded in RM (2.30%). The lowest essential oil was found in HUB-9 (0.90 %)
16. The highest oleoresin content was recorded in DAC-5 (6.65%), whereas lowest oleoresin content was found in AL-3 (1.75 %).
17. The maximum thymol content was found in the DAC-5 (49.61%). HUB-2 showed minimum thymol content (41.10%).
18. The genotype HUB-2 showed less per cent incidence of stem fly (resistance), whereas the maximum incidence of stem fly was noticed in HUB-10 (susceptible).

19. The analysis of variance indicates highly significant differences among all the traits studied, thus indicating the existence of variation among the genotypes and there was a scope for crop improvement.
20. High GCV and PCV was showed for number of umbels per plant, number of seeds per umbel, seed yield per plant (g), seed yield per plot (g) and (kg/ha), harvest index (%), essential oil (%), oleoresin (%). Moderate GCV and PCV was observed for days to germination, test weight (g), number of branches per plant at 150 DAS and number of flowers per umbellates. Low GCV and PCV was observed for plant height at 150 DAS, days to flower initiation (10%), days to 50 per cent flowering, number of umbellates per umbel and days to physiological maturity. This indicates that, there will be wide genetic base for future crop improvement programme.
21. High heritability was noticed for days to germination, number of branches per plant at 150 DAS, days to flower initiation (10%), days to 50 per cent flowering, number of flowers per umbellates, number of umbels per plant, number of seeds per umbel, seed yield per plant (g), plant height at 150 DAS, days to physiological maturity, number of umbellates per umbel, seed yield per plot (g) and (kg/ha), harvest index (%) and essential oil (%), oleoresin (%). High genetic advance was noticed for number of branches per plant at 150 DAS, number of flowers per umbellates, number of umbels per plant, number of seeds per umbel, seed yield per plot (g) and (kg/ha), harvest index (%), essential oil (%) and oleoresin (%). This indicates that simple selection was effective to bring genetic improvement.
22. Moderate genetic advance over mean noticed for days to germination, plant height at 150 DAS, days to flower initiation (10%), days to 50 per cent flowering and number of umbellates per umbel. Low genetic advance over mean was noticed for days to physiological maturity.
23. Both at genotypic and phenotypic level, total seed yield of plant was positively and highly significantly associated with harvest index (%), number of umbels per plant, number of seeds per umbel, number of flowers per umbellates, number of branches per plant at 150 DAS, number of umbellates per umbel, plant height at 150 DAS, essential oil (%), test weight (g) and oleoresin (%). It was negatively and

significantly associated with days to 50 per cent flowering, days to flower initiation (10%) and days to germination.

24. At genotypic path level, total seed yield per plant high positive direct effect was expressed by number of seeds per umbel followed by number of branches at 150 DAS, test weight (g), days to germination and oleoresin (%), whereas the number of flowers per umbellates, harvest index (%), number of umbellates per umbel, days to 50 per cent flowering, plant height at 150 DAS, number of umbels per plant, essential oil (%) and days to flower initiation (10%) had negative direct effect on total yield per plant.
25. At phenotypic path level, total seed yield per plant had highest positive direct effect was expressed by harvest index (%), number of umbels per plant, number of flowers per umbellates, number of branches per plant at 150 DAS, days to flower initiation (10%), test weight (g) and number of seeds per umbel. Oleoresin (%), days to 50 per cent flowering, plant height at 150 DAS, number of umbellates per umbel, days to germination and essential oil (%) had negative and direct effect for seed yield per plant
26. Twenty-eight genotypes were grouped into 12 clusters based on D^2 values. Cluster I found to be largest with 6 genotypes followed by cluster IV, V, VII and VIII with 5, 3, 4 and 3 genotypes. The clusters II, III, VI, IX, X, XI and XII were solitary clusters.
27. The highest intra cluster distance was noticed in the cluster VIII with D^2 value of 37.24 followed by cluster VII (34.51), cluster V (30.35), cluster IV (26.94) and cluster II (24.51), The clusters II, III, VI, IX, X, XI and XII had no intra cluster distance as they were represented by single genotype.
28. The highest inter cluster distance was noticed between the cluster VII and V (114.42) followed by cluster IX and V (99.34), cluster VIII and VII (96.59) and cluster X and V (95.06). Cluster III and II (13.51) had lowest inter cluster distance.
29. The maximum contribution to the total divergence was by oleoresin (%), followed by test weight (g), seed yield per plant (g), number of umbels per plant, essential oil

(%), number of flowers per umbellates. The traits like harvest index (%), days to flower initiation (10%), number of umbellates per umbel, number of seeds per umbel, days to germination, plant height at 150 DAS, number of branches per plant at 150 DAS, days to 50 per cent flowering had no substantial contribution to total divergence.

30. The maximum cluster mean was observed in cluster VIII for days to germination, number of branches per plant at 150 DAS, days to flower initiation (10%), days to 50 per cent flowering, number of flowers per umbellates, number of umbels per plant, number of umbellates per umbel, number of seeds per umbel, seed yield per plant (g), test weight (%) and harvest index (%). The characters like plant height and essential oil had maximum cluster mean in cluster XII.
31. Out of the 25 primers used for the study, 10 primers showed considerable per cent polymorphism. These groups of primers can be used suitably to assess genetic diversity in these local types.
32. Maximum numbers of alleles was denoted in GSSR_17 (4) and minimum number of alleles was noticed in CuminSSR_7 (2). The number of effective alleles were maximum in GSSR_63 (2.575). Minimum number of effective alleles was noticed in GSSR_6 (1.600). The maximum information index was noticed in GSSR_63 (1.003). Minimum information index was observed in GSSR_6 (0.562).
33. The maximum observed heterozygosity was highest in GSSR_63 (0.393) and minimum observed heterozygosity was noticed in CuminSSR_7 (0.000). The expected heterozygosity was highest in GSSR_63 (0.612). Lowest expected heterozygosity was observed in GSSR_6 (0.375).
34. The fixation index was maximum in CuminSSR_7 (1.000). The minimum fixation index was recorded in GSSR_63 (0.358). Highest PIC values were noticed in marker GSSR_63 (0.529) and lowest PIC value was noticed in marker CuminSSR_12 (0.304).
35. Diversity analysis of 28 ajwain genotypes collected from different geographical regions was carried out using SSR marker and cluster analysis was performed for construction of dendrogram. The dendrogram revealed 3 cluster, cluster I contains 15 genotypes, cluster II with 13 and cluster III with solitary cluster.

Conclusion

From this study, the collection of different genotypes showed significant difference with respect to morphological, yield and quality traits. Among 28 genotypes HUB-8, AZ-1, AA-93, AA-1, AA-2, HUB-1, HUB-2, RM and DAC-5 had maximum seed yield per plant (g), harvest index (%), number of umbels per plant, number of seeds per umbel, test weight (g), essential oil (%) and oleoresin (%) content under Bagalkot conditions (Plate 7). By this study, we believe that the findings will provide a valuable basis for future ajwain breeding programs and the development of high-yielding ajwain variety. The present study also shows that SSR markers can be used as tool for the assessment of genetic variability among ajwain genotypes. However some more number of SSR primers can reveal further more confirmed diversity among the genotypes used in this study. Hence, this genotype can further be assessed for checking its suitability under northern dry zone of Karnataka.

Future line of work

- Identification of superior genotypes and utilization of those genotypes for further crop improvement in Northern dry zone of Karnataka with multi location trials for stability analysis.
- Growth regulator trials may be initiated for better growth, yield and quality.
- Studies on sowing date or time for explaining the varietal diversity under southern dry zone of Karnataka.
- For improvement of yield per hectare, breeder should give consideration for number of branches per plant, harvest index (%), test weight (g), number of seeds per umbel, number of umbels per plant, number of flowers per umbellates since these traits had high direct effects on total seed yield per plant as revealed by both genotypic and phenotypic path analysis studies.
- Exploiting the genetic distance from molecular markers data helps to identifying genotypes for mapping populations and also to identify molecular markers linked to desirable traits for marker assisted selection (MAS).



Plate 7. High yielding ajwain genotypes

- Considering the availability of large markers from ajwain, level of polymorphism makes it relatively straightforward to construct a linkage map in ajwain for to locate target resistance loci.

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Appendix I

Meteorological data during the study period recorded at the meteorological observatory of MHREC, UHS, Bagalkot (2020-21)

Date	Normal	Year	Rainfall (mm)	Temp (°C)		Relative humidity
				Max	Mini	
Jan	0	2020	0	30.54	16.18	75.00
Feb	1	2020	0	32.46	17.06	63.34
Mar	14	2020	9.9	35.20	20.01	56.98
Apr	11	2020	18.8	29.15	18.28	46.35
May	51	2020	9.40	33.80	20.46	45.77
Jun	77	2020	100.4	30.22	20.29	65.98
Jul	69	2020	131.8	29.55	21.98	80.68
Aug	65	2020	131.7	28.62	21.62	81.05
Sep	213	2020	271.0	28.48	21.80	78.73
Oct	81	2020	188.3	29.66	20.98	76.55
Nov	15	2020	1.4	29.55	16.97	65.77
Dec	5	2020	0	28.78	14.52	62.37
Jan	0	2021	5.6	29.58	16.13	64.02
Feb	1	2021	0	29.99	14.69	52.14
Mar	14	2021	0	35.32	18.60	46.03
Total	617	-	868.3	-	-	-
Average	50.16	-	57.89	30.73	18.64	64.05

Appendix II

Meteorological data during the study period recorded at the meteorological observatory of MHREC, UHS, Bagalkot (20201-22)

Month	Temperature. (°C)				Relative Humidity (%)			
	Normal/AVG, Max Temp	Actual Max Temp 2021	Normal/Avg Min Temp	Actual Min Temp- 2021	Normal/ Avg Mrng RH-21	Actual Mrng. RH-2021	Normal/Avg noon. RH-21	Actual Afternoon RH-2021
Jan-21	30.0	33.90	17.0	14.20	46.00	90.00	30.00	37.00
Feb-21	33.0	34.80	19.0	12.90	43.00	76.25	23.00	23.87
Mar-21	36.0	39.40	21.0	14.70	37.00	66.00	25.00	16.00
Apr-21	37.0	38.60	23.0	22.96	43.00	80.30	27.00	21.20
May-21	36.0	36.09	22.0	23.10	55.00	88.00	31.00	40.00
Jun-21	31.0	31.40	22.0	22.60	84.00	94.00	65.00	63.00
July -21	28.0	29.90	21.0	22.50	89.00	96.00	66.00	72.00
Aug -21	29.0	30.50	21.0	22.00	86.00	97.00	68.00	64.00
Sept-21	30.0	29.07	21.0	21.85	85.00	97.80	61.00	69.26
Oct-21	31.9	31.86	20.0	21.30	84.00	94.93	69.00	47.35
Nov-21	29.0	29.60	18.0	20.69	70.00	94.80	42.00	57.30
Dec-21	28.0	29.50	17.0	16.59	62.00	97.48	33.00	46.38
Total								
Jan-22	30.0	34.20	17.0	12.1	46.00	92.00	30.00	35.00
Feb-22	33.0	33.70	19.0	16.9	43.00	79.00	23.00	23.40
Mar-22	36.0	37.01	21.0	20.7	37.00	71.00	25.00	20.20
April-22	37.0	37.90	23.0	23.5	43.00	74.30	27.00	24.20
May-22	36.0	35.5	22.0	23.9	55.00	88.80	31.00	42.10

Appendix III

Initial chemical properties of soil used in field during the research work

Parameters	Values
Chemical properties	
pH	8.17
EC (dS/m)	0.35
Organic carbon (%)	0.57
CEC (meq/100g soil)	11.3
Available Nitrogen (Kg/ha)	173
Available Phosphorus (Kg/ha)	54
Available Potassium (Kg/ha)	231.65
Available Calcium	22.65
Available Magnesium (meq/100g)	6.57
Available Sulphur (meq/100g)	12.42

**MORPHOMETRIC AND MOLECULAR CHARACTERIZATION OF AJWAIN
(*Trachyspermum ammi* L.) GENOTYPES UNDER NORTHERN DRY ZONE OF
KARNATAKA**

POOJA S.

2022

**Dr. Mohammed Farooq
Major advisor**

ABSTARCT

Twenty eight ajwain genotypes were collected from different regions and evaluated in randomised block design to study the variability, diversity, character association, path analysis and molecular diversity at the Department of Plantation, Spices, Medicinal and aromatic crops, College of Horticulture, Bagalkot during 2020-2022. Analysis of variance revealed that significant difference were observed among the genotypes for all characters. High PCV, GCV, heritability and high genetic advance over mean were recorded for parameters like number of umbels per plant, number of seeds per umbel, seed yield per plant (g), seed yield per plot (g) and (kg/ha), harvest index (%), essential oil (%) and oleoresin (%). The total seed yield of plant was positively and highly significantly associated with harvest index (%), number of umbels per plant, number of seeds per umbel, number of flowers per umbellates, number of branches per plant at 150 DAS, number of umbellates per umbel, plant height at 150 DAS, essential oil (%), test weight (g) and oleoresin (%). Path analysis revealed highest positive direct effects on total yield per plant was shown by harvest index (%), number of umbels per plant, number of flowers per umbellates, number of branches per plant at 150 DAS, days to flower initiation (10%), test weight (g) and number of seeds per umbel. Genetic divergence analysis using Mahalanobis's D^2 statistic grouped twenty-eight genotypes of ajwain into twelve clusters, of which cluster VIII showed maximum intra-cluster distance. The inter cluster average D^2 value was maximum between the cluster VII and V. DNA finger printing of twenty-eight genotypes of ajwain was carried out by 25 SSR markers. Dendogram revealed three major clusters. The promising genotypes are HUB-8, AZ-1 and AA-93 was found superior for both growth and yield parameters.

**ಕರ್ನಾಟಕ ಉತ್ತರ ಒಣ ವಲಯದಲ್ಲಿ ಅಜವಾನ ತಳಿಗಳ ಸ್ವರೂಪದಲ್ಲಿನ ಮತ್ತು ಅಣೈಕ
ಚಿತ್ರಣದ ವಿಶ್ಲೇಷಣೆ**

ಪೂಜಾ ಎಸ್

೨೦೨೨

ಡಾ. ಮೊಹಮ್ಮದ್ ಫಾರೂಕ್

ಪ್ರಧಾನ ಮಾರ್ಗದರ್ಶಕರು

ಸಾರಾಂಶ

ಸ್ಥಳೀಯ ೨೮ ಅಜವಾನ ತಳಿಗಳ ವೈವಿಧ್ಯತೆ, ಪರಸ್ಪರ ಗುಣಲಕ್ಷಣಗಳ ಸಂವಾದ ಮಾರ್ಗ ವಿಶ್ಲೇಷಣೆ ಮತ್ತು ಪರಸ್ಪರ ಅಣೈಕ ವೈವಿಧ್ಯತೆಯ ಅಧ್ಯಯನವನ್ನು ಯಾದ್ಯಚ್ಚಿಕ್ ಬ್ಲಾಕ್ ಮಾದರಿಯಲ್ಲಿ ಬಾಗಲಕೋಟೆಯ ತೋಟಗಾರಿಕಾ ಮಹಾವಿದ್ಯಾಲಯದ ನೆಡುತೋಪು, ಸಾಂಬಾರು, ಔಷಧಿ ಮತ್ತು ಸುಗಂಧಿ ಬೆಳೆಗಳ ವಿಭಾಗದಲ್ಲಿ ೨೦೨೦-೨೦೨೨ ರಲ್ಲಿ ಮಾಡಲಾಯಿತು. ಅಧ್ಯಯನದ ಎಲ್ಲಾ ಗುಣಲಕ್ಷಣಗಳಿಗೂ ಗಮನಾರ್ಹ ವ್ಯತ್ಯಾಸ ಕಂಡುಬಂದಿದೆ. ಪ್ರತಿ ಗಿಡಕ್ಕೆ ಹೂಗೊಂಚಲುಗಳ ಸಂಖ್ಯೆ, ಪ್ರತಿ ಹೂಗೊಂಚದಲ್ಲಿರುವ ಬೀಜಗಳು, ಪ್ರತಿ ಸಸ್ಯದ ಬೀಜದ ಇಳುವರಿ, ಪ್ರತಿ ತಾಕು ಮತ್ತು ಹೆಕ್ಟೇರಿನ ಬೀಜದ ಇಳುವರಿ, ಸುಗ್ಗಿ ಸೂಚ್ಯಂಕ, ಸಾರಭೂತ ತೈಲ ಮತ್ತು ಒಲಿಯೋರೆಸಿನ್ ಅಂಶದಲ್ಲಿ ಹೆಚ್ಚಿನ ವಂಶವಾಹಿ, ಬಾಹ್ಯರೂಪಿ ಅಂಶಗಳು, ಅನುವಂಶೀಯ ಸಾಮರ್ಥ್ಯ ಮತ್ತು ಸಂಯೋಜನೆ ವಂಶವಾಹಿ ಕಂಡುಬಂದಿದೆ. ಸುಗ್ಗಿ ಸೂಚ್ಯಂಕ, ಪ್ರತಿ ಗಿಡಕ್ಕೆ ಹೂಗೊಂಚಲುಗಳ ಸಂಖ್ಯೆ, ಪ್ರತಿ ಹೂಗೊಂಚದಲ್ಲಿರುವ ಬೀಜಗಳು, ಪ್ರತಿ ಹೂಗೊಂಚದಲ್ಲಿರುವ ಹೂಗಳ ಸಂಖ್ಯೆ, ೧೫ನೇ ದಿನಕ್ಕೆ ಪ್ರತಿ ಗಿಡದ ಶಾಖೆಯ ಸಂಖ್ಯೆ, ಪ್ರತಿ ಹೂಗೊಂಚಲಿಗೆ ಉಪ ಹೂಗೊಂಚಲ ಸಂಖ್ಯೆ, ೧೫ನೇ ದಿನಕ್ಕೆ ಪ್ರತಿ ಗಿಡದ ಎತ್ತರ, ಸಾರಭೂತ ತೈಲದ ಪ್ರಮಾಣ, ಸಾವಿರ ಬೀಜಗಳ ತೂಕ, ಒಲಿಯೋರೆಸಿನ್ ಅಂಶ, ಈ ಗುಣಗಳು ಪ್ರತಿ ಗಿಡದ ಬೀಜದ ಇಳುವರಿ ಜೊತೆಗೆ ಗಮನಾರ್ಹ ಹಾಗೂ ಧನಾತ್ಮಕ ಸಂಯೋಜನೆಯನ್ನು ಹೊಂದಿವೆ. ಮಾರ್ಗ ವಿಶ್ಲೇಷಣೆಯಲ್ಲಿ ಸುಗ್ಗಿ ಸೂಚ್ಯಂಕ, ಪ್ರತಿ ಗಿಡಕ್ಕೆ ಹೂಗೊಂಚಲುಗಳ ಸಂಖ್ಯೆ, ಪ್ರತಿ ಗಿಡಕ್ಕೆ ಹೂಗೊಂಚಲುಗಳ ಸಂಖ್ಯೆ, ೧೫ನೇ ದಿನಕ್ಕೆ ಪ್ರತಿ ಗಿಡದ ಶಾಖೆಯ ಸಂಖ್ಯೆ, ಶೇಕಡ ೧೦ ರಷ್ಟು ಹೂ ಬಿಡಲು ತೆಗೆದುಕೊಂಡ ದಿನಗಳ ಸಂಖ್ಯೆ, ಸಾವಿರ ಬೀಜಗಳ ತೂಕ ಮತ್ತು ಪ್ರತಿ ಹೂಗೊಂಚದಲ್ಲಿರುವ ಬೀಜಗಳು ಧನಾತ್ಮಕ ಹಾಗೂ ನೇರ ಪರಿಣಾಮ ಹೊಂದುವ ಅಂಶಗಳೆಂದು ಕಂಡುಬಂದಿವೆ. ಮಹಾಲೋನೋವಿಸ್ ಡಿ ಸ್ಕೋಯರ್ ವಿಶ್ಲೇಷಣೆಯ ಪ್ರಕಾರ ೨೮ ತಳಿಗಳಲ್ಲಿ ವೈವಿಧ್ಯತೆಯನ್ನು ಸೂಚಿಸಿದೆ ಮತ್ತು ೧೨ ವಿಧದ ಗುಂಪುಗಳನ್ನಾಗಿ ವಿಂಗಡಿಸಿ ಅವುಗಳಲ್ಲಿ ೮ನೇ ಗುಂಪು ಗರಿಷ್ಠ ಆಂತರಿಕ ಗುಂಪುಗಳ ದೂರವನ್ನು ತೋರಿಸಿದೆ. ಹಾಗೆಯೇ, ಪರಸ್ಪರ ಗುಂಪಿನ ಅಂತರ ಅತೀ ಹೆಚ್ಚಾಗಿ ೭ನೇ ಮತ್ತು ೫ನೇ ಗುಂಪುಗಳ ನಡುವೆ ಕಂಡುಬಂದಿದೆ. ೨೮ ಅಜವಾನ ತಳಿಗಳನ್ನು ೨೫ ಎಸ್ ಎಸ್ ಆರ್ ಮಾರ್ಕರ್‌ಗಳ ಮೂಲಕ ೬ ಎನ್ ಎ ಫಿಂಗರ್ ಪ್ರಿಂಟಿಂಗ್ ಮಾಡಲಾಯಿತು. ೬ ಎನ್ ಎ ಫಿಂಗರ್ ಪ್ರಿಂಟಿಂಗ್ ಆಧಾರದ ಮೇಲೆ ಅಜವಾನ ತಳಿಗಳನ್ನು ೩ ಮುಖ್ಯ ಗುಂಪುಗಳಾಗಿ ವಿಂಗಡಿಸಲಾಯಿತು. HUB-8, AZ-1 ಮತ್ತು AA-93 ತಳಿಗಳು ಉತ್ತಮ ಬೆಳವಣಿಗೆ ಮತ್ತು ಇಳುವರಿಯನ್ನು ಹೊಂದಿವೆ.