

**GENE ACTION AND COMBINING ABILITY  
STUDIES IN POMEGRANATE  
(*Punica granatum* L.)**

*Thesis*

by

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(H-2018-37-M)**

submitted to



**Dr. YASHWANT SINGH PARMAR UNIVERSITY  
OF HORTICULTURE AND FORESTRY  
SOLAN (NAUNI) HP-173 230 INDIA**

in

partial fulfilment of the requirements for the degree

of

**MASTER OF SCIENCE  
(HORTICULTURE)  
FRUIT SCIENCE**

**DEPARTMENT OF FRUIT SCIENCE  
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**2020**

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## **CERTIFICATE - I**

This is to certify that the thesis titled “**Gene action and combining ability studies in Pomegranate (*Punica granatum L.*)**” submitted in partial fulfillment of the requirements for the award of the degree of **Master of Science (Horticulture) Fruit Science** in the discipline of **Horticultural Sciences** to Dr. Yashwant Singh Parmar University of Horticulture & Forestry, (Nauni) Solan (HP) – 173 230 India is a bonafide research work carried out by **Ms Akanksha Sharma (H-2018-37-M)** daughter of Shri Pawan Kumar under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

**Place : Nauni, Solan**  
**Dated:**

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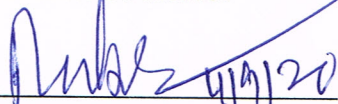
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## CERTIFICATE - II

This is to certify that the thesis titled, “**Gene action and combining ability studies in Pomegranate (*Punica granatum L.*)**” submitted by **Ms Akanksha Sharma (H-2018-37-M)** daughter of Shri Pawan Kumar to the Dr. Yashwant Singh Parmar University of Horticulture & Forestry, (Nauni) Solan (HP) - 173 230 India in partial fulfilment of the requirements for the degree of **Master of Science (Horticulture) Fruit Science** in the discipline of **Horticultural Sciences** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an Internal Examiner.

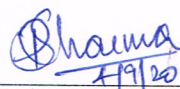
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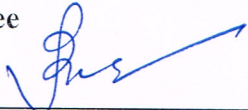
  

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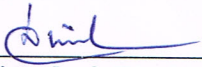
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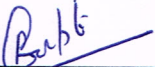
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**Dated : \_\_/\_\_/2020**

**(Akanksha)**

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## LIST OF ABBREVIATIONS

%	:	per cent
/	:	per
<	:	less than
=	:	equal to
>	:	greater than
×	:	multiplication
°B	:	degree brix
°C	:	degree celsius
°E	:	degree East
°N	:	degree North
ANOVA	:	analysis of variance
C.D.	:	critical difference
cm	:	centimeter
cm <sup>2</sup>	:	square centimeter
<i>et al.</i>	:	co-workers
E-W	:	East-West
g	:	gram
GCA	:	general combining ability
H.P.	:	Himachal Pradesh
i.e.	:	that is to say
kg	:	kilogram
m	:	meter
m <sup>3</sup>	:	cubic meter
ml	:	milliliters
mm	:	millimeter

MT	:	metric tons
NS	:	non-significant
N-S	:	North-South
p	:	pages
pp	:	particular page
S.E.	:	standard error
SCA	:	specific combining ability
SE (d)±	:	standard error of difference
SE (m)±	:	standard error of mean
SS	:	sum of squares
TSS	:	total soluble solids
viz.,	:	videlicet (namely)
<sup>2</sup> A	:	additive variance
<sup>2</sup> D	:	dominance variance

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## Chapter-1

# INTRODUCTION

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Pomegranate (*Punica granatum* L.) belongs to the family Punicaceae. It is considered as an excellent fruit which can be grown in tropical and sub-tropical areas of the world. It is famous for its attractive, juicy, sweet acidic and refreshing arils. It is a non-climacteric fruit and harvested after attaining optimum maturity. There is a growing demand for good quality fruits for table purpose and for processed products like juice, syrup, squash, wine and anardana which is an acidulant product. It is regarded as 'super fruit' due to its high nutritive worth, high antioxidant properties, high conceivably bioactive mixes, chemo-preventive properties having therapeutic worth and high consumer's intrigue (Hertog *et al.*, 1997). It is a rich source of vitamins, minerals, carbohydrates and proteins. Its aril juice provides about 16 per cent of the adults daily vitamin C requirement. It is also a good source of vitamin B<sub>5</sub>, K and polyphenols. The edible part comprises of 78 per cent juice and 22 per cent seed (Kulkarni and Aradhya, 2005). There are various potential benefits of pomegranate. It is used as an antioxidant and helps to stop the growth of prostate cancer cells. Pomegranate juice is very much helpful for the patients suffering from leprosy. Pomegranate juice has a powerful anti-inflammatory properties and also helps to protect heart and arteries. Pomegranate is traditionally used as a remedy for diabetes in the middle East and India. In some countries, it is commonly used for decorative purposes whereas, its fresh kernels are used for garnishing desserts and salads.

In Latin word, 'pomegranate' signifies apple with numerous seeds. Pomegranate natural product is viewed as an image of flourishing and desire (Duman *et al.*, 2009). Pomegranate originated in the region extending from Iran to northern India, and has been cultivated since ancient times throughout the Mediterranean region. *Punica* possibly is the primary known genus of its family, which incorporates enormous shrubs over small trees with two species viz., *Punica protopunica* and *Punica granatum*. *Punica protopunica* was discovered wild in Socotra Island and the other *Punica granatum* species developed in tropical and sub-tropical world (Chandra *et al.*, 2010). *Punica granatum* has been grouped into two sub-species *Chlorocarpa*

and *Prophyrocarpa*, each having two assortments (Patil *et al.*, 2002). The cultivation of pomegranate is mainly confined to semi-arid, sub temperate to subtropical climate representing to Mediterranean countries, Afganistan, Iran, India, China, Japan and United States (Stover and Mercure, 2007).

In India, it is cultivated for domestic consumption as well as for export purpose, and the area under cultivation is 246 thousand hectares with a production of 2,865 thousand MT (Anonymous, 2018a). It is cultivated commercially only in Maharashtra. Small scale plantations are also seen in Gujarat, Rajasthan, Karnataka, Tamil Nadu, Andhra Pradesh, Uttar Pradesh, Punjab, Haryana and Himachal Pradesh. The state of Maharashtra accounts for 78 per cent of the total area and 84 per cent of the total production in the country. The various cultivars which have been recommended for commercial cultivation are Ganesh and Muscat in Maharashtra; Dholka in Gujarat; Jalore Seedless, Jodhpuri Red, Jodhpuri White and Seedless Bedana in Rajasthan; Bassein Seedless and Madhurigi in Karnataka; Chawla, Nabha, Country Large Red in Haryana and Srinagar Special in valley areas of Garhwal hills.

Pomegranate has wide range of adaptability as it can withstand heat, drought and salinity. Pomegranate growing areas in the world lie between latitude 41 °N and 42 °S (Hodgson, 1917). Pomegranate plant can withstand frost and can grow up to an altitude of 1600 meters above mean sea level (Rana and Dwivedi, 1997). Good quality pomegranate fruits are produced in Deccan Plateau having altitudes between 270-900 m above sea level (Chandra and Meshram, 2010). Pomegranate can withstand maximum temperature up to 45-48 °C. Fruit trees with the best quality fruits are provided in the zones with cold winters and blistering dry summers. In this manner, Himachal Pradesh has friendly atmosphere for pomegranate. The wild pomegranate, locally known as 'daru' has been found growing wild in the belts experiencing such a climate in Himachal Pradesh. However, the temperature remains below 40 °C during summer months. In Himachal Pradesh, pomegranate is being cultivated on 2,847 hectares with an annual production of 3,215 MT (Anonymous, 2018b). The pomegranate which has high market demand, longer time span of usability, flexible adaptability, strong nature, consistent and high return which gives better choice to stone fruits in the mid-hills of Himachal Pradesh (Patil *et al.*, 2004).

Combining ability studies are important to understand the cultivars or parent's ability to combine with each other during hybridization process. It ensures the nature and magnitude of different types of gene actions involved in the expression of quantitative traits. The term general combining ability is used to designate the average performance of a line in hybrid combination. The term specific combining ability is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of average performances of the lines involved (Sprague and Tatum, 1942). The phenotypic expression of any character is controlled by the genetic constitution of the plant and prevailing environmental conditions. Genetic variance of the quantitative traits is further composed of additive variance and non-additive variance which also includes non-allelic (dominance and epistasis) interactions.

Therefore, the present investigation entitled “Gene action and combining ability studies in Pomegranate (*Punica granatum* L.)” comprising five lines and two testers was carried out with the following objectives:

1. To assess general and specific combining ability of lines and testers for important horticultural traits
2. To estimate nature and magnitude of gene action

## *Chapter-2*

# REVIEW OF LITERATURE

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The literature available on various related aspects of present investigation entitled “**Gene action and combining ability studies in Pomegranate (*Punica granatum* L.)**” has been presented under following headings:

### **2.1 MEAN PERFORMANCES OF HYBRIDS**

#### **2.1.1 PLANT GROWTH CHARACTERISTICS**

Karale (1997) during his work on varietal improvement of *Punica granatum* by hybridization recorded significant differences in tree volume of hybrids. The range for this trait varied from 2.56 m<sup>3</sup> to 10.63 m<sup>3</sup>.

Varietal evaluation on nine cultivars of pomegranate conducted by Prasad and Bankar (2000), reported that the cultivars were significantly different for various plant traits viz., plant height and plant spread. The cultivar P-23 had maximum plant spread and plant height. The minimum plant spread and plant height was observed in cultivar GKVK-1.

Sharma and Bist (2005) evaluated eight pomegranate cultivars namely, Chawla, Anar Shirin Mohammad Ali, Jodhpur Red, Ganesh, Mridula, Kandhari Hansi, PS-75-K-5 and G-137 under mid-hills of Himachal Pradesh. They found maximum plant height and plant spread in Chawla cultivar whereas, minimum plant height and plant spread in PS-75-K-5.

Singh (2012) evaluated thirty genotypes of pomegranate germplasm at CIAH, Bikaner, Rajasthan. Plant height was recorded maximum in Khog (2.70 m) and minimum in Bedana Suri (1.70 m). The leaf length was maximum 8.20 cm in Kurvi-2EL-24685 and lowest 4.20 cm in Basein Seedless.

Wani *et al.* (2012) characterized thirty three wild accessions of pomegranate during 2009-2010. Pomegranate genotypes for their vegetative characters were significantly different as plant height ranged from 2.34 m in SKAU-Pg-Sr-001 to 4.78 m in SKA-Pg-Sr-012. The plant spread was maximum 2.47 m in SKAU-Pg-Sr-

005 and minimum 1.24 m in SKAU-Pg-Sr-010. For leaf area also those accessions varied significantly from 14.0 cm<sup>2</sup> (SKAU-Pg-Sr-004) to 7.48 cm<sup>2</sup> (SKAU-Pg-Sr-011).

Sinha (2014) studied exotic germplasm of pomegranate under conditions of Himachal Pradesh at Dr. YS Parmar University of Horticulture and Forestry, Solan. Maximum plant height was reported in Dewey (3.18 m) and minimum in 20090265 (1.35 m). The trunk girth was recorded maximum in Dewey (96.09 mm) and minimum in Purple Heart (20.11 mm).

Sharma (2019) on evaluation of F<sub>1</sub> hybrids reported that the hybrid Kandhari Kabuli × NT-1 was best hybrid for plant height, stem girth and plant spread. The plant height varied from 1.40 m to 3.83 m, stem girth from 20.36 mm to 45.66 mm, plant spread N-S from 0.44 m to 2.34 m and for E-W 0.41 m to 2.10 m. Whereas, for leaf area the range varied from 5.69 cm<sup>2</sup> to 16.58 cm<sup>2</sup>.

### **2.1.2 FLOWERING CHARACTERISTICS**

Chadha (1983) investigated seven cultivars of pomegranate at Bilaspur, Himachal Pradesh. He reported that the flowering in Russian cultivars started from first week of March and in Iranian cultivars from last week of February. The full bloom for all the cultivars was reported in first week of May except Anar Shirin Mohammad Ali for which it was observed in first three week of April. He also found that the range for duration of flowering vary between 37 days and 58 days.

Umrao and Singh (1995) evaluated evergreen cultivars viz., Ganesh and Dholka on the basis of their performance in central plains of Uttar Pradesh. They observed that Ganesh flowered throughout the year and Dholka flowered from February to October. However, the deciduous cultivars of pomegranate flowered from March to August.

Sinha (2014) evaluated exotic germplasm of pomegranate at Dr. YS Parmar University of Horticulture and Forestry, Solan. She recorded earliest flowering in genotype Orange and late in Haku-botan. Whereas, the date of opening of last flower was earliest in Paryfyanets and late in Haku-botan.

Sharma (2019) while studying F<sub>1</sub> hybrids of pomegranate reported that the time of full bloom started from the end of April and extended till third week of May. The duration of flowering varied between 48 days (Mridula × MH-1) and 63 days (NT-1 × Bhagwa).

### **2.1.3 FRUIT CHARACTERISTICS**

Karale (1997) conducted a study on varietal improvement by hybridization in pomegranate at MPKV, Rahuri, Maharashtra. He concluded that maximum TSS : acid ratio was recorded in G-137 × No. 408 and minimum in Ganesh × No. 177.

Poyrazoglu *et al.* (2002) carried out study on thirteen pomegranate cultivars. The range for total sugars varied from 139.60 to 160.60 g/l and titratable acidity ranged from 4.58 to 17.30 g/l in cultivars.

Sharma and Bist (2005) evaluated the fruit quality characteristics of nineteen wild pomegranate accessions from Gharsa and Nagar Valley Kullu and Lahul Spiti district of HP. The range for total soluble solids for these accessions varied from 10.30 °B to 12.80 °B and titratable acidity varied between 3.36 per cent to 4.24 per cent.

Kumar (2008) studied the standardization of maturity indices in pomegranate under mid hill conditions of HP. The days taken from full bloom to harvest was found maximum in Ganesh (127 to 155 days) and minimum in Kandhari Kabuli (122 to 150 days). He also reported maximum reducing sugars in Kandhari Kabuli. Significantly maximum non-reducing sugars was observed in Ganesh cultivar.

Akbarpour *et al.* (2009) studied chemical properties for twelve pomegranate cultivars from various regions of Iran. They revealed that total soluble sugars ranged from 15.17 °B to 22.03 °B and reducing sugars varied between 13.89 and 29.83 g/100ml.

Thakur *et al.* (2011) examined physico-chemical properties of wild pomegranate from different locations of Himachal Pradesh. The results revealed that the highest weight (83.50 g), highest length (62.80 mm) and maximum number of arils per fruit (372) were found in Bathri, Chamba while 53.40 g, 45.40 mm and 252

recorded as lowest fruit weight, length and number of arils per fruit, respectively in Darlaghat, Solan. The colour of arils was reported Red Purple (62A) in all locations.

Zaouay and Mars (2011) evaluated physico-chemical characteristics of thirteen cultivars of pomegranate grown in southern Tunisia. Among all the cultivars, the heaviest fruits and large size fruits were observed in CH8-2 cultivar having weight of 549.70 g and average size of 95.10 mm. The cultivar having smallest fruits was found to be in GSI with 101.3 g weight and 51.50 mm size.

Patil *et al.* (2013) analysed various physico-chemical properties of two varieties of pomegranate viz., Arakta and Ganesh. The results revealed that the aril colour in Arakta was blood red and pinkish in Ganesh cultivar. The average weight of fruit for Arakta and Ganesh was 252.40 g and 210.90 g, respectively.

Sinha (2014) examined twenty newly introduced pomegranate germplasm accessions at Dr. YSPUHF, Solan H.P. She found that total soluble solids ranged from 9.93 °B in Ovadan to 15.87 °B in Purple Heart. Total sugars were found maximum in Purple Heart (14.13%) and minimum in Ovadan whereas, reducing sugars ranged between 6.27 per cent in Saharnyi and 12.51 per cent in Purple Heart. She also reported maximum non-reducing sugars in Saharnyi (2.34%) and minimum in Haku-botan (1.04). The fruit yield was found maximum 13.60 kg/plant in Green Globe and minimum 1.11 kg/plant in Kaimanar.

Hmid *et al.* (2016) investigated various physical properties of fruits of eighteen cultivars of pomegranate collection at National Institute for Agricultural Research Experimental Station, Meknes-Morocco. The average fruit weight varied between 206.60 g in Chelfi and 506.67 g in Sefri 2. They found that the values for fruit length and fruit diameter ranged from 58.93 to 86.07 mm and 72.13 to 96.33 mm, respectively. The study also revealed that the seed colour varied from pink to dark red.

Wiyar *et al.* (2017) studied different physical characteristics of pomegranate cultivars grown in Afganistan. They reported that the average weight of fruit ranged from 608 g in MKS-5025 to 206 g in T-390. Similarly, the fruit length and diameter were found maximum in MKS-5025 and minimum in T-390. Whereas, the maximum number of arils having small seeds were observed in MS-384.

Sharma (2019) evaluated F<sub>1</sub> hybrids of pomegranate at Dr. YSPUHF, Solan. She observed that among all the hybrids G-137 × NT-1 had maximum fruit weight, fruit length, fruit diameter and number of arils per fruit. She also reported that Kandhari Kabuli × NT-1 had maximum value for biochemical characteristics except titratable acidity which was maximum for G-137 × MH-1. The fruit yield of hybrids ranged from 0.80 kg/tree to 2.82 kg/tree.

## 2.2 COMBINING ABILITY

The importance of combining ability was first realized by Richey and Mayer (1925) in inbreds of maize. Now a days, the concept of combining ability is being widely applied in most of the crop plants. In any crop, the success of hybrid is determined on the basis of its superiority than its parents and or the best local standards. Therefore, the study of combining ability is vital for the selection of superior parents for heterosis as well as recombination breeding programmes.

Griiffing (1956) developed different techniques for the estimation of GCA and SCA effect under different situations. He found that SCA includes dominance and epistasis whereas, GCA involves mostly additive effects and additive × additive type of epistasis. He further gave the concept of combining ability related to diallel crossing system and discussed the different analysis which resulted from combination of four different diallel crossing models.

Oydvin (1965) studied the inheritance of yield and berry size in five strawberry varieties. He noted that the cultivars ‘Abundance’, ‘Gorella’, ‘Senga Precosa’, ‘Senga Sengana’ and ‘Ydun’ gave significant difference in combining ability for yield, fruit size, number of fruits per plant when used as parents. He also reported that the cultivar ‘Ydun’ had greatest combining ability for yield, ‘Gorella’ for fruit size and ‘Abundance’ for number of fruits.

Sherman *et al.* (1966) studied the inheritance of fruit size in strawberry and found that when species of small fruited as tester was involved, the highest GCA effect was estimated from diallel analysis and when large fruited varieties were involved, SCA was predominant than GCA.

Spangelo *et al.* (1970) studied combining ability and interrelationships in six gooseberry (*Ribes grossularia*) progenies resulting from crossing of two thornless with three large-fruited cultivars at Research Station, Canada Department of Agriculture, Ottawa. Measurements for fruit yield and 100 berry weight were recorded for four consecutive years and for thorniness and plant height, it was recorded for one year. The results revealed that general combining ability effects in 'Captivator' as male parent for berry weight and fruit yield and 'Fredonia' as female parent for fruit yield were significant. The specific combining ability effects were significant for berry weight and fruit yield but the interactions with years were not significant. They also found general combining ability effects significant for thorniness.

Spangelo *et al.* (1971) studied general and specific combining ability in a diallel cross of eight cultivars of strawberry for total, marketable, early and late yield at Ottawa. The mean squares for general and specific combining ability were observed to be highly significant for traits under study thereby, indicating their importance in the expression of characters. Two cross combinations showed good marketable yield and total yield as a result of both general and specific combining ability effects.

Maclachlan (1974) in a study of inheritance of colour of fruit and the assessment of plants as sources of colour in the cultivated strawberry reported that GCA effects were more important than SCA effects in the inheritance of strawberry fruit colour.

Ulynkin *et al.* (1976) using diallel of six strawberry cultivars observed that general combining ability and specific combining ability effects were significant for fruit yield.

Visser (1976) analysed two incomplete half-diallel schemes at Institute for Horticultural Plant Breeding (IVT) Wageningen, the Netherlands for the comparison of juvenile period of apple and pear seedlings. They reported additive nature of inheritance for juvenile period as they observed significantly high general combining ability variance and non-significant specific combining ability variance.

Wenzel *et al.* (1976) evaluated strawberry varieties for breeding purpose. They reported that 'Parfaite' a cultivar which was superior for general combining abilities as well as specific combining abilities. They also revealed that the traits like yield, berry size and number of berries had additive variation in small amount.

Barritt (1979) estimated in his study that general combining ability effects were significant and higher than specific combining ability effects for all the characters but not for marketable yield of strawberry.

Ogol and Bayanova (1981) reported that the cultivars 'Senga Sengana', 'Purpurovaya' and 'Festiva Naya' had high GCA effects for various yield components and for breeding of large fruit cultivars 'Robinson', 'Purpurovaya' and 'Festiva Naya' were the best.

Lal and Seth (1982) studied combining ability in strawberry at Horticultural Experiments and Training Centre, Chaubattia, U.P. Ten cultivars of strawberry were crossed in full diallel mating design. They observed positive significant general combining ability effects in 'Albritton' designated as good general combiner for fruit weight, fruit size and also for fruit yield. For TSS highest GCA effects were reported in 'Kalompong Local' followed by 'Cavalier' therefore, found to be the best general combiners. The study also revealed that in  $F_1$  generation the cross 'Phenomenal'  $\times$  'Swiss Seedling' and in  $F_2$  'Torrey'  $\times$  'Albritton' had good specific combining ability effects for fruit weight. Whereas, Clark  $\times$  Captivator cross combination had the highest values for specific combining ability effects for fruit yield. The best specific combiners for fruit length in  $F_1$  was 'Premier'  $\times$  'Torrey' and in  $F_2$  was 'Swiss Seedling'  $\times$  'Cavalier'. For fruit diameter the best specific cross combiners were 'Redcoat'  $\times$  'Elista' and 'Premier'  $\times$  'Albritton' in  $F_1$  and  $F_2$  generation, respectively. For TSS some cross combinations also had positive significant specific combining ability effects. Variance due to GCA exceeded the variance due to SCA.

Zubov and Stankevich (1982) in a  $5 \times 5$  diallel crosses involving American and West European strawberry varieties studied different fruit quality traits in progenies and observed high GCA for Vitamin C in cultivar Fairfax and for fruit firmness. It was shown in cultivar Senga Sengana and Fairfax  $\times$  Senga Sengana, its reciprocal and Senga Sengana  $\times$  Redcoat were the best crosses.

Simpson and Sharp (1988) conducted an experiment on everbearing strawberry progeny developed from half diallel crossing scheme without selfs between three short-day (Cambridge Vigour, Gorella and Tioga) and four everbearing genotypes (Aromel, Gento, Sans Rivale and Rabunda) at Institute of Horticultural Research, East Malling, Maidstone, UK. The study was aimed to estimate the inheritance of fruit yield and stolon production in everbearing strawberries. They reported that GCA was found to be important for yield but SCA was more important for stolon production.

Hortynski (1989) observed that the varieties 'Merton Dawn' and 'Senga Tigaiga' had highest GCA effects for the yield, 'Merton Dawn' and 'Tioga' had highest GCA for the size of fruit and for fruit firmness highest GCA was found in 'Senga Tigaiga' and 'Tioga'. He also observed good SCA in cross combinations 'Senga Tigaiga' × 'Merton Dawn' and 'Senga Tigaiga' × 'Tioga'.

Bell and Janick (1990) studied general and specific combining ability for fruit quality traits in a pear breeding population at Beltsville. The study revealed that GCA variances were 4.5 to 12.0 times those for SCA variances, although both were statistically significant for all the traits and the weighted quality index.

Bell and Zimmerman (1990) studied combining ability at the Agricultural Research Station, Beltsville for transmission of juvenile period in a large pear breeding population by crossing 92 parents into 298 combinations. The results indicated that GCA was highly significant than SCA indicating additive genetic control in juvenile period length.

Erb *et al.* (1990) determined combining ability effects for six traits (plant size, berry size, the number of days between flowering and fruiting, the ratio of total fruit weight to canopy volume, days to fruit ripe and yield) in blueberry involving one high bush (*Vaccinium corymbosum* L.) clone and three interspecific hybrids at Beltsville. The crosses were attempted in 1982 in diallel fashion. In 1983 and 1984 all the parent and progeny plots were evaluated. In 1985 the parents and seedling of F<sub>1</sub> were evaluated. The study revealed that SCA effects were significant for plant size in 1983, days between flowering and fruiting, the ratio of total fruit weight to canopy volume in 1984 and berry size in 1985 and GCA effects were significant for all characters under study except yield and berry size in 1984.

Dinesh *et al.* (1992) at Indian Institute of Horticultural Research, Hesaraghatta, Bangalore compared the mean performance of parents and the general combining ability effects obtained by the diallel analysis for various plant, fruit and physicochemical characters of papaya. It was observed that the cultivar Coorg Honey Dew was the best combiner and the mean performance was high for yield and fruit weight. 'Sunrise Solo' had negative significant general combining ability effects therefore, referred as a best general combiner for plant height and 'Pink Flesh Sweet' had positive significant effects was a good general combiner for stem girth. They also found that there were some other cultivars which were observed to have high mean performance and good general combiners for characters: TSS Pink Flesh Sweet, Carotene Sunrise Solo and Waimanalo and fruit cavity index Pink Flesh Sweet, Sunrise Solo and Waimanalo.

Finn and Luby (1992) in blueberry studied the inheritance of fruit quality traits by using progenies from partial diallel mating scheme at Becker, Minnesota in which seventeen high bush (*Vaccinium corymbosum* L.), low bush (*V. Angustifolium* Ait.) and half-high (*V. Corymbosum/V. Angustifolium* hybrids) parents were evaluated for several traits like fruit color, picking scar and firmness. The results revealed that GCA mean squares were significant ( $P < 0.01$ ) for all traits and SCA was not significant for any trait ( $P > 0.05$ ). GCA effects depended to some extent on the species ancestry.

Simpson (1992) studied the inheritance of fruiting season in short-day strawberries at Horticulture Research International, East Malling, England. The results revealed that the general combining ability was significant for all the studied traits. The specific combining ability was also significant for all the characters except maturity time.

Topp *et al.* (1993) in a study conducted on five parent diallel in a greenhouse at Florida to estimate the general and specific combining ability effects for resistance of Japanese plum to *Xanthomonas campestris* pv. *pruni* dye stem canker, reported that 'Burbank', 'Wilson' and 'Wade' had similar GCA values for length of inoculated cankers and Wade was the best parent in transmitting canker resistance. They observed that SCA was not important in determining the performance of a cross. The highly significant GCA effect and non-significant SCA effect suggest that mean cross performance may be predicted by the average of the parental phenotypic values.

Dhaliwal and Lal (1996) carried out study using line  $\times$  tester mating design in muskmelon at PAU, Ludhiana. Eight economic characters contributing to earliness, fruit yield and sweetness were studied by using sixty F<sub>1</sub> hybrids which included three females and twenty males. Analysis of variance for combining ability revealed that MS due to GCA lines (except TSS%) GCA testers and SCA hybrids were highly significant for all the characters under study. Magnitude of GCA lines was greater as compared to the two other components. For TSS all the three lines were average combiners.

Karale (1997) at Mahatma Phule Krishi Vidyapeeth, Maharashtra carried out an investigation on varietal improvement of *Punica granatum* L. by hybridization. He observed that G-137 a female parent for diameter of fruit and fruit weight, P-26 also as a female parent for tree height and aril : rind ratio whereas, Ganesh for plant spread and tree volume were good general combiners. No. 303, No. 5 and No. 31 male parents for tree height, No. 219, No. 177 and No. 242 for plant spread (N-S) and tree volume, No. 379 for TSS, No. 408 for fruit weight and diameter of fruit were also good general combiners. He also found that for plant height of pomegranate negatively significant effects were desirable. All the lines and testers had non-significant general combining ability effects for TSS : acid ratio and also for aril : rind ratio. But the only line P-26 had significant general combining ability effects for aril : rind ratio. Whereas, the crosses Ganesh  $\times$  No. 303, G-137  $\times$  No. 462, were the best crosses having good specific combining ability for plant spread and tree volume. He also revealed that the cross P-26  $\times$  No. 177 was a best specific combiner for fruit length, fruit breadth and fruit weight. While, G-137  $\times$  No. 31, P-26  $\times$  No. 382 and P-26  $\times$  No. 379 had positive significant effects for aril : rind ratio.

Ahmed *et al.* (2003) studied combining ability and heterosis in line  $\times$  tester crosses of summer squash among fourteen hybrids resulting from crossing of seven lines with two testers at Sudan. The results revealed that the tester Whitaker had significant positive general combining ability which proved it to be good combiner for yield. Mean separation showed that five top crosses with respect to yield involved Whitaker as a common parent. Thus they can be used as high yielding commercial hybrids. They also found that none of the lines as well as testers showed significant GCA or SCA for plant size.

Rumpunen and Kviklys (2003) at Department of Crop Science, Balsgard investigated phenotypic variation and pattern of inheritance for plant and fruit traits in Japanese quince (*Chaenomeles japonica*) population consisting of fourteen hybrid families. The results revealed that GCA was significant for all investigated traits (five plant vegetative traits, eight fruit yield and morphological traits and five fruit biochemistry traits) and SCA was detected significant for yield, plant height and several fruit traits.

Chua (2005) studied combining ability and heterosis in strawberry at Dr YSPUHF, Solan, HP using a full diallel scheme of mating involving ten genetically different genotypes in two different ways referred as open pollinated population and self pollination population. He observed that a genotype named 'Selva' as a good general combiner due to its positive significant general combining ability effects in OP population for plant spread. He also found that 'Chandler', 'Belrubi' and 'Selva' as OP and SP population showed best general combining ability effects for leaf area. Whereas, 'Chandler' and 'Belrubi' in both OP and SP population population for fruit length and the parents 'Chandler' and 'Selva' in both the populations for fruit breadth had desirable significant general combining ability effects. The genotypes 'Belrubi' and 'Torrey' were good general combiners for titratable acidity and total sugars also. Among all the hybrids Fairfax × Chandler, Selva × Chandler, Tioga × Blakemore and Belrubi × Chandler in OP population and Seascape × Selva in SP population were the best specific combiners. Some cross combination had significant positive specific combining ability effects for plant spread, leaf area, fruit size, titratable acidity and total sugars also. A hybrid Seascape × Tioga of OP population had significant effects on both titratable acidity and total sugars. But all the ninety hybrids showed non-significant specific combining ability effects for plant height.

Masny *et al.* (2005) conducted combining ability analysis for fruit yield and fruit quality in everbearing strawberry cultivars using an incomplete diallel cross design at Poland. The general and specific combining ability effects differed for most of the traits. They found that cultivar Selva and Capitola had significantly positive general combining ability effect that would be useful for improving fruit weight, fruit size and fruit colour. Whereas, Selva was also found useful for improving yield, fruit size and fruit firmness. They also concluded that the cross combination had both

significantly positive specific combining ability effects negative specific combining ability effects for fruit weight and fruit yield.

Marin *et al.* (2006) in papaya evaluated the combining ability of eight genotypes from the 'Solo' group, crossed with eight genotypes from 'Formosa' group at Linhares, State of Espirito Santo, Brazil using a partial diallel scheme. They reported significant positive GCA in different genotypes for mean fruit weight and TSS. For plant height negative significant general combining ability effects are desirable and it was observed in some genotypes of 'Solo' group. While, SCA was found to be significantly positive in some hybrid combinations for fruit weight, TSS and total fruit yield.

Dossett *et al.* (2008) in black raspberry constructed an incomplete partial diallel consisting of ten parents and twenty six sibling families at Oregon State University, Corvallis for the study of variation and inheritance of phenological, vegetative and fruit chemistry traits. They found that general combining ability (GCA) effects were significant and larger than specific combining ability (SCA) effects for all traits except for fruit size. They observed that the parent NC 84-10-3 was a good general combiner and Mac Black was a poor general combiner for total soluble solids but the highest positive general combining ability effects were found in Mac Black for titratable acidity.

Ide *et al.* (2009) studied use of testers for combining ability and selection of papaya hybrids at Linhares, State of Espirito Santo. Twenty papaya hybrids were developed from the crossing of thirteen 'Solo' with tester 'Formosa' (JS-12) and seven 'Formosa' lines crossed with 'Solo' (SS72/12). They determined SCA for fourteen traits of papaya and observed that JS-12  $\times$  SS72/12, JS-12  $\times$  SaO Mateus and SS72/12  $\times$  Sekati were the genotypes with the best value of SCA for fruit quality and yield traits.

Lan-Ying *et al.* (2009) analysed combining ability of nut quality of walnut at Sichuan University of Agricultural, Yaan, Sichuan, China. Twenty four hybrid combinations which include four female parents (P<sub>11</sub> to P<sub>14</sub>) selected from Yunnan province and six male parents from *J. sigillata* (P<sub>21</sub> to P<sub>26</sub>) were picked from Sichuan province in China. They revealed that for nut weight and nut diameter the GCA values for P<sub>24</sub> was the highest and for kernel rate it was highest for P<sub>21</sub>. They also

concluded that the parents having low GCA effects may form a combination with higher SCA effects. Therefore, GCA and SCA had no connection as their effects being compared and the expressions of characters depend upon multiple factors.

Zeinanloo *et al.* (2009) in olive studied the combining ability for nine quantitative characters at Iran. The analysis of combining ability in relation to GCA effects of parents showed that almost all types of SCA effects were obtained from any kind of combination of GCA effects for quantitative characters. Performance of crosses was found to be independent of parental GCA status. Zard and Roghani cultivars were found to be good combiners mainly for the improvement of fruit weight, fruit width and fruit length. The crosses 'Lechino' × 'Manzanilla' and 'Balidi' × 'Manzanilla' had maximum significant positive specific combining ability effects for fruit weight and fruit size. The crosses that had significant positive SCA involved atleast one parent with GCA effect.

Glala *et al.* (2011) crossed six sweet melon inbred lines with three muskmelon inbred lines in a line × tester mating design at Egypt that resulted into eighteen hybrids. The three lines L1, L2 and L3 and two testers T1 and T3 were found good combining parents for the yield and fruit quality traits. They found that the crosses L3 × T2, L4 × T1 and L5 × T3 showed significant SCA effect for TSS and fruit yield, L2 × T1 for fruit yield.

Vivas *et al.* (2011) evaluated the use of tester to estimate combining ability and select hybrids resistance to fungal diseases. The results revealed that when tester 'JS12' was crossed with 'Sunrise Solo' and 'Kaphoro Solo PV', 'Maradol' with 'Caliman G' , 'Caliman AM' and 'Sunrise Solo PT' and tester 'Americano' with 'Caliman M5', 'Sunrise Solo', 'Baixinho de Santa Amalia' and 'Waimanalo', the combining ability was found negative for all traits.

Raju *et al.* (2012) in line × tester analysis revealed that the line EC 163663 for TSS, fruit juice and yield per plant, the line EC 338717 for plant height, rind thickness and days to 50 per cent flowering and the line EC 145057 for fruit weight, fruit length, fruit diameter and ascorbic acid content showed desirable significant GCA effects for these traits and among all the testers, Pusa Early Dwarf and Pusa Ruby were found to be good general combiners for plant height, days to 50 per cent flowering, fruit weight, fruit length, fruit volume, fruit diameter, rind thickness, fruit

juice, TSS, yield and seed content. On the basis of magnitude of SCA the hybrid EC 538735 × Marutham was found to be best performing for different traits like days to 50% flowering, fruit weight, fruit length, fruit diameter and fruit yield per plant and the hybrid EC 14507 × Pusa Ruby was best for fruit volume and rind thickness, EC 338714 × Pusa Ruby for more plant height and ascorbic acid content and EC145057 × Arka Sourabh for TSS, fruit juice (%).

According to line × tester analysis by Shende *et al.* (2012) involving 3 lines (CLN2762-A, CLN2498-D and CLN2777-C) and 3 testers (DVRT-2, BCT-53 and BCT-110). They concluded that CLN2498-D, CLN2762-A and BCT-110 were the best general combiners for fruit yield and component characters and the two hybrids CLN2498-D × DVRT-2 and CLN 2777-C × BCT-53 could be used commercially for high yield on the basis of their performance *per se*, heterosis manifested in them and the SCA effects.

Pluta *et al.* (2014) in a half diallel mating design involving 45 sibling families derived from ten parental cultivars of gooseberry studied the general and specific combining ability for plant vigour, plant habit and yield at Poland. They found that the cultivars ‘Pax’ and ‘Martlet’ had maximum positive significant general combining ability effects considered as good general combiners for fruit weight. Worcesterberry and White Smith were good combiners. It was also found that some crosses which showed good SCA effects ‘Pax’ × ‘Kamieniar’, ‘Captivator’ × ‘Niesluchowski’, ‘Niesluchowski’ × ‘Bieloruskij Sacharnyj’, and ‘Pax’ × ‘Worcesterberry’ were good specific cross combiners for fruit weight.

Masny *et al.* (2015) by using half diallel mating design conducted an experiment at the Research Institute of Horticulture in Skierniewice during 2011-2013 on thirteen dessert strawberry genotypes. The results revealed that highest general combining ability effects for fruit weight were observed in cultivars ‘Palomar’, ‘Figaro’, ‘Camarosa’ and ‘Elianny’. For soluble solid content the GCA effects were highest in ‘Palomora’ and ‘Figaro’ and for marketable yield it was highest for ‘Camarosa’ and ‘Charlotte’. Whereas, the four hybrids showed high positive specific combining ability effects.

Vilas *et al.* (2015) in a genetic analysis in tomato crossed 10 lines and 5 testers and revealed that among those lines EC 620533, EC 620391, EC620534 , BBWR-11-1 and BBWR-10-3-17 were the good general combiners and Punjab Chuhara, Arka Meghali and Palam Pink were the good general combiner among testers as they showed significant GCA effects for traits like number of branches per plant and total number of fruits per plant. Among 51 F<sub>1</sub> hybrids the best specific combiner of the above traits was BBWR-11-1 × Palam Pink.

Masny *et al.* (2016) estimated GCA and SCA of 13 strawberry cvs. for tolerance to leaf diseases during 2011-2013 at Research Institute of Horticulture in Skierniewice, Poland following diallel cross mating design. They found most significant positive GCA effects in cv. Salsa for low plant susceptibility to diseases whereas, lowest GCA effects were observed in cv. Alibon. The combination ‘Aromas’ × ‘Elianny’ was found to have significantly negative SCA effects for susceptibility of plant to strawberry leaf scorch and leaf spot.

Ciulca *et al.* (2017) studied combining ability for plant yield, fruit number per plant and fruit weight of strawberry in 30 hybrids of six parents at Romania. They observed that ‘Marmolada’ was a good general combiner for sugar content and fruit weight especially when used as female genitor. They also revealed that the crosses ‘Alba’ × ‘Onda’, ‘Al’ × ‘Mira’ and ‘Mrmolada’ × ‘Clery’ were best specific combiners for fruit weight. Whereas, ‘Mira’ × ‘Alba’, ‘Alba’ × ‘Clery’ and ‘Mira’ × ‘Marmolada’ were good specific combiners for total soluble solids.

Dishri *et al.* (2017) analysed the combining ability for yield and component traits in indeterminate tomato. They observed that the lines Solan Vajar, UHF-55 and EC-2791 were good general combiner for fruit yield, average fruit weight and number of fruits per cluster. The crosses Solan Vajar × EC-2791, UHF-55 × EC-2798 and EC-2791 × EC-29414 had high SCA effects for most of the traits including fruit yield per plant.

Reddy *et al.* (2017) evaluated 40 hybrids of tomato developed through 10 lines and 4 testers. The results depicted that the best general combiners for yield along with other traits were CO-3, Pant T-3 lines and Flawery testers, H-24 and H-86 and Flawery × Sel-7, Fla-7171 × Azad T-5, GT-20 × Azad T-5, CO-3 × Sel-7 and B-S-31-3 × H-24 were the most promising specific combiners for yield and other traits.

Savale and Patel (2017) observed in an investigation consisting of eight lines and four testers of tomato in line  $\times$  tester analysis and concluded that AVTO-7, JTL-12-12, AVTO-5, JT-3 and GT-2 were good general combiner for fruit yield and its contributing characters. The cross AVTO-5  $\times$  GT-2 had the significant highest SCA effect for titratable acidity, non-reducing sugar and for fruit yield also.

Masny *et al.* (2018) carried out study at Research Institute of Horticulture in Skierniewice, Poland on fifteen parental genotypes of blackcurrant to assess the breeding value which was based on the effects of general and specific combining abilities in terms of fruit yield and quality. The crosses were made by using 12 maternal and 3 paternal cultivars. It was found that the cultivars 'Ruben', 'Big Ben' and D13B/11 had significant positive GCA effect on fruit weight and fruit yield. For total soluble solids they observed that the maternal genotypes viz., 'Tines', 'Chereshnieva', 'Sofievskaia', 'Gofert', 'Titania' and 'Tihope' and paternal genotypes 'Ceres' and 'Saniuta' had positive significant values for general combining ability effects. Whereas, the positive value of SCA was estimated in eight cross combinations for two traits describing fruit yield and quality. They also reported 'Chereshnieva'  $\times$  'Saniuta' with positive significant GCA effects for fruit weight.

Soloklui *et al.* (2018) at Iran in a half diallel crossing scheme crossed five cultivars of Iranian pomegranate cultivars with total of 10 crosses and found that both general and specific combining ability were statistically significant. They also revealed that Poost Nazok Torosh Abarkuh had a highest positive GCA effects. Highest SCA effects were found from a cross between Poost Nazok Torosh Abarkuh and Malas Pishva Varamin.

Vieira *et al.* (2019) at Federal University of Lavras, south of the State of Minas Gerais, Brazil carried out an experiment to study the combining ability in strawberry population. They observed that among all the cultivars 'Camarosa' and 'Aromas' were the most propitious cultivars which can be used in commercial fruit production as parents. The cultivars which were selected for strawberry breeding on the basis of good general combining ability were 'Sweet Charlie' and 'Dover' for the taste of fruit.

### 2.3 GENE ACTION

Comstock *et al.* (1958) studied eight characters involving 40 parents and found that epistatic variance accounted for a sizeable part of the total genetic variance for size of plant, number of berries, average weight per berry and weight of berries per unit plot size, significant levels of additive and dominance variance were also observed.

Sherman *et al.* (1966) carried out study on strawberry fruit size of progenies of selfing, diallel cross and crosses of five varieties to varietal and species (*F. Virginiana*) testers. The results revealed that large amount of total genetic variance was due to the presence of considerable epistatic effects observed for fruit size and other characters.

Watkins and Spangelo (1968) studied the components of genetic variation in cultivated strawberry. They observed dominance, additive and epistatic components of genetic variance for marketable total early and late yields in the garden strawberry. They observed that the epistatic variance made up 12.4, 47.0, 30.0 and 37.2 per cent of total genetic variance for the four characters respectively whereas, the dominance variance for the four characters were 56.9, 18.8, 20.8 and 5.4 per cent respectively.

Watkins and Spangelo (1970) studied the components of genetic variance for plant survival and vigour of apple trees in a diallel mating design at Ottawa. It was observed that exploitation of additive variance helps to improve plant survival and change plant height for successive generations. It was also predicted that potential parents except for vigour in a population having a range of dwarfing abilities could be efficiently screened phenotypically.

Bedard (1971) during the study of components of genetic variance for 30 morphological and agricultural characters in strawberry revealed more significant non-additive variance for half of the characters than additive variance. In many of the cases, the main source of non-additive variance was epistasis.

Hortynski (1980) in his study on strawberry seedlings for variability and heritability of some quantitative characters estimated that both additive and non-additive gene effects were important but most of the yield components had large non-additive gene effects.

Ogol and Bayanova (1981) studied combining ability for various yield components of five strawberry varieties. The additive gene effects were observed because the cultivars 'Purple', 'Senga Sengana' and 'Festival' showed high GCA effects for various yield components.

Wasee *et al.* (1983) investigated inheritance of various characters in two papaya cultivars. They observed additive gene effects for various characters i.e. fruit shape, fruit weight, TSS and flesh thickness in papaya.

Singh and Jalikop (1986) in their studies on variability found that the additive gene action controlled traits viz., number of bunches per vine and berry weight of grapes.

Bell and Janick (1990) in quantitative genetic analysis of fruit quality in pear reported significant, but variable, amounts of additive genetic variance for fruit quality traits. Non-additive genetic factors (dominance and epistasis), as estimated by SCA, contributed significantly to the total variance but at lower level than genetic factors.

Erb *et al.* (1990) in their study on blueberry at Beltsville using diallel scheme of mating observed that for various traits under study, the general combining ability effects were higher than the specific combining ability effects for all the fruiting traits except for one total fruit weight. Therefore they reported the role of non-additive gene action for total fruit weight and additive gene action for all the other traits.

Dhaliwal and Lal (1996) carried out study on muskmelon involving three females and twenty males in a line  $\times$  tester mating design at PAU, Ludhiana. The material was evaluated in field conditions in randomized block design with three replications. They reported inheritance of characters (earliness, fruit yield, sweetness) were governed by both additive and non-additive gene effects.

Karale (1997) conducted study at MPKV, Maharashtra on pomegranate including four lines and thirteen testers. He concluded that the variance due to specific combining ability was larger than variance due to general combining ability for all the traits. He also reported more dominance variance than additive variance which indicated predominant role of non-additive gene action for all the traits.

Anido *et al.* (1998) studied the importance of non-additive gene action for vegetative characters, leaf number, leaf diameter and plant height in summer squash. They also reported that additive and non-additive gene action were important for fruit number.

Ahmed *et al.* (2003) conducted study to measure and evaluate additive and non-additive gene action in summer squash at Sudan involved in the expression of economically important quantitative traits. They observed that the ratio of  $^2GCA$  to  $^2SCA$  was less than one for the plant vigour and number of days of flowering which indicates the importance of non-additive gene action for these characters.

Rumpunen and Kviklys (2003) in a study of combining ability and pattern of inheritance for plant and fruit traits in Japanese quince reported that most of the traits under study were governed by additive gene action except some traits like yield, plant height and several fruit biochemistry traits which were governed by non-additive gene action.

Chua (2005) conducted an experiment on strawberry at Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan. He reported that most of the characters under study viz., plant spread, leaf area, fruit size, average fruit weight, fruit yield, TSS, titratable acidity and total sugars were governed by non-additive gene action whereas, plant height and fruit firmness were governed by additive gene action.

Masny *et al.* (2005) evaluated eight strawberry genotypes in an incomplete  $8 \times 8$  half diallel design at Poland to study the effect of gene action on fruit yield, fruit firmness and fruit colour. They observed that fruit colour and fruit firmness were mostly affected by additive genetic effects. Fruit yield was affected by non-additive genetic effects.

Marin *et al.* (2006) studied in papaya the combining ability for important economic traits at Brazil and observed involvement of both the additive genetic effects and non-additive genetic effects. Additive genetic effects were predominant for traits viz., mean fruit weight, plant height, soluble solid content of the fruit pulp and flavour assessment in case of the genotypes of 'Solo' group. For 'Formosa' group also additive genetic effects were popular for total fruit yield, mean fruit weight, soluble solid content of the fruit pulp and flavour assessment.

Dossett *et al.* (2008) using partial diallel mating scheme in black raspberry reported that the specific combining ability effects were higher than the general combining ability effects for fruit size. But for all the other studied traits the general combining ability effects were higher than the specific combining ability effects. It revealed the role of non-additive gene action for fruit size and additive gene action for the other traits.

Lan-Ying *et al.* (2009) analysed twenty four hybrid combinations using hybrid (*J.sigillata* × *J. regia*) 7926 (P<sub>11</sub>), (*J.sigillata* × *J. regia*) 8064 (P<sub>12</sub>), (*J. regia* × *J.sigillata*) 8034 (P<sub>13</sub>), (*J.sigillata* × *J. regia*) 7914 (P<sub>14</sub>) as female parent found from Yunnan province and six superior trees of *J. sigillata* as male parent were choosed from Sichuan province in China by following NCII biparental mating design. The male parents were represented by P<sub>21</sub> to P<sub>26</sub> respectively. The combining ability study for four traits viz., walnut diameter, weight, thickness and rate of kernel revealed significant additive and non-additive variation for all the characters, but the additive variation was observed to be predominant.

Zeinanloo *et al.* (2009) studied variance component and heritability of some fruit characters in olive at Iran. The study revealed the role of both additive and non-additive genetic effects played a role in the heritability of these characters. The quotients of the mean squares of the GCA and SCA effects ranged from 0.027 to 0.128, thereby indicating the preponderance of non additive effects over additive effects.

Gawronski (2011) carried out an investigation in strawberry using complete diallel design at University of Life Sciences in Lubin. They examined polygenic traits viz., number of inflorescences, time of flowering and ripening, average fruit weight, flowers per inflorescence, crowns, fruits and yield. The results revealed that all the characters were governed by non-additive genetic effects except ripening time, which was governed by additive genetic effects.

Gawronski and Hortynski (2011) in their study used hierarchic crossing design and estimated genetic control of quantitative characters of strawberry. They observed that both the additive genetic effects and non-additive genetic effects governed the evaluated traits (time of flowering, time of ripening, number of inflorescence, number

of stolons, number of fruits, average fruit weight and yield). But the non-additive genetic effects were predominate in governing the evaluated traits.

Glala *et al.* (2011) in line  $\times$  tester analysis reported that out of all the studied traits except fruit shape index non-additive genetic components of variance played important role. It was indicated by analysis of components of genetic variance and combining ability analysis. All the studied traits had variance ratio less than one except fruit shape index also indicated the predominant role of non-additive gene action.

Angadi *et al.* (2012) in combining ability studies for productivity related traits in tomato revealed that the characters viz., fruit cluster per plant, fruits per cluster average fruit weight locule per fruit, number of fruits per plant, fruit yield per plant , plant height , number of branches, pH of fruit juice, TSS, pericarp thickness, lycopene and shelf life had the influence of non-additive gene action. They also observed the preponderance of dominance variance because SCA was higher than GCA.

Katkar *et al.* (2012) in his study of combining ability analysis for yield, its contributing characters and fruit quality parameters of exotic tomato (*Solanum lycopersicum* L.) breeding lines observed that values of variances due to SCA was higher than GCA showed non-additive gene action in different traits like number of flowers per cluster, determination of days to flowering , pericarp thickness, TSS, pH of juice and fruit yield per plant and they also indicated presence of over dominance for these characters because the ratio of GCA/SCA was less than one.

The role of non-additive gene action was reported by Kumari and Sharma (2012) in tomato as indicated by  $\frac{2A}{2D}$  ratio for all the characters viz., days from anthesis to turning stage, days to first flowering, number of fruits per plant , number of fruits per cluster, average fruit weight, TSS, pericarp thickness, ascorbic acid content and fruit shape index.

Shende *et al.* (2012) in a line  $\times$  tester analysis of *Solanum lycopersicum* L. observed non-additive gene action for the traits like days to 50 per cent flowering, number of flowers per cluster, plant height, polar diameter, equatorial diameter, number of fruits per cluster, fruit weight, fruit yield per plant and titratable acidity. They found both additive and non-additive gene action in total soluble solids.

Pluta *et al.* (2014) in a randomized complete block design evaluated the gooseberry breeding lines for plant vigour, plant habit and yield at Poland. The material was generated by crossing 10 parental cultivars in a half-diallel mating design. The result revealed that additive effect played relatively minor role in genetic variation of these traits and non-additive effects are predominantly involved in the genetic variation.

Masny *et al.* (2015) evaluated thirteen genotypes of dessert strawberry in a half- diallel mating design at Skierniewice. They reported that both additive genetic effects and non-additive genetic effects played an important role in the determination of inheritance of majority of analyzed characters. But, in the inheritance of some characters viz., fruit weight, fruit firmness and soluble solid contents additive genetic effects had the predominant role.

Rao *et al.* (2016) carried out study in bell pepper with eleven lines and three testers for twelve quantitative and qualitative traits. They reported that the non-additive gene action was predominant as showed by variance due to SCA and GCA and they also found additive component significant.

Ciulca *et al.* (2017) carried out an evaluation to study the gene effects in 30 hybrids of strawberry for plant yield, fruits number per plant and fruit weight. They observed that although additive and non-additive gene action as well as the maternal effects were involved in the inheritance of the studied traits, but additive effects played the predominant role over the non-additive effects.

Saniya *et al.* (2017) conducted an experiment at Department of Fruit Science, College of Horticulture, Mandsaur, RVSKVV during 2015-2016 by using five genotypes of grape (Bangalore Blue, Arka Shyam, Country Bangalore, Medika and Pusa Navrang). They reported that most of the traits (number of berries per bunch, weight of bunch, days to ripening, yield per vine, juice %, TSS and acidity) under study were controlled by additive gene action.

Masny *et al.* (2018) conducted an experiment at Poland using fifteen parental genotypes of blackcurrant (*Ribes nigrum* L.).The study concluded that the traits fruit weight, fruit yield, the soluble solids and ascorbic acid contents were determined by both additive and non-additive genetic effects whereas, in the inheritance of two traits (fruit yield and fruit weight) the additive genetic effect played dominant role.

## Chapter-3

# MATERIALS AND METHODS

The present experiment entitled “**Gene action and combining ability studies in Pomegranate (*Punica granatum* L.)**” was carried out at Pomegranate Block of Department of Fruit Science, Dr Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (HP) during 2018-2019. The experimental area was at 31 °N latitude and 77 °E longitude with the elevation of 1220 m above mean sea level, having mild temperate climate. The material for present study consisted of ten hybrids obtained by crossing five varieties as female parents (lines) i.e. Mridula, G-137, Kandhari Kabuli, Bhagwa and Ganesh with the two wild pomegranate selections as male parents (testers) i.e. NT-1 (from Naina Tikker) and MH-1 (from Mehlog) using line × tester mating design during 2012-2013.

Sr. No.	Hybrid
1.	Mridula × NT-1
2.	Mridula × MH-1
3.	G-137 × NT-1
4.	G-137 × MH-1
5.	Kandhari Kabuli × NT-1
6.	Kandhari Kabuli × MH-1
7.	Bhagwa × NT-1
8.	Bhagwa × MH-1
9.	Ganesh × NT-1
10.	Ganesh × MH-1

### 3.1 OBSERVATIONS RECORDED

The following observations were recorded in three replications, consecutive to randomized complete block design.

#### 3.1.1 Plant growth characteristics

##### 3.1.1.1 Plant height

Skilled staff measured the plant height from ground level to the highest tip of plant, and was expressed in meters (m).

### 3.1.1.2 Plant spread

The spread of plant was measured by a calibrated staff in two directions i.e. North-South (N-S) and East-West (E-W) and the observations were recorded in meters (m).

### 3.1.1.3 Tree volume

The tree volume above ground per replication was calculated from the data on height and tree spread measurements following the methodology suggested by Westwood (1993) and was expressed in cubic meters (m<sup>3</sup>).

- The tree taller than its width (Prolate spheroid),  
Volume =  $\frac{4}{3} ab^2$
- The tree wider than its height (Oblate spheroid),  
Volume =  $\frac{4}{3} a^2b$

Where,

$$= 3.1416$$

$$a = 1/2 \text{ the major axis (height)}$$

$$b = 1/2 \text{ the minor axis (spread)}$$

### 3.1.1.4 Stem girth

Stems of plant having diameter greater than 2 cm were collectively measured using digital Vernier Callipers (Model No. CD-6"CS, Mitutoyo Corp. Japan) at 15 cm height from the ground level. Sum of all the stem diameters determined the cumulative stem girth of the plant in millimeter (mm).

### 3.1.1.5 Leaf area

It was measured by using digital leaf area meter (LICOR-model 3100A). The average area of total ten leaves was contemplated as one replication and three such replications were made. Thirty full sized and mature leaves were collected randomly from the perimeter of each hybrid plant in the month of July. It was expressed in square centimeter (cm<sup>2</sup>).

## 3.1.2 Flowering characteristics

### 3.1.2.1 Date of opening of first flower

The date recorded during the first flower opening in each F<sub>1</sub> hybrid plant.

### **3.1.2.2 Date of full bloom**

Date registered at the opening of above 75% flowers was considered as full bloom.

### **3.1.2.3 Date of opening of last flower**

The date was recorded at the opening of last flower in each F<sub>1</sub> hybrid plant.

### **3.1.2.4 Duration of flowering**

Days between the opening of first flower and the opening of last flower in each F<sub>1</sub> hybrid was recorded for duration of flowering.

## **3.1.3 Fruit characteristics**

### **3.1.3.1 Fruit weight**

It was estimated by taking average weight of the fruits in grams (three fruits per replication) of each F<sub>1</sub> hybrid.

### **3.1.3.2 Fruit size**

Size of fruit with regard to length and breadth, was computed with the help of digital vernier caliper and the values of length and breadth of fruits were expressed in centimeter (cm).

### **3.1.3.3 Fruit shape**

Different shapes in the representative fruit sample were observed visually following the descriptor (Anonymous, 2015).

### **3.1.3.4 Number of arils per fruit**

Number of arils per fruit was determined by counting average number of arils from representative sample of nine fruits in each F<sub>1</sub> hybrid (three fruits per replication).

### **3.1.3.5 Aril : rind ratio**

Aril : rind ratio was determined by dividing aril weight to rind weight of individual fruit of nine representative fruits (three fruits per replication) of each accession, followed by determining average for each accession.

### 3.1.3.6 Colour of aril

The colour of aril was determined by employing Colour Charts of the Royal Horticultural Society, London (Wilson, 1941).

### 3.1.3.7 Days from full bloom to harvest

Total number of days from date of full bloom to the date of maturity in each F<sub>1</sub> hybrid was calculated for days from full bloom to harvest.

### 3.1.3.8 Fruit yield

The average yield per plant was calculated in each F<sub>1</sub> hybrid and was expressed as kg/tree.

### 3.1.3.9 Total sugars

The content of total sugars in the fruits was determined by Lane and Eynon's volumetric method (A.O.A.C., 1980). The remaining extract from titratable acidity (200 ml) was taken and 10 ml of 45 per cent standard lead acetate was added. Ten minutes later, 10 ml of 22 per cent potassium oxalate was added in order to precipitate the excessive lead acetate; the volume was then made to 250 ml by distilled water followed by solution filtration. 5ml of concentrated HCl was added to 50 ml of the filtrate. The resulting solution was allowed to sit overnight for hydrolysis carried out at room temperature. The following day, excess amount of HCl was treated with saturated 1% NaOH to neutralize it, after which distilled water was added to make the final volume to 250 ml. The determination of total sugars was carried out by titration of boiling mixture of 5 ml each of Fehling A and Fehling B, along with the hydrolyzed solution by using methylene blue as an indicator. During the titration, appearance of brick red colour indicated the end point. The total sugars content was expressed as percentage of fresh weight of fruit pulp.

$$\text{Total sugars (\%)} = \frac{0.05 \times \text{Dilution}}{\text{Titre value} \times \text{Weight of sample taken} \times \text{Volume of aliquot taken}} \times 100$$

### 3.1.3.10 Reducing sugars

The remnant un-hydrolyzed solution attained after the total sugar estimation was titrated against boiling solution of 5 ml each of Fehling A and Fehling B using methylene blue as an indicator (A.O.A.C., 1980). The end point was marked when the

solution reached brick red colour. The reducing sugars content was expressed as percentage of fresh weight of fruit pulp.

$$\text{Reducing sugars (\%)} = \frac{0.05 \times \text{Dilution}}{\text{Titre value} \times \text{Weight of sample taken}} \times 100$$

### 3.1.3.11 Non-reducing sugars

The estimation of non-reducing sugars was done by subtracting the reducing sugars from total sugars and multiplying the difference with a standard factor i.e. 0.95. The results were demonstrated as per cent of non-reducing sugars by employing the formula:

$$\text{Non-reducing sugars (\%)} = (\text{Total sugars} - \text{Reducing sugars}) \times 0.95$$

### 3.1.3.12 Total soluble solids

Total soluble solids (TSS) content in fruit samples were measured with Erma Hand Refractometer (0-32 °Brix) by placing a drop of fruit juice squeezed (at full ripe stage) on its prism. The refractometer was standardised with distilled water prior using. After every test, the prism plate was cleaned with distilled water and wiped with a soft tissue. Ten readings from each sample were averaged and the results were expressed as °Brix.

### 3.1.3.13 Titratable acidity

25 g of fruit pulp was taken in an electric blender and homogenized thoroughly with distilled water and volume was increased to 250 ml. The contents were then filtered through Whatman No. 1 filter paper. The titration of 10 ml of the extract against 0.1 N NaOH solution using phenolphthalein as an indicator was carried out. The appearance of light pink colour marked the end point. The results were expressed as per cent of fresh weight of the fruit pulp. The remnant extract was used for estimation of sugars. Excess lead acetate was filtered. The volume was increased to 250 ml using distilled water. From this solution, 50 ml was kept for determining total sugars after that the titratable acidity was calculated:

$$\text{Titratable acidity (\%)} = \frac{\text{Titre value} \times \text{Normality of NaOH} \times \text{Volume made} \times \text{Equivalent weight of acid}}{\text{Volume of extract} \times \text{Weight of sample(g)} \times 1000} \times 100$$

### 3.1.3.14 TSS : acid ratio

TSS : acid ratio is determined by dividing the obtained value of total soluble solids to the titratable acidity of the fruit samples.

## 3.2 Statistical analysis

### 3.2.1 Analysis of variance

The data was analyzed by using this model as suggested by Panse and Sukhatme (1967):

$$Y_{ij} = \mu + g_i + r_j + e_{ij}$$

Where,

$Y_{ij}$  = Phenotypic observation of  $i^{\text{th}}$  entry grown in  $j^{\text{th}}$  replication

$\mu$  = General population mean

$g_i$  = Effect of  $i^{\text{th}}$  entry

$r_j$  = Effect of  $j^{\text{th}}$  replication

$e_{ij}$  = Error component

### Analysis of variance

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	Expected mean sum of squares
Replication (r)	r-1	$S_r$	$S_r/(r-1) = M_r$	$\sigma_e^2 + \sigma_g^2 \frac{1}{r}$
Genotypes (g)	g-1	$S_g$	$S_g/(g-1) = M_g$	$\sigma_e^2 + r \sigma_g^2$
Error (e)	(r-1) (g-1)	$S_e$	$S_e / (r-1) (g-1) = M_e$	$\sigma_e^2$

Where,

r = Number of replications

g = Number of genotypes

$S_r$  = Sum of squares due to replications

$S_g$  = Sum of squares due to genotypes

$S_e$  = Sum of squares due to error

$M_r$  = Mean sum of squares due to replications

$M_g$  = Mean sum of squares due to genotypes

$M_e$  = Mean sum of squares due to error

$\sigma_r^2$  = Variance due to replications

$\sigma_g^2$  = Variance due to genotypes

$\sigma_e^2$  = Error variance

The replication and genotype mean sum of square were tested against error mean square by 'F' test for (r-1), (r-1) (g-1) and (g-1), (r-1) (g-1) degree of freedom at P=0.05. The result of calculated F-value was compared with tabulated F-value. When F-test was found significant, critical difference was calculated to find out the superiority of one genotype over the others.

The standard error and critical differences were calculated as follows:

$$SE(m) \pm = \sqrt{\frac{M_e}{r}}$$

$$SE(d) \pm = \sqrt{\frac{2M_e}{r}}$$

$$CD_{0.05} = S.E. (d) \times t_{(0.05) (r-1) (g-1) df}$$

Where,

SE (m)  $\pm$  = Standard error of mean

SE (d)  $\pm$  = Standard error of difference

CD<sub>0.05</sub> = Critical difference at 5 per cent level of significance

### 3.2.2 Line x tester analysis

For Line x tester analysis, values of F<sub>1</sub> generation were arranged replication wise, and 10 crosses per trait were subjected to statistical analysis as per the model suggested by Kempthorne (1957) and the solved example given by Dabholkar (1992) as follows:

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$$

Where,

$Y_{ijk}$  = Value of the  $ijk^{th}$  observation of the cross involved  $i^{th}$  line and  $j^{th}$  tester in  $k^{th}$  replication

$\mu$  = General mean (an effect common to all hybrids in all replications)

$g_i$  = General combining ability (GCA) effect of  $i^{th}$  line

$g_j$  = General combining ability (GCA) effect of  $j^{th}$  tester

- $s_{ij}$  = Specific combining ability (SCA) effect of the cross involving  $i^{\text{th}}$  line and  $j^{\text{th}}$  tester  
 $e_{ijk}$  = Error associated with  $ijk$  observation  
 $i$  =  $i^{\text{th}}$  line (1, 2, 3...5)  
 $j$  =  $j^{\text{th}}$  tester (6 and 7)  
 $k$  =  $K^{\text{th}}$  replication (1, 2, 3)

### Analysis of variance for crosses and combining ability

Source of variation	d. f.	Sum of squares	Mean squares	Expected squares	mean
Replication	(r-1)	RSS	$M_r$	-	
Crosses	(fm-1)	CSS	$M_c$	-	
Lines	(f-1)	FSS	$M(f)$	$^2_{e+r} \quad ^2_{fm+rm} \quad ^2_f$	
Testers	(m-1)	MSS	$M(m)$	$^2_{e+r} \quad ^2_{fm+rf} \quad ^2_m$	
Line x tester	(f-1)(m-1)	FMSS	$M(fm)$	$^2_{e+r} \quad ^2_{fm}$	
Error	(fm-1)(r-1)	TSS-RSS-CSS	$M_e$	$^2_e$	
Total	(fmr-1)	TSS	-	-	

Where,

$$\text{RSS} = \text{Replication sum of squares} = \sum_{k=1}^r \frac{(x.k.)^2}{r} - \frac{x^2 \dots}{fmr}$$

$$\text{CSS} = \text{Crosses sum of squares} = \sum_{ij=1}^{fm} \frac{x^2 .ij.}{rf} - \frac{x^2 \dots}{fmr}$$

$$\text{FSS} = \text{Line sum of squares} = \sum_{i=1}^f \frac{x^2 .i.}{mf} - \frac{x^2 \dots}{fmr}$$

$$\text{MSS} = \text{Tester sum of squares} = \sum_{j=1}^m \frac{x^2 .j.}{rm} - \frac{x^2 \dots}{fmr}$$

$$\text{FMSS} = \text{Line x tester sum of squares} = \sum_{ij=1}^{fm} \frac{x^2 .ij.}{r} - \sum_{i=1}^f \frac{x^2 .i.}{mr} - \sum_{j=1}^m \frac{x^2 .j.}{fr} + \frac{x^2 \dots}{fmr}$$

$$\text{TSS} = \text{Total sum of squares} = \sum_{i=1}^f \sum_{j=1}^m \sum_{k=1}^r x^2 .ijk. - \frac{x^2 \dots}{fmr}$$

Where

f = Number of lines

m = Number of testers

x.k. = sum of  $k^{\text{th}}$  replication of crosses

x.. = Sum of all crosses of all lines and testers over all replications

xij. = Sum of  $ij^{\text{th}}$  hybrid combination over all replications

$x_{i..}$	=	Sum of $i^{\text{th}}$ line over all testers and replications
$x_{.j.}$	=	Sum of $j^{\text{th}}$ tester over all lines and replications
$x_{ijk}$	=	$ij^{\text{th}}$ observation in $k^{\text{th}}$ replication
$M(f)$	=	Mean sum of squares due to lines
$M(m)$	=	Mean sum of squares due to testers
$M(f \times m)$	=	Mean sum of squares due to line x tester interaction
$M_e$	=	Error mean squares
$\sigma_f^2$	=	Variance due to line/progeny variance arising from differences among female parents/ lines
$\sigma_m^2$	=	Variance due to testers/progeny variance arising from differences among male parents/ testers
$\sigma_{f \times m}^2$	=	Variance due to line x testers/progeny variance arising from interaction of the contribution of female and male parents
$\sigma_e^2$	=	Environmental variance/error variance among individuals from same mating

### 3.2.2.1 Estimation of general and specific combining ability effects

From the two way table consisting of female vs male parents GCA and SCA effects were attained in which each figure was total over replications. The individual effects were estimated as follow:

**(i) GCA effects of  $i^{\text{th}}$  line**

$$\hat{g}_i = \frac{x_{i..}}{mr} - \frac{x}{fmr}$$

**(ii) GCA effects of  $j^{\text{th}}$  tester**

$$\hat{g}_j = \frac{x_{.j.}}{fr} - \frac{x}{fmr}$$

**(iii) SCA effects of  $ij^{\text{th}}$  cross**

$$\hat{s}_{ij} = \frac{x_{ij}}{r} - \frac{x_{i..}}{mr} - \frac{x_{.j.}}{fr} + \frac{x_{...}}{fmr}$$

**(iv) Standard errors for different combining ability effects**

(a)  $SE(\hat{g}_i) \text{ lines} = \pm \sqrt{\frac{M_e}{mr}}$

$$(b) SE (\hat{g}_j) \text{ lines} = \pm \sqrt{\frac{M_e}{fr}}$$

$$(c) SE (\hat{s}_{ij}) \text{ lines} = \pm \sqrt{\frac{M_e}{r}}$$

$$(d) SE (\hat{g}_i - \hat{g}_j) \text{ lines} = \pm \sqrt{\frac{2M_e}{mr}} = SE (D_1)$$

$$(e) SE (\hat{g}_i - \hat{g}_j) \text{ lines} = \pm \sqrt{\frac{2M_e}{fr}} = SE (D_2)$$

$$(f) SE (\hat{s}_{ij} - \hat{s}_{kj}) \text{ crosses} = \pm \sqrt{\frac{2M_e}{r}} = SE (D_3)$$

**(v) Test of significance for GCA and SCA effects**

The two known methods for testing the significance for GCA and SCA effects:

**Method-I**

GCA and SCA effects  $[(SE_{g_i}/SE_{g_j}/SE_{g_{ij}}) \times 't'$  tabulated at error degree of freedom and  $P=0.05]$  were marked significant (\*).

**Method-II**

- (a)  $t_i$  (cal) for GCA of lines (females) =  $(g_i-0)/SE (g_i)$
- (b)  $t_j$  (cal) for SCA of testers (males) =  $(g_j-0)/SE(g_j)$
- (c)  $t_{ij}$  (cal) for SCA of crosses =  $(S_{ij}-0)/SE(S_{ij})$

Where,

$t_i$  (cal),  $t_j$  (cal) and  $t_{ij}$  (cal) are the calculated 't' values

$g_i$  = GCA effect of  $i^{th}$  lines

$g_j$  = GCA effect of  $j^{th}$  tester

$S_{ij}$  = SCA effect of  $ij^{th}$  cross

The GCA effect of lines and testers and SCA effects of crosses were marked significant (\*) when the values of  $t_i$  (cal),  $t_j$  (cal) and  $t_{ij}$  (cal) 't' tabulated value at error degree of freedom and  $P=0.05$ .

**(vi) Critical differences (CD) for comparing GCA effects of lines/testers and SCA effect of crosses**

- (a) CD for GCA (lines) = SE (D1) × 't' tab (error df, P=0.05)  
 (b) CD for GCA (testers) = SE (D2) × 't' tab (error df, P=0.05)  
 (c) CD for GCA (crosses) = SE (D3) × 't' tab (error df, P=0.05)

The difference between GCA of any two lines/testers and SCA of any two crosses were respective CD values.

**3.2.2.2 Estimation of variance components**

The variance components were determined by covariance of full sib and half sibs as suggested by Singh and Chaudhary (1977) and Dabholkar (1992) as follows:

$$\begin{aligned} \text{Cov (Hs)} &= \sigma_f^2 \text{ (females)} = (\text{Mf}-\text{Mfm})/\text{mr} \\ \text{Cov (Hs)} &= \sigma_m^2 \text{ (males)} = (\text{Mm}-\text{Mfm})/\text{fr} \\ \sigma_{\text{fm}}^2 \text{ (females x males)} &= \sigma_{\text{SCA}}^2 = (\text{Mfm}-\text{Me})/\text{r} \end{aligned}$$

**i. Estimation of Cov Hs (average) and Cov (FS)**

These were calculated as:

$$\begin{aligned} \text{Cov Hs (average)} &= (\text{m} \sigma_f^2 + \text{f} \sigma_m^2) / (\text{f} + \text{m}) \\ \text{Cov (FS)} &= \sigma_{\text{fm}}^2 + 2\text{Cov (HS)} \end{aligned}$$

These can also be calculated from the expectation of mean squares as:

$$\begin{aligned} \text{Cov Hs (average)} &= (\text{Mf} + \text{Mm} - 2\text{Mfm}) / \text{r} (\text{f} + \text{m}) \\ \text{Cov Hs (Fs)} &= [\text{Mf} + \text{Mm} + \text{Mfm} - 3 \text{Me} + 6\text{r Cov (Hs)} - \text{r} (\text{f} + \text{m})\text{Cov (HS)}] / 3\text{r} \end{aligned}$$

**ii. Estimation of GCA and SCA variances**

From the estimates of Cov (Hs) and Cov (FS), variances due to general combining and specific combining ability were calculated as:

$$\begin{aligned} \sigma_{\text{GCA}}^2 = \text{Cov (HS)} &= \frac{(\text{Mf} + \text{Mm} - 2\text{Mfm})}{\text{rE} (\text{f} + \text{m})} \\ \sigma_{\text{SCA}}^2 = \text{Cov(FS)} - 2\text{Cov (HS)} &= \frac{(\text{mfm} - \text{Me})}{\text{r}} \end{aligned}$$

### iii. Estimation of additive ( $\sigma^2_A$ ) and dominance ( $\sigma^2_D$ ) component of variances

For measuring the additive and dominance components of variances following formulae have been used (Singh and Choudhary, 1977 and Dabholkar, 1992):

$$\begin{aligned} \sigma^2_{GCA} &= [(1+F)/4] \sigma^2_A = 1/2 \sigma^2_A \\ S_o \sigma^2_A &= 2 \sigma^2_{GCA} \\ \sigma^2_{SCA} &= [(1+F)/2]^2 \sigma^2_D = \sigma^2_D \\ S_o \sigma^2_D &= \sigma^2_{SCA} \end{aligned}$$

Where,

$$\begin{aligned} F &= \text{Inbreeding coefficient} \\ \sigma^2_A &= \text{Additive variance} \\ \sigma^2_D &= \text{Dominance variance} \end{aligned}$$

#### 3.2.2.3 Per cent contribution of lines, testers and their interactions

These were computed as per the formulae suggested by Singh and Chaudhary (1977):

$$\begin{aligned} \text{(i) Per cent contribution of lines} &= \frac{SS(\text{lines})}{SS(\text{crosses})} \times 100 \\ \text{(ii) Per cent contribution to testers} &= \frac{SS(\text{testers})}{SS(\text{crosses})} \times 100 \\ \text{(iii) Per cent contribution of line x tester} &= \frac{SS(\text{lines} \times \text{testers})}{SS(\text{crosses})} \times 100 \end{aligned}$$

Where,

$$\begin{aligned} SS(\text{lines}) &= \text{Sum of squares due to lines} \\ SS(\text{testers}) &= \text{Sum of squares due to testers} \\ SS(\text{lines} \times \text{testers}) &= \text{Sum of squares due to lines x testers} \end{aligned}$$

## *Chapter-4*

# **RESULTS AND DISCUSSION**

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The present investigation entitled “**Gene action and combining ability studies in Pomegranate (*Punica granatum L.*)**” was carried out at Experimental Farm, Department of Fruit Science, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, H.P. during 2018-2019. The experimental material consisted of ten cross combinations resulted from crosses among five lines and two testers using Line  $\times$  Tester mating design (Kempthorne, 1957). The study was aimed to test the general combining ability of the parents, the specific combining ability of the crosses and nature of gene action based on combining ability variances with respect to various plant growth, flowering and fruit characteristics. The results thus obtained are presented under appropriate headings.

### **4.1 STUDIES ON MEAN PERFORMANCES**

#### **4.1.1 PLANT GROWTH CHARACTERISTICS**

##### **4.1.1.1 Plant height**

The mean performance of ten crosses for plant height has been given in table 4.1. Among the crosses, it ranged from 2.02 m to 3.61 m. The hybrid Kandhari Kabuli  $\times$  NT-1 recorded maximum plant height of 3.61 m. It was statistically at par with Mridula  $\times$  NT-1 (3.26 m), Kandhari Kabuli  $\times$  MH-1 (3.21 m), Bhagwa  $\times$  NT-1 (3.12 m) and Ganesh  $\times$  NT-1 (3.07 m). The minimum value for this trait was recorded in G-137  $\times$  MH-1.

These observations are in consonance with the previous studies carried by Prasad and Bankar (2000), Sharma and Bist (2005), Wani *et al.* (2012), Sinha (2014) and Sharma (2019) for plant height in different cultivars of pomegranate who also reported a wide variation among different genotypes.

##### **4.1.1.2 Plant spread**

Among the ten hybrids, Kandhari Kabuli  $\times$  NT-1 reported highest value for plant spread i.e 2.04 m in N-S direction followed by Mridula  $\times$  MH-1, Ganesh  $\times$  MH-

1 and Kandhari Kabuli × MH-1. The lowest value for plant spread in N-S direction was reported in Bhagwa × MH-1 i.e. 0.80 m. The maximum value for plant spread in E-W direction was recorded in Kandhari Kabuli × NT-1 (1.92 m) which is statistically at par with Mridula × MH-1 (1.58 m) and the minimum value for this trait was recorded in Bhagwa × MH-1 (0.48 m).

The present findings for plant spread are in agreement with those of Prasad and Bankar (2000), Sharma and Bist (2005), Wani *et al.* (2012), Sinha (2014) and Sharma (2019) in pomegranate.

#### **4.1.1.3 Tree volume**

Maximum tree volume was (7.46 m<sup>3</sup>) recorded in Kandhari Kabuli × NT-1 followed by Mridula × MH-1 and Ganesh × MH-1. It ranged from 0.51 m<sup>3</sup> to 7.46 m<sup>3</sup> and the minimum 0.51 m<sup>3</sup> was recorded in Bhagwa × MH-1. It was observed that all the hybrids were statistically different.

The findings in present study are supported by Karale (1997) in pomegranate for this trait.

#### **4.1.1.4 Stem girth**

The highest value for stem girth was observed 36.64 mm in Kandhari Kabuli × NT-1 followed by 27.35 mm in Bhagwa × MH-1, 26.83 mm in Ganesh × NT-1 and 24.65 mm in Mridula × MH-1. Kandhari Kabuli × NT-1 was statistically superior to other crosses. The lowest value for stem girth was observed 21.35 mm in G-137 × NT-1.

These findings of stem girth are in line with the observations of Sinha (2014) and Sharma (2019).

#### **4.1.1.5 Leaf area**

The values for leaf area ranged from 15.08 cm<sup>2</sup> to 8.59 cm<sup>2</sup>. The maximum leaf area was reported in Bhagwa × MH-1 and it was significantly at par with Bhagwa × NT-1 and Mridula × NT-1. The minimum leaf area was reported in Ganesh × NT-1.

These results are further corroborated by the findings of Wani *et al.* (2012) and Sharma (2019).

**Table 4.1 Mean performance of hybrids for various plant growth traits in pomegranate**

Hybrid (s)	Plant height (m)	Plant spread (m)		Tree volume (m <sup>3</sup> )	Stem girth (mm)	Leaf area (cm <sup>2</sup> )
		N-S	E-W			
Mridula × NT-1	3.26	1.07	1.21	2.22	24.06	13.67
Mridula × MH-1	2.91	1.36	1.58	3.33	24.65	11.25
G-137 × NT-1	2.85	0.85	0.84	1.10	21.35	11.09
G-137 × MH-1	2.02	0.81	0.91	0.78	24.37	11.16
Kandhari Kabuli × NT-1	3.61	2.04	1.92	7.46	36.64	12.34
Kandhari Kabuli × MH-1	3.21	1.38	1.17	2.81	23.73	8.95
Bhagwa × NT-1	3.12	0.95	1.42	2.32	23.77	14.33
Bhagwa × MH-1	2.20	0.80	0.48	0.51	27.35	15.08
Ganesh × NT-1	3.07	1.17	1.08	2.07	26.83	8.59
Ganesh × MH-1	2.88	1.38	1.23	3.17	24.60	11.98
<b>S.E. <math>\pm</math> (m)</b>	<b>0.23</b>	<b>0.18</b>	<b>0.13</b>	<b>0.68</b>	<b>1.97</b>	<b>0.49</b>
<b>S.E. <math>\pm</math> (d)</b>	<b>0.32</b>	<b>0.26</b>	<b>0.19</b>	<b>0.96</b>	<b>2.79</b>	<b>0.70</b>
<b>C.D. (0.05)</b>	<b>0.68</b>	<b>0.54</b>	<b>0.40</b>	<b>2.02</b>	<b>5.90</b>	<b>1.48</b>

## **4.1.2 FLOWERING CHARACTERISTICS**

### **4.1.2.1 Date of opening of first flower**

Data in Table 4.2 indicates that the opening of first flower was earliest in Mridula × NT-1 on 14<sup>th</sup> of April followed by Ganesh × NT-1, G-137 × MH-1 and Bhagwa × NT-1. Whereas, G-137 × MH-1 was the last in opening of first flower on 24<sup>th</sup> of April.

Further to it, Sinha (2014) and Sharma (2019) also observed similar trend in date of opening of first flower.

### **4.1.2.2 Date of full bloom**

Date of full bloom varied between 26<sup>th</sup> of April and 13<sup>th</sup> of May. It was earliest for Mridula × NT-1 and last for G-137 × MH-1 and Bhagwa × MH-1. These findings got the support of Chadha (1983) and Sharma (2019) for full bloom.

### **4.1.2.3 Date of opening of last flower**

The date of opening of last flower was recorded as earliest (11<sup>th</sup> of June) in Mridula × MH-1, Bhagwa × NT-1 and Bhagwa × MH-1 and latest (20<sup>th</sup> of June) in G-137 × MH-1.

The same trend for date of opening of last flower was also reported in the work of Sinha (2014) and Sharma (2019).

### **4.1.2.4 Duration of flowering**

Duration of flowering ranged from 52.33 days to 59.33 days. The longest duration was recorded in Mridula × NT-1 and it was shortest for Mridula × MH-1. Among various hybrids for duration of flowering the results showed non-significant effects.

The results are in close contiguity with the observations of Chadha (1983), Umrao and Singh (1995) and Sharma (2019).

**Table 4.2 Mean performance of hybrids for various flowering traits in pomegranate**

<b>Hybrid (s)</b>	<b>Date of opening of first flower</b>	<b>Date of full bloom</b>	<b>Date of opening of last flower</b>	<b>Duration of flowering</b>
Mridula × NT-1	14/4/19	26/4/19	13/6/19	59.33
Mridula × MH-1	19/4/19	5/5/19	11/6/19	52.33
G-137 × NT-1	16/4/19	3/5/19	14/6/19	58.67
G-137 × MH-1	24/4/19	13/5/19	20/6/19	56.00
Kandhari Kabuli × NT-1	18/4/19	6/5/19	10/6/19	52.67
Kandhari Kabuli × MH-1	19/4/19	11/5/19	15/6/19	56.33
Bhagwa × NT-1	17/4/19	8/5/19	11/6/19	55.00
Bhagwa × MH-1	18/4/19	13/5/19	11/6/19	53.67
Ganesh × NT-1	16/4/19	3/5/19	14/6/19	58.00
Ganesh × MH-1	23/4/19	7/5/19	17/5/19	54.33
<b>S.E. <math>\pm</math> (m)</b>				<b>1.83</b>
<b>S.E. <math>\pm</math> (d)</b>				<b>2.59</b>
<b>C.D. (0.05)</b>				<b>NS</b>

### **4.1.3 FRUIT CHARACTERISTICS**

#### **4.1.3.1 Fruit weight**

Maximum fruit weight was found in G-137 × NT-1 having 266.17 g average weight followed by Bhagwa × NT-1. The minimum value for this trait was recorded in Mridula × MH-1 (102.36 g). It was revealed that all the hybrids were significantly different.

Present results of fruit weight are found similar with the findings obtained by Wiyar *et al.* (2017), Hmid *et al.* (2016) and Sharma (2019).

#### **4.1.3.2 Fruit size**

Maximum fruit length (7.69 cm) was observed in G-137 × NT-1 followed by Bhagwa × NT-1, Kandhari Kabuli × MH-1 and G-137 × MH-1 with the analogous values of 6.96, 6.63 and 6.38 cm, respectively. However, minimum (5.58 cm) was recorded in Bhagwa × MH-1. Fruit breadth was recorded maximum (8.01 cm) in G-137 × NT-1 which was statistically at par with Bhagwa × NT-1 (7.63 cm) while, minimum (5.87 cm) was in Bhagwa × MH-1.

The results are in consonance with the findings of Wiyar *et al.* (2017), Hmid *et al.* (2016) and Sharma (2019) for fruit size.

#### **4.1.3.3 Fruit shape**

Fruit shape was observed as ovate in Bhagwa × MH-1 and oval in Ganesh × NT-1. All the other hybrids had round shaped fruits.

For this trait, present observations are found in agreement with the findings of Sharma (2019).

#### **4.1.3.4 Number of arils per fruit**

The count of number of arils per fruit varied between 456.67 in G-137 × NT-1 and 167.67 in Mridula × MH-1.

Similar results and variation in number of arils per fruit were also reported by Sharma (2019).

**Table 4.3 Mean performance of hybrids for various fruit traits in pomegranate**

Hybrid (s)	Fruit weight (g)	Fruit size		Fruit Shape
		Fruit length (cm)	Fruit breadth (cm)	
Mridula × NT-1	139.28	6.14	6.46	Round
Mridula × MH-1	102.36	5.71	5.91	Round
G-137 × NT-1	266.17	7.69	8.01	Round
G-137 × MH-1	144.45	6.38	6.68	Round
Kandhari Kabuli × NT-1	132.88	6.17	6.48	Round
Kandhari Kabuli × MH-1	124.80	6.63	6.92	Round
Bhagwa × NT-1	208.69	6.96	7.63	Round
Bhagwa × MH-1	105.67	5.58	5.87	Ovate
Ganesh × NT-1	124.82	5.76	6.05	Oval
Ganesh × MH-1	123.62	5.65	6.12	Round
<b>S.E. <math>\pm</math> (m)</b>	<b>7.09</b>	<b>0.18</b>	<b>0.18</b>	
<b>S.E. <math>\pm</math> (d)</b>	<b>10.03</b>	<b>0.26</b>	<b>0.26</b>	
<b>C.D. <sub>(0.05)</sub></b>	<b>21.24</b>	<b>0.55</b>	<b>0.55</b>	

#### **4.1.3.5 Aril : rind ratio**

Maximum aril : rind ratio (1.12) was observed in G-137 × NT-1 and minimum (0.89) was in Bhagwa × NT-1. The results also showed the non-significant effect among different hybrids.

Sinha (2014) also reported aril : rind ratio in the same range in different genotypes of pomegranate.

#### **4.1.3.6 Colour of arils**

The aril colour of all the fruits of hybrids belongs to Red group having little differences in the shade. Mridula × NT-1 having colour similar to Red Group (43 C), (45 A) in fruits of Mridula × MH-1, (37 D) in G-137 × NT-1, (37 B) in G-137 × MH-1, (42 B) in Kandhari Kabuli × NT-1, (42 C) in Kandhari Kabuli × MH-1, (45 B) in Bhagwa × NT-1, (46 B) in Bhagwa × MH-1, (40 C) in Ganesh × NT-1, (39 B) in Ganesh × MH-1.

For colour of arils, similar observations and variations have also been recorded by Thakur *et al.* (2011), Patil *et al.* (2013), Hmid *et al.* (2016) and Sharma (2019).

#### **4.1.3.7 Days from full bloom to harvest**

Days from full bloom to harvest ranged from 106.67 days to 93.00 days. Maximum days from full bloom to harvest were recorded in Ganesh × NT-1 which was statistically at par with Mridula × NT-1 (105.67 days). G-137 × MH-1 observed minimum days from full bloom to harvest.

The findings are in accordance with the studies carried by Sinha (2014) and Sharma (2019) for days from full bloom to harvest.

#### **4.1.3.8 Fruit yield**

Fruit yield ranged from 2.62 kg/tree which was maximum in G-137 × NT-1 to 0.99 kg/tree in Bhagwa × MH-1. The fruit yield for G-137 × NT-1 was statistically at par with Bhagwa × NT-1.

These findings are supported by the work of Sinha (2014) and Sharma (2019) in various cultivars and hybrids of pomegranate.



**MRIDULA × NT-1**



**MRIDULA × MH-1**

**Plate 1. Fruit and aril characteristics of hybrids of pomegranate**



**G-137 × NT-1**



**G-137 × MH-1**

**Plate 2. Fruit and aril characteristics of hybrids of pomegranate**



**KANDHARI KABULI × NT-1**



**KANDHARI KABULI × MH-1**

**Plate 3. Fruit and aril characteristics of hybrids of pomegranate**



**BHAGWA × NT-1**



**BHAGWA × MH-1**

**Plate 4. Fruit and aril characteristics of hybrids of pomegranate**



**GANESH × NT-1**



**GANESH × MH-1**

**Plate 5. Fruit and aril characteristics of hybrids of pomegranate**

**Table 4.4 Mean performance of hybrids for various fruit traits in pomegranate**

<b>Hybrid (s)</b>	<b>Number of arils per fruit</b>	<b>Aril : rind ratio</b>	<b>Colour of aril</b>	<b>Days from full bloom to harvest</b>	<b>Fruit yield (kg/tree)</b>
Mridula × NT-1	302.67	0.97	Red Group 43 C	105.67	1.38
Mridula × MH-1	167.67	0.97	Red Group 45 A	99.00	1.14
G-137 × NT-1	456.67	1.12	Red Group 37 D	99.00	2.62
G-137 × MH-1	328.00	0.96	Red Group 37 B	93.00	1.47
Kandhari Kabuli × NT-1	268.67	1.04	Red Group 42 B	101.67	1.31
Kandhari Kabuli × MH-1	276.67	0.92	Red Group 42 C	98.33	1.32
Bhagwa × NT-1	332.33	0.89	Red Group 45 B	101.33	2.45
Bhagwa × MH-1	363.00	0.98	Red Group 46 B	101.00	0.99
Ganesh × NT-1	280.00	1.00	Red Group 40 C	106.67	1.32
Ganesh × MH-1	181.33	1.06	Red Group 39 B	99.67	1.52
<b>S.E. <math>\pm</math> (m)</b>	<b>15.94</b>	<b>0.05</b>		<b>1.59</b>	<b>0.13</b>
<b>S.E. <math>\pm</math> (d)</b>	<b>22.55</b>	<b>0.08</b>		<b>2.25</b>	<b>0.19</b>
<b>C.D. (0.05)</b>	<b>47.73</b>	<b>NS</b>		<b>4.77</b>	<b>0.39</b>

#### **4.1.3.9 Total sugars**

Highest total sugars content was observed as 10.99 per cent in Kandhari Kabuli × NT-1 and lowest as 7.57 per cent in G-137 × MH-1. It was reported that Kandhari Kabuli × NT-1 was statistically at par with 10.58 per cent in Bhagwa × MH-1 and 10.46 per cent in Bhagwa × NT-1.

These findings are supported by the work of Sinha (2014) and Sharma (2019) in various cultivars and hybrids of pomegranate.

#### **4.1.3.10 Reducing sugars**

Reducing sugars was maximum 8.29 per cent in Kandhari Kabuli × NT-1 and minimum 6.08 per cent in G-137 × MH-1. Kandhari Kabuli × NT-1 was statistically at par with Bhagwa × MH-1 and Bhagwa × NT-1.

Akabarpour *et al.* (2009), Sinha (2014) and Sharma (2019) have also observed similar results for reducing sugars in pomegranate.

#### **4.1.3.11 Non-reducing sugars**

The non-significant effects among various hybrids was reported for this trait. Maximum non-reducing sugars was observed 2.57 per cent in Kandhari Kabuli × NT-1 and minimum 1.42 per cent in G-137 × MH-1.

The findings of present study are in line with the results obtained by Sinha (2014) and Sharma (2019) during their research work on pomegranate.

#### **4.1.3.12 Total soluble solids**

Total soluble solids recorded highest 13.57 °B in Kandhari Kabuli × NT-1 which was significantly superior. It was followed by Bhagwa × MH-1 (12.6 °B) and Bhagwa × NT-1 (12.53 °B). Total soluble solids was reported lowest 11.47 °B in Mridula × NT-1.

The observations of TSS are in conformity with the results of Sharma and Bist (2005), Sinha (2014) and Sharma (2019).

**Table 4.5 Mean performance of hybrids for various bio-chemical traits in pomegranate**

<b>Hybrid (s)</b>	<b>Total sugars (%)</b>	<b>Reducing sugars (%)</b>	<b>Non-reducing sugars (%)</b>	<b>TSS (°B)</b>	<b>Titrateable acidity (%)</b>	<b>TSS : acid ratio</b>
Mridula × NT-1	8.21	6.60	1.52	11.47	2.54	4.54
Mridula × MH-1	8.46	6.18	2.17	11.8	2.05	5.77
G-137 × NT-1	9.51	7.08	2.31	12.43	1.99	6.25
G-137 × MH-1	7.57	6.08	1.42	11.67	1.97	5.95
Kandhari Kabuli × NT-1	10.99	8.29	2.57	13.57	1.32	10.56
Kandhari Kabuli × MH-1	9.67	7.15	2.40	12.40	1.47	8.45
Bhagwa × NT-1	10.46	8.04	2.30	12.53	1.43	8.78
Bhagwa × MH-1	10.58	8.15	2.31	12.6	1.39	9.06
Ganesh × NT-1	8.39	6.48	1.82	11.97	2.15	5.57
Ganesh × MH-1	9.04	6.80	2.13	12.30	1.83	6.75
<b>S.E. ± (m)</b>	<b>0.38</b>	<b>0.23</b>	<b>0.40</b>	<b>0.25</b>	<b>0.08</b>	<b>0.45</b>
<b>S.E. ± (d)</b>	<b>0.53</b>	<b>0.33</b>	<b>0.57</b>	<b>0.35</b>	<b>0.12</b>	<b>0.63</b>
<b>C.D. (0.05)</b>	<b>1.13</b>	<b>0.70</b>	<b>NS</b>	<b>0.74</b>	<b>0.24</b>	<b>1.34</b>

#### **4.1.3.13 Titratable acidity**

It is revealed from Table 4.5 that the highest acidity was reported in Mridula × NT-1 (2.54 per cent) followed by Ganesh × NT-1 (2.15 per cent) and Mridula × MH-1 (2.05 per cent). The lowest titratable acidity was reported in Kandhari Kabuli × NT-1 (1.32 per cent). It was observed that titratable acidity of all the crosses was statistically different.

The results for titratable acidity are in close proximity with those of Poyrazoglu *et al.* (2002) and Sharma and Bist (2005).

#### **4.1.3.14 TSS : acid ratio**

TSS : acid ratio ranged from 10.56 as maximum in Kandhari Kabuli × NT-1 and 4.54 as minimum in Mridula × NT-1. It was found that TSS : acid ratio of all the hybrids was significantly different.

These observations are in agreement with the results of Karale (1997) in pomegranate.

## **4.2 STUDIES ON COMBINING ABILITY**

The knowledge about the combining ability of the parents and crosses, the type of gene action and the genetic components of variance are effective in improvement of polygenic traits which is of great importance to the breeder. Choosing the parents on the basis of adoption, performance and genetic variability is a common approach which does not always lead to useful results because the differential ability of parents depends upon the complex interactions among the genes and cannot be judged by the alone performance (Allard, 1960). Combining ability analysis, partitions phenotypic variance among progeny means into components due to additive contributions of individual parents (general combining ability), and the variance due to interactions among parents (specific combining ability), can estimate the relative breeding value of the parents. The information which can be used in various breeding programmes is collected by the study on general and specific combining ability and the parents which perform very well in cross combinations are of great benefit to the breeders. The results could be used in assessing the efficacy of alternate selection strategies and in selecting parents for future crosses.

#### **4.2.1 Analysis of variance for experimental design**

The analysis of variance for randomized block design (Appendix-I) revealed significant differences for most of the traits under study except duration of flowering, aril : rind ratio and non-reducing sugars.

#### **4.2.2 Analysis of variance for combining ability**

A perusal of analysis of variance for combining ability (Appendix-II) showed significant differences among maximum crosses for majority of the characters studied except duration of flowering, aril : rind ratio and non-reducing sugars. Sum of square of crosses were further partitioned into lines, testers and line  $\times$  tester interactions. The results for mean sum of squares due to lines followed the same trend as that of crosses. The mean sum of squares due to testers were significant for the traits under study except plant spread (N-S), stem girth, leaf area, duration of flowering, aril : rind ratio, total sugars, non-reducing sugars, TSS and TSS : acid ratio. In case of line  $\times$  tester interaction the mean sum of square was significant for traits except plant height, plant spread (N-S), duration of flowering, aril : rind ratio, days from full bloom to harvest and non-reducing sugars.

The magnitude of mean sum of squares due to lines was higher for the traits plant spread in N-S and E-W direction, tree volume, stem girth, leaf area, aril : rind ratio, total sugars, reducing sugars, non-reducing sugars, TSS, titratable acidity, TSS : acid ratio as compared to the mean sum of squares due to testers which revealed that the lines had more diversity in comparison to testers. The remaining traits such as plant height, duration of flowering, fruit weight, fruit length, fruit breadth, number of arils per fruit, days from full bloom to harvest and fruit yield had more diversity in testers as compared to the lines. Line  $\times$  tester interactions compared to lines and testers were of lower magnitude for most of the traits except plant spread (E-W), stem girth, aril : rind ratio, non-reducing sugars, thereby, revealed preponderance of additive genetic variance in the lines and testers used in this study.

#### **4.2.3 Estimates of general combining ability (GCA) effects of parents**

General combining ability effects estimates of parents are given in Table 4.6, 4.7 and 4.8 and described below trait wise:

#### **4.2.3.1 Plant height**

Among the lines, G-137 (-0.48) was categorized as good general combiner as negative general combining ability effects are desirable for this trait. Whereas, Kandhari Kabuli (0.50) indicated poor general combining ability due to significant positive general combining ability effects. The lines Mridula (0.17), Bhagwa (-0.25) and Ganesh (0.06) had non-significant general combining ability effects, therefore observed average general combining ability. For plant height, both the testers MH-1 (-0.27) and NT-1 (0.27) exhibited good general combining ability and poor general combining ability due to negative significant general combining ability effect and positive significant general combining ability effect, respectively.

Negative significant general combining ability effects for plant height has also been reported by Dinesh *et al.* (1992) in papaya, Karale (1997) in pomegranate and Marin *et al.* (2006) in papaya.

#### **4.2.3.2 Plant spread**

The positive significant general combining ability effects for plant spread was observed in Kandhari Kabuli N-S direction (0.53) and E-W direction (0.36), Mridula (0.21) for E-W direction and these two lines were designated as good general combiners. The lines G-137 (-0.35 and -0.31) and Bhagwa (-0.31 and -0.24) had significant negative general combining ability effects for plant spread in N-S and E-W direction respectively, revealed as poor general combiners. The line Ganesh was reported as average general combiners due to non-significant general combining ability effects.

Both the testers showed non-significant general combining ability effects in N-S direction, considered as average general combiners. In E-W direction, tester NT-1 (0.11) was a good general combiner (positive significant general combining ability effects), whereas, tester MH-1 (-0.11) was considered as poor general combiner (negative significant general combining ability effects).

The results depicted for plant spread are in line with Karale (1997) for pomegranate and Chua (2005) for strawberry.

**Table 4.6 Estimates of general combining ability effects of parents for different plant growth traits in pomegranate**

Parent (s)	Plant height (m)	Plant spread (m)		Tree volume (m <sup>3</sup> )	Stem girth (mm)	Leaf area (cm <sup>2</sup> )	Duration of flowering
		N-S	E-W				
<b>Line(s)</b>							
Mridula	0.17	0.03	0.21*	0.20	-1.38	0.62	0.20
G-137	-0.48*	-0.35*	-0.31*	-1.63*	-2.87*	-0.72*	1.70
Kandhari Kabuli	0.50*	0.53*	0.36*	2.56*	4.45*	-1.20*	-1.13
Bhagwa	-0.25	-0.31*	-0.24*	-1.16*	-0.18	2.86*	-1.30
Ganesh	0.06	0.09	-0.03	0.04	-0.02	-1.56*	0.53
<b>Tester(s)</b>							
NT-1	0.27*	0.04	0.11*	0.46*	0.80	0.16	1.10
MH-1	-0.27*	-0.04	-0.11*	-0.46*	-0.80	-0.16	-1.10
<b>S.E. (gi) (lines)</b>	<b>0.14</b>	<b>0.12</b>	<b>0.09</b>	<b>0.43</b>	<b>1.25</b>	<b>0.31</b>	<b>1.16</b>
<b>S.E. (gj) (testers)</b>	<b>0.07</b>	<b>0.06</b>	<b>0.04</b>	<b>0.21</b>	<b>0.62</b>	<b>0.16</b>	<b>0.58</b>
<b>C.D. (gi) (lines)</b>	<b>0.30</b>	<b>0.24</b>	<b>0.18</b>	<b>0.90</b>	<b>2.62</b>	<b>0.66</b>	<b>2.44</b>
<b>C.D. (gj) (testers)</b>	<b>0.15</b>	<b>0.12</b>	<b>0.09</b>	<b>0.45</b>	<b>1.31</b>	<b>0.33</b>	<b>1.22</b>

\*Significant at 5% level of significance

#### **4.2.3.3 Tree volume**

Significant positive general combining ability effects was observed in Kandhari Kabuli (2.56), it was designated to be good general combiner for tree volume. On the contrary, the lines G-137 (-1.63) and Bhagwa (-1.16), exhibited negative general combining ability effects, observed to be poor general combiners. The remaining lines Mridula (0.20) and Ganesh (0.04) exhibited average general combining ability due to their non-significant general combining ability effects. Among the testers, NT-1 (0.46) showed significant positive general combining ability effects, therefore, considered to be a good combiner. Negative general combining ability effects for another tester MH-1 (-0.46) indicated it as poor combiner.

The observations for tree volume confirm the results of Karale (1997) in pomegranate that the parents had significant positive general combining ability effects.

#### **4.2.3.4 Stem girth**

For stem girth, line Kandhari Kabuli (4.45) indicated as good general combiners due to significant positive general combining ability effects, whereas, lines G-137 (-2.87) had significant negative general combining ability effects which revealed poor general combining ability. The lines Mridula (-1.38), Bhagwa (-0.18) and Ganesh (-0.02) showed non-significant general combining ability effects and hence, represented as average general combiners. Of the testers; NT-1 (0.80) and MH-1 (-0.80) were average general combiners for stem girth because of non-significant effects.

The present results are in agreement with the work of Dinesh *et al.* (1992) who studied combining ability effects on the basis of mean performance in papaya for stem girth.

#### **4.2.3.5 Leaf area**

Out of seven parents, one female parent viz., Bhagwa (2.86) considered as good general combiner due to significant general combining ability effects in positive direction whereas, three female parent G-137 (-0.72), Kandhari Kabuli (-1.20) and Ganesh (-1.56) had negative significant general combining ability effects indicated

poor general combining ability. Mridula is one female parent which showed average general combining ability (non-significant general combining ability effects). Non-significant general combining ability effects observed in both the male parents indicated them as average general combiners.

These observations are in line with Chua (2005) who also revealed similar results pertaining to combining ability in strawberry.

#### **4.2.3.6 Duration of flowering**

Duration of flowering showed non-significant general combining ability effects for all the lines and testers therefore, all of them were identified as average general combiners.

Sharma (2019) reported indistinguishable results for pomegranate as the duration of flowering ranges from 63 days of NT-1 × Bhagwa to 48 days of Mridula × MH-1.

#### **4.2.3.7 Fruit weight**

Data on general combining effects revealed that two lines viz., G-137 (58.04) and Bhagwa (9.91) were good general combiners as they had positive significant general combining ability effects. The other three lines Mridula (-26.45), Kandhari Kabuli (-18.43) and Ganesh (-23.06) showed significant general combining ability effects in negative direction, indicated as poor general combiners. Testers NT-1 (27.09) and MH-1 (-27.09) showed positive significant general combining ability effects and negative significant general combining ability effects respectively hence, revealed NT-1 as good general combiner and MH-1 as poor general combiner for fruit weight.

The findings of various workers Spangelo *et al.* (1970) in gooseberry, Lal and Seth (1982) in strawberry, Dinesh *et al.* (1992) in papaya, Karale (1997) in pomegranate, Masny *et al.* (2005) in strawberry, Marin *et al.* (2006) in papaya, Pluta *et al.* (2014) in gooseberry and Masny *et al.* (2018) in blackcurrant were also matched with the recent observations for this trait.

#### **4.2.3.8 Fruit size**

Of the five lines and two testers used in genetic analysis in the present study for fruit length of pomegranate fruits, line G-137 (0.77) and tester NT-1 (0.28) had significant general combining ability effects in positive direction indicated good general combining ability. The lines Mridula (-0.34) and Ganesh (-0.56) and tester MH-1 (-0.28) had negative significant general combining ability effects showed poor general combining ability. For fruit breadth, line G-137 (0.73) and tester NT-1(0.31) represented good general combining ability on accounting significant positive general combining ability effects and significant negative general combining ability effects as revealed by two lines Mridula (-0.43) and Ganesh (-0.53) and tester MH-1 (-0.31) indicated them as poor general combiners. The remaining lines viz; Kandhari Kabuli and Bhagwa were average general combiners (non-significant general combining ability effects) for fruit length and fruit breadth.

The results are in conformity with the findings of Karale (1997) in pomegranate, Lal and Seth (1982) in strawberry, Chua (2005) in strawberry and Zeinanloo *et al.* (2009) in olive.

#### **4.2.3.9 Number of arils per fruit**

Among the lines, significant positive general combining ability was found for number of arils per fruit in G-137 (96.63) and Bhagwa (51.97) therefore, these two lines were good general combiners. The lines Mridula (-60.53), Kandhari Kabuli (-23.03) and Ganesh (-65.03) had significant negative general combining ability effects, thereby indicating poor general combiners. Among testers NT-1 (32.38) exhibited significant positive and MH-1 (-32.38) significant negative general combining ability effects, hence depicted as good and poor general combiners, respectively.

The findings are in accordance with Sharma (2019) as the number of arils per fruit were highest in G-137 × NT-1 and it was lowest in Mridula × MH-1.

#### **4.2.3.10 Aril : rind ratio**

The perusal of data showed non-significant general combining ability effects for all the lines and testers used in line × tester mating design for genetic analysis,

indicated that all the five lines and two testers were average general combiners for this trait.

Karale (1997) in his study on pomegranate also observed non-significant general combining ability effects for aril : rind ratio with an exception of line P-26 having significant general combining ability effects.

#### **4.2.3.11 Days from full bloom to harvest**

Among the five lines, the line G-137 (-4.53) was found to be a good general combiner due to negative significant general combining ability effects because for days of full bloom to harvest negative general combining ability effects are desirable. On the contrary, Ganesh (2.63) had significant positive general combining ability effects indicated poor general combining ability and the remaining three lines were average general combiners for this trait. Among testers, the tester MH-1 (-2.33) was rated as good general combiner (significant negative general combining ability effects) and tester NT-1 as a poor general combiner (significant positive general combining ability effects).

Sharma (2019) recorded similar results for number of days from full bloom to harvest as it ranged from 90 to 112 days.

#### **4.2.3.12 Fruit yield**

For fruit yield, significant positive general combining ability effects were exhibited by line G-137 (0.49) and tester NT-1 (0.26) were appointed as good general combiners. On the other hand, lines Mridula (-0.29) and Kandhari Kabuli (-0.24) and tester MH-1 (-0.26) registered significant negative general combining ability effects represented poor general combining ability. The remaining two lines Bhagwa (0.17) and Ganesh (-0.13) were represented as average general combiner due to non-significant general combining ability effects in case of fruit yield.

The results of present study on the fruit yield are supported by Spangelo *et al.* (1970) for gooseberry, Lal and Seth (1982) for strawberry, Dinesh *et al.* (1992) for papaya, Masny *et al.* (2005) for strawberry, Marin *et al.* (2006) for papaya and Masny *et al.* (2018) for blackcurrant.

**Table 4.7 Estimates of general combining ability effects of parents for different fruit traits in pomegranate**

Parent (s)	Fruit weight (g)	Fruit size		Number of arils per fruit	Aril : rind ratio	Days from full bloom to harvest	Fruit yield (kg/tree)
		Fruit length (cm)	Fruit breadth (cm)				
<b>Line (s)</b>							
Mridula	-26.45*	-0.34*	-0.43*	-60.53*	-0.02	1.80	-0.29*
G-137	58.04*	0.77*	0.73*	96.63*	0.05	-4.53*	0.49*
Kandhari Kabuli	-18.43*	0.13	0.09	-23.03*	-0.01	-0.53	-0.24*
Bhagwa	9.91*	0.004	0.14	51.97*	-0.06	0.63	0.17
Ganesh	-23.06*	-0.56*	-0.53*	-65.03*	0.04	2.63*	-0.13
<b>Tester (s)</b>							
NT-1	27.09*	0.28*	0.31*	32.38*	0.01	2.33*	0.26*
MH-1	-27.09*	-0.28*	-0.31*	-32.38*	-0.01	-2.33*	-0.26*
<b>S.E. (gi) (lines)</b>	<b>4.49</b>	<b>0.12</b>	<b>0.12</b>	<b>10.08</b>	<b>0.03</b>	<b>1.01</b>	<b>0.08</b>
<b>S.E. (gj) (testers)</b>	<b>2.24</b>	<b>0.06</b>	<b>0.06</b>	<b>5.04</b>	<b>0.02</b>	<b>0.50</b>	<b>0.04</b>
<b>C.D. (gi) (lines)</b>	<b>9.43</b>	<b>0.25</b>	<b>0.25</b>	<b>21.18</b>	<b>0.07</b>	<b>2.12</b>	<b>0.17</b>
<b>C.D. (gj) (testers)</b>	<b>4.71</b>	<b>0.13</b>	<b>0.13</b>	<b>10.59</b>	<b>0.04</b>	<b>1.06</b>	<b>0.09</b>

\*Significant at 5% level of significance

#### **4.2.3.13 Total sugars**

For total sugars, the lines Kandhari Kabuli (1.05) and Bhagwa (1.23) reported significant positive general combining ability effect indicating good general combining ability and the lines Mridula (-0.96), G-137 (-0.75) and Ganesh (-0.57) showed negative significant general combining ability effects therefore, designated as poor general combiners. For this trait both the testers NT-1 (0.23) and MH-1 (-0.23) had non-significant general combining ability effects and hence, considered as average general combiners.

Similar to present results Chua (2005) reported significant positive general combining ability effects of parents for total sugars in strawberry.

#### **4.2.3.14 Reducing sugars**

The lines Kandhari Kabuli (0.63) and Bhagwa (1.01) were designated as good general combiners as they showed significant positive general combining ability effects whereas, the lines Mridula (-0.69), G-137 (-0.51) and Ganesh (-0.45) reported negative significant general combining ability effects indicating poor general combining ability. Among testers, NT-1 (0.22) was found to be a good general combiner due to positive general combining ability effects and as negative significant general combining ability effects was observed in tester MH-1 (-0.22) exhibited poor general combining ability for this trait.

Sharma (2019) at Dr YSPUHF, Nauni, Solan also recorded similar results for this trait, as Kandhari Kabuli  $\times$  NT-1 had maximum value for reducing sugars.

#### **4.2.3.15 Non-reducing sugars**

For non-reducing sugars, all the lines and testers were considered as average general combiners because of non-significant general combining ability effects.

The maximum per cent of non-reducing sugars was also reported in Kandhari Kabuli  $\times$  NT-1 by Sharma (2019).

#### **4.2.3.16 Total soluble solids**

Kandhari Kabuli (0.71) was found to be a good general combiner, because of positive general combining ability effects and Mridula (-0.64) was designated as poor general combiner due to negative significant general combining ability effects. The

remaining lines had non-significant general combining ability effects hence, designated as average general combiners for total soluble solids. For this trait, both the testers showed non-significant general combining ability effects therefore, displayed as average general combiners.

The observation are in conformity with Lal and Seth (1982), Dinesh *et al.* (1992), Karale (1997), Marin *et al.* (2006), Dossett *et al.* (2008) and Masny *et al.* (2018) in different fruit crops. They also reported significant positive general combining ability effects for total soluble solids.

#### **4.2.3.17 Titratable acidity**

The significant positive general combining ability effects were recorded in lines Mridula (0.48), G-137 (0.17) and Ganesh (0.18) and tester NT-1 (0.07) exhibited good general combining ability. The lines Kandhari Kabuli (-0.42) and Bhagwa (-0.40) and tester MH-1 (-0.07) showed significant negative general combining ability effects exhibited poor general combining ability for this trait.

Chua (2005) in strawberry and Dossett *et al.* (2008) in black raspberry also reported positive general combining ability effects in different parents for titratable acidity.

#### **4.2.3.18 TSS : acid ratio**

Out of seven parents, two female parents Kandhari Kabuli (2.34) and Bhagwa (1.75) exhibited positive significant general combining ability effects therefore, identified as good general combiners. The remaining 3 female parents Mridula (-2.01), G-137 (-1.07) and Ganesh (-1.01) were identified as poor general combiners due to significant negative general combining ability effects. Both the male parents (testers) recorded non-significant general combining ability effects and hence, were designated as poor general combiners.

The results are in contradiction with Karale (1997), as the general combining ability effects were found non-significant for TSS : acid ratio in pomegranate. However, the positive and significant TSS : acid ratio in the present study may be due the dominant effect of testers (Daru), which had higher value for this trait.

**Table 4.8 Estimates of general combining ability effects of parents for different bio-chemical traits in pomegranate**

<b>Parent (s)</b>	<b>Total sugars (%)</b>	<b>Reducing sugars (%)</b>	<b>Non-reducing sugars (%)</b>	<b>TSS (°B)</b>	<b>Titrateable acidity (%)</b>	<b>TSS : acid ratio</b>
<b>Line (s)</b>						
Mridula	-0.96*	-0.69*	-0.25	-0.64*	0.48*	-2.01*
G-137	-0.75*	-0.51*	-0.23	-0.22	0.17*	-1.07*
Kandhari Kabuli	1.05*	0.63*	0.39	0.71*	-0.42*	2.34*
Bhagwa	1.23*	1.01*	0.21	0.29	-0.40*	1.75*
Ganesh	-0.57*	-0.45*	-0.12	-0.14	0.18*	-1.01*
<b>Tester (s)</b>						
NT-1	0.23	0.22*	0.01	0.12	0.07*	-0.03
MH-1	-0.23	-0.22*	-0.01	-0.12	-0.07*	0.03
<b>S.E. (gi) (lines)</b>	<b>0.24</b>	<b>0.15</b>	<b>0.25</b>	<b>0.16</b>	<b>0.05</b>	<b>0.28</b>
<b>S.E. (gj) (testers)</b>	<b>0.12</b>	<b>0.07</b>	<b>0.13</b>	<b>0.08</b>	<b>0.03</b>	<b>0.14</b>
<b>C.D. (gi) (lines)</b>	<b>0.50</b>	<b>0.31</b>	<b>0.53</b>	<b>0.33</b>	<b>0.11</b>	<b>0.59</b>
<b>C.D. (gj) (testers)</b>	<b>0.25</b>	<b>0.16</b>	<b>0.27</b>	<b>0.17</b>	<b>0.05</b>	<b>0.30</b>

\*Significant at 5% level of significance

#### **4.2.4 Estimates of specific combining ability (SCA) effects of crosses**

##### **4.2.4.1 Plant height**

For this trait all the cross combinations exhibited non-significant specific combining ability effects considered them as average specific cross combiners.

These findings are in accordance with Chua (2005) in strawberry, as he also observed non-significant specific combining ability effects for plant height in all the ninety hybrids.

##### **4.2.4.2 Plant spread**

The positive significant specific combining ability effects were estimated in Kandhari Kabuli  $\times$  NT-1 (0.30) in N-S direction and Mridula  $\times$  MH-1 (0.29), Kandhari Kabuli  $\times$  NT-1 (0.26), Bhagwa  $\times$  NT-1 (0.36) and Ganesh  $\times$  MH-1 (0.18) in E-W direction resulted as good specific cross combinations. On the contrary, Kandhari Kabuli  $\times$  MH-1 (-0.30) in N-S direction and Mridula  $\times$  NT-1 (-0.29), Kandhari Kabuli  $\times$  MH-1 (-0.26), Bhagwa  $\times$  MH-1 (-0.36) and Ganesh  $\times$  NT-1 (-0.18) in E-W direction had significant negative specific combining ability effects indicating poor specific combiners for this trait.

Similar findings for plant spread, positive specific combining ability effects are also reported by Karale (1997) in pomegranate and Chua (2005) in strawberry.

##### **4.2.4.3 Tree volume**

From the study of data, the cross combinations Mridula  $\times$  MH-1 (1.01), Kandhari Kabuli  $\times$  NT-1 (1.87) and Ganesh  $\times$  MH-1 (1.01) expressed significant positive specific combining ability effects which resulted into good specific combiners. The crosses which exhibited negative significant specific combining ability effects were Mridula  $\times$  NT-1 (-1.01), Kandhari Kabuli  $\times$  MH-1 (-1.87) and Ganesh  $\times$  NT-1 (-1.01) indicating them as poor specific cross combinations for this trait. The remaining four crosses had non-significant specific combining ability effects reported as average specific combiners.

These results are in consonance with the observations of Karale (1997) in pomegranate for tree volume.

#### **4.2.4.4 Stem girth**

Out of ten crosses, Kandhari Kabuli  $\times$  NT-1 (5.66) had significant positive specific combining ability effects and Kandhari Kabuli  $\times$  MH-1 (-5.66) had significant negative specific combining ability effects displayed them as good specific cross combination and poor specific cross combination respectively for stem girth. The other eight cross combinations were designated as average specific combiners due to non-significant specific combining ability effects.

The results on stem girth are in agreement with the observations recorded by Sharma (2019) in her study on  $F_1$  hybrids of pomegranate. The highest plant girth was recorded in Kandhari Kabuli  $\times$  NT-1 and minimum in G-137  $\times$  NT-1 crosses.

#### **4.2.4.5 Leaf area**

The three combinations which perceived significant positive specific combining ability effects were Mridula  $\times$  NT-1 (1.05), Kandhari Kabuli  $\times$  NT-1 (1.54) and Ganesh  $\times$  MH-1 (1.86) appointed as good specific cross combiners. The cross combinations which were allocated as poor specific cross combiners, because of negative significant specific combining ability effects were Mridula  $\times$  MH-1 (-1.05), Kandhari Kabuli  $\times$  MH-1 (-1.54) and Ganesh  $\times$  NT-1 (-1.86). The remaining four crosses had non-significant specific combining ability effects indicated as average specific cross combinations.

Similar results, positive significant specific combining ability effects for leaf area has also been reported by Chua (2005) in his study of combining ability in strawberry.

#### **4.2.4.6 Duration of flowering**

From the data under study, it was found that among all the cross combinations Kandhari Kabuli  $\times$  MH-1 (2.93) and Kandhari Kabuli  $\times$  NT-1 (-2.93) had significant positive and significant negative specific combining ability effects respectively, which indicated former as good specific combiner and later as poor specific cross combiner for duration of flowering. Whereas, all the other eight crosses were designated as average specific combiner due to their non-significant specific combining ability effects.

Sharma (2019) reported similar results in hybrids of pomegranate for duration of flowering.

**Table 4.9 Estimates of specific combining ability effects of hybrids for different plant growth traits in pomegranate**

Sr. No.	Hybrid (s)	Plant height (m)	Plant spread(m)		Tree volume (m <sup>3</sup> )	Stem girth (mm)	Leaf area (cm <sup>2</sup> )	Duration of flowering
			N-S	E-W				
1.	Mridula × NT-1	-0.10	-0.18	-0.29*	-1.01*	-1.09	1.05*	2.40
2.	Mridula × MH-1	0.10	0.18	0.29*	1.01*	1.09	-1.05*	-2.40
3.	G-137 × NT-1	0.15	-0.01	-0.15	-0.30	-2.31	-0.20	0.23
4.	G-137 × MH-1	-0.15	0.01	0.15	0.30	2.31	0.20	-0.23
5.	Kandhari Kabuli × NT-1	-0.07	0.30*	0.26*	1.87*	5.66*	1.54*	-2.93*
6.	Kandhari Kabuli × MH-1	0.07	-0.30*	-0.26*	-1.87*	-5.66*	-1.54*	2.93*
7.	Bhagwa × NT-1	0.19	0.04	0.36*	0.45	-2.58	-0.54	-0.43
8.	Bhagwa × MH-1	-0.19	-0.04	-0.36*	-0.45	2.58	0.54	0.43
9.	Ganesh × NT-1	-0.18	-0.14	-0.18*	-1.01*	0.32	-1.86*	0.73
10.	Ganesh × MH-1	0.18	0.14	0.18*	1.01*	-0.32	1.86*	-0.73
	<b>S.E. (sij) (crosses)</b>	<b>0.14</b>	<b>0.12</b>	<b>0.09</b>	<b>0.43</b>	<b>1.25</b>	<b>0.31</b>	<b>1.16</b>
	<b>C.D. (sij) (crosses)</b>	<b>0.30</b>	<b>0.24</b>	<b>0.18</b>	<b>0.90</b>	<b>2.62</b>	<b>0.66</b>	<b>2.44</b>

\*Significant at 5% level of significance

#### 4.2.4.7 Fruit weight

The positive significant specific combining ability effects were observed in four out of ten hybrids viz., G-137 × NT-1 (33.77), Kandhari Kabuli × MH-1 (23.06), Bhagwa × NT-1 (24.42) and Ganesh × NT-1 (26.49) reported as good specific cross combinations. The hybrids G-137 × MH-1 (-33.77), Kandhari Kabuli × NT-1 (-23.06), Bhagwa × MH-1 (-24.42) and Ganesh × MH-1 (-26.49) were reported as poor specific cross combinations because of negative significant specific combining ability effects. The cross combinations Mridula × NT-1 (-8.64) and Mridula × MH-1 (8.64) revealed non-significant specific combining ability effects identified as average specific combiners for fruit weight.

These findings are in close conformity with the results obtained by Spangelo *et al.* (1970), Lal and Seth (1982) and Masny *et al.* (2005) for strawberry, Marin *et al.* (2006) in papaya, Zeinanloo *et al.* (2009) in olive, Pluta *et al.* (2014) in gooseberry, Ciulca *et al.* (2017) in strawberry and Masny *et al.* (2018) in blackcurrant for this trait.

#### 4.2.4.8 Fruit size

Among ten cross combinations, three hybrids G-137 × NT-1 (0.38), Kandhari Kabuli × MH-1 (0.51) and Bhagwa × NT-1 (0.41) for fruit length and four hybrids G-137 × NT-1 (0.35), Kandhari Kabuli × MH-1 (0.53), Bhagwa × NT-1 (0.57) and Ganesh × MH-1 (0.35) for fruit breadth showed significant positive specific combining ability effects which categorized them as good specific cross combiners. The hybrids that displayed poor specific cross combinations were G-137 × MH-1 (-0.38), Kandhari Kabuli × NT-1 (-0.51) and Bhagwa × MH-1 (-0.41) for fruit length and G-137 × MH-1 (-0.35), Kandhari Kabuli × NT-1 (-0.53), Bhagwa × MH-1 (-0.57) and Ganesh × NT-1 (-0.35) for fruit breadth because they had significant negative specific combining ability effects.

The results of present study are in accordance with those of Lal and Seth (1982) in strawberry, Karale (1997) in pomegranate, Chua (2005) in strawberry and Zeinanloo *et al.* (2009) in olive for combining ability.

#### **4.2.4.9 Number of arils per fruit**

For number of arils per fruit, four of the cross combinations viz., Mridula × NT-1 (35.13), G-137 × NT-1 (31.97), Kandhari Kabuli × MH-1 (36.37) and Bhagwa × MH-1 (47.70) revealed significant positive specific combining ability effects, stipulating them as good specific combiners. The crosses which had significant negative specific combining ability effects were Mridula × MH-1 (-35.13), G-137 × MH-1 (-31.97), Kandhari Kabuli × NT-1 (-36.37) and Bhagwa × NT-1 (-47.70) specified as poor specific cross combinations. The crosses Ganesh × NT-1 (16.97) and Ganesh × MH-1 (-16.97) were average specific combiners (non-significant specific combining ability effects).

The results are in accordance with findings of Sharma (2019) for this trait.

#### **4.2.4.10 Aril : rind ratio**

All the ten hybrids indicated as average specific cross combiners due to the presence of non-significant specific combining ability effects.

The results are in disagreement with the earlier study by Karale (1997) who reported G-137 × No.31, P-26 × No.382 and P-26 × No.379 as best specific combiners for aril : rind ratio in pomegranate.

#### **4.2.4.11 Days from full bloom to harvest**

For days from full bloom to harvest, negative significant specific combining ability effects are desirable and it was observed in Bhagwa × NT-1 (-2.17) which resulted into good specific combiners and Bhagwa × MH-1 (2.17) was a poor specific combiner for this trait because of positive significant specific combining ability effects. On the contrary, the rest of the eight crosses had non-significant specific combining ability effects considered them as average specific cross combiners for this trait.

The findings are in agreement with those of Kumar (2008) and Sharma (2019) as the days from full bloom to harvest varied between 122 to 155 days and 90 to 112 days, respectively in different cultivars and hybrids of pomegranate.

**Table 4.10** Estimates of specific combining ability effects of hybrids for different fruit traits in pomegranate

Sr. No.	Hybrid (s)	Fruit weight (g)	Fruit size		Number of arils per fruit	Aril : rind ratio	Days from full bloom to harvest	Fruit yield (kg/tree)
			Fruit length (cm)	Fruit breadth (cm)				
1.	Mridula × NT-1	-8.64	-0.06	-0.04	35.13*	-0.01	1.00	-0.14
2.	Mridula × MH-1	8.64	0.06	0.04	-35.13*	0.01	-1.00	0.14
3.	G-137 × NT-1	33.77*	0.38*	0.35*	31.97*	0.07	0.67	0.31*
4.	G-137 × MH-1	-33.77*	-0.38*	-0.35*	-31.97*	-0.07	-0.67	-0.31*
5.	Kandhari Kabuli × NT-1	-23.06*	-0.51*	-0.53*	-36.37*	0.05	-0.67	-0.27*
6.	Kandhari Kabuli × MH-1	23.06*	0.51*	0.53*	36.37*	-0.05	0.67	0.27*
7.	Bhagwa × NT-1	24.42*	0.41*	0.57*	-47.70*	-0.06	-2.17*	0.46*
8.	Bhagwa × MH-1	-24.42*	-0.41*	-0.57*	47.70*	0.06	2.17*	-0.46*
9.	Ganesh × NT-1	26.49*	-0.22	-0.35*	16.97	-0.05	1.17	-0.36*
10.	Ganesh × MH-1	-26.49*	0.22	0.35*	-16.97	0.05	-1.17	0.36*
	<b>S.E. (sij) (crosses)</b>	<b>4.49</b>	<b>0.12</b>	<b>0.12</b>	<b>10.08</b>	<b>0.03</b>	<b>1.01</b>	<b>0.08</b>
	<b>C.D. (sij) (crosses)</b>	<b>9.43</b>	<b>0.25</b>	<b>0.25</b>	<b>21.18</b>	<b>0.07</b>	<b>2.12</b>	<b>0.17</b>

\*Significant at 5% level of significance

#### 4.2.4.12 Fruit yield

As significant positive specific combining ability effects were noticed in cross combinations viz., G-137 × NT-1 (0.31), Kandhari Kabuli × MH-1 (0.27), Bhagwa × NT-1 (0.46) and Ganesh × MH-1 (0.36) resulted as good specific cross combiners. Significant negative specific combining ability effects were observed in G-137 × MH-1 (-0.31), Kandhari Kabuli × NT-1 (-0.27), Bhagwa × MH-1 (-0.46) and Ganesh × NT-1 (-0.36) exhibited poor specific cross combinations. The remaining cross combinations had non-significant specific combining ability effects reported as average specific cross combiners.

The observations pertaining to fruit yield are in consonance with the results of Spangelo *et al.* (1970) and Lal and Seth (1982) in strawberry, Masny *et al.* (2005) in strawberry, Marin *et al.* (2006) in papaya and Masny *et al.* (2018) in blackcurrant. They observed significant positive specific combining ability effects of various hybrids for this trait.

#### 4.2.4.13 Total sugars

Data for total sugars revealed that cross combinations G-137 × NT-1 (0.75) and Ganesh × MH-1 (0.55) were good specific combiners, due to the significant positive specific combining ability effects. The crosses G-137 × MH-1 (-0.75) and Ganesh × NT-1 (-0.55) had significant negative specific combining ability effects stipulating poor specific combining ability whereas, the six crosses were found to have average specific combining ability for this trait.

Earlier study also reported significant positive specific combining ability effects of various crosses for total sugars in strawberry (Chua, 2005).

#### 4.2.4.14 Reducing sugars

Crosses with significant positive specific combining ability effects were Kandhari Kabuli × NT-1 (0.36) and Ganesh × MH-1 (0.37) resulted into good specific cross combiners. On the contrary, the crosses Kandhari Kabuli × MH-1 (-0.36) and Ganesh × NT-1 (-0.37) had poor specific combining ability due to significant negative specific combining ability effects. The other six hybrids with non-significant specific combining ability effects reported to have average specific combining ability.

The results by Kumar (2008) and Sharma (2019) are in close contiguity with the present investigation as they reported maximum per cent reducing sugars in Kandhari Kabuli and Kandhari Kabuli  $\times$  NT-1 respectively.

#### **4.2.4.15 Non-reducing sugars**

For non-reducing sugars, all the crosses found to have non-significant specific combining ability values which resulted into average specific combiners.

Similar observations for non-reducing sugars are also reported by Kumar (2008) ranged from (1.62 % to 2.09 %) and Sharma (2019) ranged from (0.83 % to 2.92 %).

#### **4.2.4.16 Total soluble solids**

The study of data on specific combining ability effects on total soluble solids revealed that Kandhari Kabuli  $\times$  NT-1 (0.46) had significant positive specific combining ability effects and Kandhari Kabuli  $\times$  MH-1 (-0.46) had significant negative specific combining ability values for this trait which represented them as good specific cross combiner and poor specific cross combiner. The other eight cross combinations were represented as average specific combiners due to its non-significant specific combining ability effects.

Similar findings for total soluble solids have also been reported earlier by various workers (Lal and Seth (1982), Marin *et al.* (2006) and Ciulca *et al.* (2017) in different fruit crops.

#### **4.2.4.17 Titratable acidity**

Good specific cross combinations for titratable acidity resulted due to significant positive specific combining ability effects of crosses were Mridula  $\times$  NT-1 (0.17) and Kandhari Kabuli  $\times$  MH-1 (0.15) whereas, poor specific cross combinations revealed due to significant negative specific combining ability effects in crosses Mridula  $\times$  MH-1 (-0.17) and Kandhari Kabuli  $\times$  NT-1 (-0.15). The rest of the crosses were average specific cross combiners due to their non-significant specific combining ability effects.

Results obtained for titratable acidity are in accordance with Chua (2005), who reported desirable significant positive specific combining ability effects.

**Table 4.11 Estimates of specific combining ability effects of hybrids for different bio-chemical traits in pomegranate**

<b>Sr. No.</b>	<b>Hybrid (s)</b>	<b>Total sugars (%)</b>	<b>Reducing sugars (%)</b>	<b>Non-reducing sugars (%)</b>	<b>TSS (°B)</b>	<b>Titrateable acidity (%)</b>	<b>TSS : acid ratio</b>
1.	Mridula × NT-1	-0.35	-0.01	-0.33	-0.29	0.17*	-0.59
2.	Mridula × MH-1	0.35	0.01	0.33	0.29	-0.17*	0.59
3.	G-137 × NT-1	0.75*	0.29	0.44	0.26	-0.06	0.18
4.	G-137 × MH-1	-0.75*	-0.29	-0.44	-0.26	0.06	-0.18
5.	Kandhari Kabuli × NT-1	0.44	0.36*	0.07	0.46*	-0.15*	1.09*
6.	Kandhari Kabuli × MH-1	-0.44	-0.36*	-0.07	-0.46*	0.15*	-1.09*
7.	Bhagwa × NT-1	-0.28	-0.27	-0.02	-0.15	-0.06	-0.11
8.	Bhagwa × MH-1	0.28	0.27	0.02	0.15	0.06	0.11
9.	Ganesh × NT-1	-0.55*	-0.37*	-0.16	-0.29	0.09	-0.56
10.	Ganesh × MH-1	0.55*	0.37*	0.16	0.29	-0.09	0.56
	<b>S.E. (sij) (crosses)</b>	<b>0.24</b>	<b>0.15</b>	<b>0.25</b>	<b>0.16</b>	<b>0.05</b>	<b>0.28</b>
	<b>C.D. (sij) (crosses)</b>	<b>0.50</b>	<b>0.31</b>	<b>0.53</b>	<b>0.33</b>	<b>0.11</b>	<b>0.59</b>

\*Significant at 5% level of significance

#### **4.2.4.18 TSS : acid ratio**

The study of data revealed significant positive specific combining ability effect in Kandhari Kabuli  $\times$  NT-1 (1.09) designated as good specific cross combiner whereas, Kandhari Kabuli  $\times$  MH-1 (-1.09) with negative significant specific combining ability effect was indicated as poor specific cross combiner. The remaining crosses were average specific combiners.

For TSS : acid ratio Karale (1997) reported non-significant specific combining ability effects for all the hybrids of pomegranate under study which is in contradiction with the present study for this trait.

### **4.3 GENE ACTION**

#### **4.3.1 Estimates of genetic components of variance**

There are various designs used for evaluating inbred lines in crop improvement programme in terms of genetic component of variation. Among all the designs, the line  $\times$  tester along with evaluation of parents and crosses for combining ability it provides information regarding nature of gene action. The way in which genes express themselves in genetic population is referred as gene action. It is very much essential to have the knowledge of gene action as it helps in selecting the parents for their use in hybridization programmes and also for the selection of suitable breeding procedures for genetic improvement of different quantitative characters. Nature of gene action has been estimated from the general combining ability and specific combining ability variances or additive component of variance and dominant component of variance.

As the dominant component of variance ( $\sigma^2D$ ) is a function of specific combining ability variance and additive component of variance ( $\sigma^2A$ ) is a function of general combining ability variance. Under present investigation (Table 4.12), it was estimated that the dominant components of variance ( $\sigma^2D$ ) were higher than the additive components of variance ( $\sigma^2A$ ) for plant spread (N-S), plant spread (E-W), tree volume, stem girth, leaf area, duration of flowering, fruit length, fruit breadth, aril : rind ratio, fruit yield, total sugars and TSS represented the role of non-additive gene action. The remaining traits viz., plant height, fruit weight, number of arils per fruit, days from full bloom to harvest, reducing sugars, non-reducing sugars, titratable

**Table 4.12 Estimates of genetic components of variance for different horticultural and quality traits in pomegranate**

Character (s)	<sup>2</sup> GCA	<sup>2</sup> SCA	<sup>2</sup> A	<sup>2</sup> D	<sup>2</sup> A/ <sup>2</sup> D (Variance ratio)
Plant height (m)	0.13	-0.01	0.26	-0.01	-26.00
Plant spread(N-S) (m)	0.018	0.039	0.035	0.039	0.89
Plant spread(E-W) (m)	-0.008	0.152	-0.017	0.152	-0.11
Tree volume (m <sup>3</sup> )	0.225	2.450	0.450	2.450	0.18
Stem girth (mm)	-3.432	18.788	-6.865	18.788	-0.37
Leaf area (cm <sup>2</sup> )	-0.073	3.376	-0.147	3.376	-0.04
Duration of flowering	0.007	4.209	0.014	4.209	0.003
Fruit weight (g)	973.587	1,472.012	1,947.175	1,472.012	1.32
Fruit length (cm)	0.094	0.277	0.189	0.277	0.68
Fruit breadth (cm)	0.091	0.390	0.183	0.390	0.46
Number of arils per fruit	2,080.778	2,816.810	4,161.556	2,816.810	1.48
Aril : rind ratio	-0.001	0.003	-0.002	0.003	-0.67
Days from full bloom to harvest	8.887	1.436	17.773	1.436	12.37
Fruit yield (kg/tree)	0.053	0.250	0.106	0.250	0.42
Total sugars (%)	0.208	0.485	0.415	0.485	0.86
Reducing sugars (%)	0.174	0.157	0.349	0.157	2.22
Non-reducing sugars (%)	-0.025	0.007	-0.049	0.007	-7.00
TSS (°B)	0.030	0.174	0.059	0.174	0.34
Titrateable acidity (%)	0.043	0.027	0.085	0.027	3.14
TSS : acid ratio	0.784	0.740	1.568	0.740	2.12

acidity and TSS : acid ratio in which the additive components of variance ( $\sigma^2_A$ ) were more than the dominant components of variance ( $\sigma^2_D$ ), indicating the role of additive gene action.

Allied results were reported by various researchers for traits viz., additive gene action for plant height by Rumpunen and Kviklyns (2003), Chua (2005) and Marin *et al.* (2006); non-additive gene action for plant spread by Karale (1997) and Chua (2005); for tree volume by Karale (1997); for leaf area by Chua (2005); for fruit weight by Erb *et al.* (1990), Karale (1997), Chua (2005), Zeinanloo *et al.* (2009), Gawronski (2011) and Pluta *et al.* (2014); for fruit size by Karale (1997), Chua (2005), Dossett *et al.* (2006) and Zeinanloo *et al.* (2009); for aril : rind ratio by Karale (1997); for fruit yield by Chua (2005), Masny *et al.* (2005), Gawronski (2011) and Pluta *et al.* (2014); for total sugars by Chua (2005) and for total soluble solids by Karale (1997), Chua (2005) and Masny *et al.* (2018). For titratable acidity Karale (1997) and Chua (2005) reported non-additive gene action which was in contradiction with the present study.

Additionally, in our study, the variance ratio ( $\sigma^2_A / \sigma^2_D$ ) was less than one for plant spread (N-S) (0.89), plant spread (E-W) (-0.11), tree volume (0.18), stem girth (-0.37), leaf area (-0.04), duration of flowering (0.003), fruit length (0.68), fruit breadth (0.46), aril : rind ratio (-0.67), fruit yield (0.42), total sugars (0.86) and TSS (0.34) indicating the predominant role of non-additive gene action. Whereas, the remaining traits having variance ratio more than one suggesting the role of additive gene action. The findings by Glala *et al.* (2011) for variance ratio are similar with the present study.

#### **4.4 PROPORTIONAL CONTRIBUTION OF LINES, TESTERS AND THEIR INTERACTIONS (%)**

The proportional contributions ranged from 22.60 to 88.65, 0.03 to 40.89 and 9.22 to 59.35 for lines, testers and line  $\times$  tester interactions, respectively, represented in Table 4.13. The percent contribution of lines for most of the traits viz., plant height (55.59%), plant spread (N-S) (77.36%), tree volume (60.75%), leaf area (63.71%), fruit weight (42.86%), fruit length (50.98%), fruit breadth (43.40%), number of arils per fruit (64.26%), days from full bloom to harvest (47.18%), total sugars (74.51%), reducing sugars (78.30%), TSS (66.29%), titratable acidity (87.12%) and TSS : acid ratio (88.65%), were higher than testers and line  $\times$  tester interactions. For rest of the

**Table 4.13 Proportional contribution of lines, testers and their interactions to different horticultural traits**

Character (s)	Per cent contribution		
	Lines	Testers	Line x Tester
Plant height (m)	55.59	34.65	9.76
Plant spread(N-S) (m)	77.36	0.94	21.71
Plant spread(E-W) (m)	45.15	8.07	46.80
Tree volume (m <sup>3</sup> )	60.75	5.96	33.29
Stem girth (mm)	38.21	4.02	57.77
Leaf area (cm <sup>2</sup> )	63.71	0.63	35.65
Duration of flowering	22.60	22.09	55.31
Fruit weight (g)	42.86	31.23	25.91
Fruit length (cm)	50.98	18.62	30.40
Fruit breadth (cm)	43.40	20.70	35.90
Number of arils per fruit	64.26	16.45	19.29
Aril : rind ratio	36.59	4.07	59.35
Days from full bloom to harvest	47.18	40.89	11.93
Fruit yield (kg/tree)	32.92	26.31	40.79
Total sugars (%)	74.51	4.27	21.22
Reducing sugars (%)	78.30	7.65	14.04
Non-reducing sugars (%)	49.23	0.08	50.67
TSS (°B)	66.29	4.47	29.25
Titrateable acidity (%)	87.12	3.66	9.22
TSS : acid ratio	88.65	0.03	11.33

traits viz., plant spread (E-W) (46.80%), stem girth (57.77%), duration of flowering (55.31%), aril : rind ratio (59.35%), fruit yield (40.79%) and non-reducing sugars (50.67%) the percent contribution of line  $\times$  tester interactions were higher than lines and testers.

## Chapter-5

# SUMMARY AND CONCLUSION

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The present study entitled “**Gene action and combining ability studies in Pomegranate (*Punica granatum* L.)**” was carried out in Pomegranate Block of Department of Fruit Science, Dr Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (HP) during 2018-2019.

The research programme comprised of ten hybrids resulted from crossing between five lines (Mridula, G-137, Kandhari Kabuli, Bhagwa and Ganesh) with two testers (NT-1 and MH-1). Using line × tester mating design suggested by Kempthorne (1957) to find the suitable cross combinations and to estimate their performance, by using general combining ability variances and specific combining ability variances their effects along with gene action.

The recorded observations were plant height (m), plant spread (m), tree volume (m<sup>3</sup>), stem girth (mm), leaf area (cm<sup>2</sup>), date of opening of first flower, date of full bloom, date of opening of last flower, duration of flowering, fruit weight (g), fruit size (cm), fruit shape, number of arils per fruit, colour of arils, aril : rind ratio, days from full bloom to harvest, fruit yield (kg/tree), total sugars (%), reducing sugars (%), non-reducing sugars (%), total soluble solids (°B), titratable acidity (%) and TSS : acid ratio. The results pertaining to the present investigations are summarized below:

### 5.1 STUDIES ON COMBINING ABILITIES

#### 5.1.1 General combining ability studies

- The general combining ability effects for plant height revealed that, the line G-137 and tester MH-1 were the best general combiners because of their negative significant general combining ability effects.
- For plant spread, line Kandhari Kabuli in N-S whereas, line Kandhari Kabuli followed by Mridula and tester NT-1 in E-W direction of plant spread were the best general combiners because of significant positive general combining ability effects.

- Due to the positive significant general combining ability effects, the line Kandhari Kabuli and tester NT-1 for tree volume and for stem girth, line Kandhari Kabuli were the best general combiners whereas, none of the tester had significant general combining ability effects .
- The estimation of general combining ability effects for leaf area indicated that, the line Bhagwa were the best general combiners because of its positive significant general combining ability effects, but the testers had non-significant effects.
- For fruit weight, line G-137 and Bhagwa and tester NT-1 were reported to be best general combiners showed significant positive general combining ability effects. Positive significant general combining ability effects were also observed in line G-137 and tester NT-1 for fruit length and fruit breadth were good general combiners.
- The lines G-137 and Bhagwa and tester NT-1 reported positive significant general combining ability effects for number of arils per fruits were the good general combiners.
- The general combining ability effects indicated that the line G-137 and tester MH-1 were the best general combiners for days from full bloom to harvest due to the desirable significant negative general combining ability effects.
- The general combining ability effects for fruit yield revealed that, the line G-137 and tester NT-1 were best general combiners because of their significant positive general combining ability effects.
- For total soluble solids, the line Kandhari Kabuli were good general combiner as reported positive significant general combining ability effects whereas, both the testers were average combiners. The lines Mridula, Ganesh and G-137 and tester NT-1 were best general combiners for titratable acidity due to positive significant general combining ability effects.

- For total sugars, reducing sugars and TSS: acid ratio, the lines Kandhari Kabuli and Bhagwa were best general combiners had significant positive general combining ability effects. Both the testers were average combiners for total sugars and TSS: acid ratio but NT-1 had significant positive effects for reducing sugars revealed as good general combiner.

On the basis of general combining ability studies, among lines G-137, Kandhari Kabuli and Bhagwa whereas, among testers NT-1 were revealed as best general combiners for most of the traits under study, which can be further employed for obtaining better hybrids using hybridization programmes.

### **5.1.2 Specific combining ability studies**

- The cross combinations Mridula  $\times$  MH-1, Kandhari Kabuli  $\times$  NT-1, Bhagwa  $\times$  NT-1 and Ganesh  $\times$  MH-1 reported significant specific combining ability effects for plant spread designated as best specific cross combiners.
- The estimation of specific combining ability effects showed that the hybrids Mridula  $\times$  MH-1, Kandhari Kabuli  $\times$  NT-1 and Ganesh  $\times$  MH-1 were good specific combiners for tree volume due to the positive significant specific combining ability effects.
- For stem girth the significant positive specific combining ability effects were found in the hybrid Kandhari Kabuli  $\times$  NT-1 reported as good specific combiner.
- The specific combining ability effects of parents revealed that the crosses Mridula  $\times$  NT-1, Kandhari Kabuli  $\times$  NT-1 and Ganesh  $\times$  MH-1 were best specific cross combiners due to their significant positive specific combining ability effects for leaf area.
- The best specific cross combiners for fruit weight were G-137  $\times$  NT-1, Kandhari Kabuli  $\times$  MH-1, Bhagwa  $\times$  NT-1 and Ganesh  $\times$  NT-1 because of significant positive specific combining ability effects for this trait.

- For the estimation of specific combining ability effects the crosses G-137 × NT-1, Kandhari Kabuli × MH-1, Bhagwa × NT-1 and Ganesh × MH-1 were best specific combiners because they had significant positive effects for fruit size i.e. fruit length and fruit breadth.
- For number of arils per fruit the cross combinations Mridula × NT-1, G-137 × NT-1, Kandhari Kabuli × MH-1 and Bhagwa × MH-1 were revealed as best specific cross combinations as they had positive significant specific combining ability effects.
- The hybrids G-137 × NT-1, Kandhari × MH-1, Bhagwa × NT-1 and Ganesh × MH-1 were the best specific combiners for fruit yield because of significant positive specific combining ability effects. Bhagwa × NT-1 was also found to be the best specific combiner for days from full bloom to harvest due to desirable significant negative specific combining ability effects.
- For total sugars the cross combinations G-137 × NT-1 and Ganesh × MH-1 whereas, Kandhari Kabuli × NT-1 and Ganesh × MH-1 for reducing sugars had positive significant specific combining ability effects reported them as best specific cross combiners.
- The cross combination Kandhari Kabuli × NT-1 was a best specific combiner for TSS and for titratable acidity Mridula × NT-1 and Kandhari Kabuli × NT-1 were the best specific combiners as they reported positive significant specific combining ability effects. For TSS : acid ratio Kandhari Kabuli × NT-1 revealed as good specific combiner due to positive significant combining ability effects.

According to overall specific combining ability performance, the hybrids G-137 × NT-1, Kandhari Kabuli × NT-1, Bhagwa × NT-1, Kandhari Kabuli × MH-1 and Ganesh × MH-1 performed superior for most of the studied traits.

## 5.2 STUDIES ON GENE ACTION

- The specific combining ability variance represents the dominant component of variance ( $\sigma^2 D$ ) and the general combining ability variance represents additive

component of variance ( $\sigma^2 A$ ). The data in Table 4.12 revealed that the dominant component of variance ( $\sigma^2 D$ ) were higher than the additive component of variance ( $\sigma^2 A$ ) for plant spread (N-S), plant spread (E-W), tree volume, stem girth, leaf area, duration of flowering, fruit length, fruit breadth, aril : rind ratio, fruit yield, total sugars and TSS which indicated predominant role of non-additive gene action. The remaining traits having higher additive component of variance ( $\sigma^2 A$ ) than the dominant component of variance ( $\sigma^2 D$ ) suggesting the role of additive gene action for those traits.

- It was also estimated that the traits plant spread (N-S), plant spread (E-W) tree volume, stem girth, leaf area, duration of flowering, fruit length, fruit breadth, aril : rind ratio, fruit yield, total sugars and TSS had variance ratio less than one indicated the role of non-additive gene action. Whereas, the other traits plant height, fruit weight, number of arils per fruit, days from full bloom to harvest, reducing sugars, non-reducing sugars, titratable acidity and TSS : acid ratio was found to be more than one suggested the role of additive gene action.

## CONCLUSION

Present study concluded that various parents and hybrids were found superior or best general and specific combiners for different horticultural traits presented as follows :

Superior general combiners for important horticultural traits in pomegranate

Parents	Characters
G-137	Plant height, fruit weight, fruit size, number of arils per fruit, days from full bloom to harvest, fruit yield and titratable acidity
Kandhari Kabuli	Plant spread, tree volume, stem girth, total sugars, reducing sugars, TSS and TSS : acid ratio
Bhagwa	Leaf area, fruit weight, number of arils per fruit, total sugars, reducing sugars and TSS : acid ratio
NT-1	Plant spread (E-W), tree volume, stem girth, fruit weight, fruit size, number of arils per fruit and fruit yield

Superior specific combiners for important horticultural traits in pomegranate

Hybrids	Characters
G-137 × NT-1	Fruit weight, fruit size, number of arils per fruit, fruit yield and total sugars
Kandhari Kabuli × NT-1	Plant spread, tree volume, stem girth, leaf area, TSS, reducing sugars and TSS : acid ratio
Bhagwa × NT-1	Plant spread (E-W), fruit weight, fruit size, days from full bloom to harvest and fruit yield
Kandhari Kabuli × MH-1	Fruit weight, fruit size, number of arils per fruit, fruit yield and titratable acidity
Ganesh × MH-1	Plant spread (E-W), tree volume, leaf area, fruit yield, total sugars and reducing sugars

On the basis of present investigation, for most of the important horticultural traits, the parents G-137 and Bhagwa based on the general combining ability effects and the crosses G-137 × NT-1 and Bhagwa × NT-1 on the basis of specific combining ability effects were found to be most promising.

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## APPENDIX-I

### Analysis of variance for randomized block design for various traits in Pomegranate

Sr. No.	Source of Variation		Replication	Treatment	Error
	Trait	df →	2	9	18
1.	Plant height (m)		0.05	0.69*	0.15
2.	Plant spread(N-S) (m)		0.08	0.44*	0.10
3.	Plant spread(E-W) (m)		0.01	0.49*	0.05
4.	Tree volume (m <sup>3</sup> )		1.12	11.65*	1.37
5.	Stem girth (mm)		47.06*	52.31*	11.64
6.	Leaf area (cm <sup>2</sup> )		0.76	13.53*	0.73
7.	Duration of flowering		2.53	18.26	10.09
8.	Fruit weight (g)		355.63	7835.20*	150.92
9.	Fruit length (cm)		0.07	1.36*	0.10
10.	Fruit breadth (cm)		0.02	1.57*	0.10
11.	Number of arils per fruit		828.4	21228.40*	762.44
12.	Aril : rind ratio		0.007	0.01	0.01
13.	Days from full bloom to harvest		18.53	44.39*	7.61
14.	Fruit yield (kg/tree)		0.23*	0.87*	0.05
15.	Total sugars (%)		0.20	3.94*	0.43
16.	Reducing sugars (%)		0.13	2.01*	0.17
17.	Non-reducing sugars (%)		0.38	0.44	0.48
18.	TSS (°B)		0.13	1.08*	0.19
19.	Titrateable acidity (%)		0.06	0.48*	0.02
20.	TSS : acid ratio		1.17	11.07*	0.60

\*Significant at 5% level of significance

## APPENDIX-II

### Analysis of variance for combining ability for various traits in Pomegranate

Sr. No.	Source of Variation		Replication	Crosses	Line(s)	Tester(s)	Line × Tester	Error
	Trait	df →	2	9	4	1	4	18
1.	Plant height (m)		0.05	0.69*	0.86*	2.16*	0.15	0.15
2.	Plant spread(N-S) (m)		0.08	0.44*	0.77*	0.04	0.22	0.10
3.	Plant spread(E-W) (m)		0.01	0.49*	0.49*	0.35*	0.51*	0.05
4.	Tree volume (m <sup>3</sup> )		1.11	11.64*	15.92*	6.25*	8.72*	1.37
5.	Stem girth (mm)		47.06*	52.31*	44.97*	18.95	67.99*	11.64
6.	Leaf area (cm <sup>2</sup> )		0.76	13.53*	19.40*	0.77	10.86*	0.73
7.	Duration of flowering		2.53	18.26	9.28	36.30	22.72	10.09
8.	Fruit weight (g)		355.63	7835.20*	7556.59*	22022.65*	4556.95*	150.92
9.	Fruit length (cm)		0.07	1.36*	1.56*	2.29*	0.93*	0.10
10.	Fruit breadth (cm)		0.02	1.57*	1.53*	2.93*	1.27*	0.10
11.	Number of arils per fruit		828.40	21228.40*	30694.03*	31428.03*	9212.87*	762.44
12.	Aril : rind ratio		0.007	0.01	0.01	0.005	0.02	0.008
13.	Days from full bloom to harvest		18.53	44.39*	47.12*	163.33*	11.92	7.61
14.	Fruit yield (kg/tree)		0.23*	0.87*	0.65*	2.07*	0.80*	0.05
15.	Total sugars (%)		0.20	3.94*	6.61*	1.52	1.88*	0.43
16.	Reducing sugars (%)		0.13	2.01*	3.55*	1.39*	0.64*	0.16
17.	Non-reducing sugars (%)		0.39	0.44	0.49	0.003	2.01	0.48
18.	TSS (°B)		0.13	1.08*	1.60*	0.43	0.71*	0.19
19.	Titrateable acidity (%)		0.06	0.48*	0.94*	0.16*	0.09*	0.02
20.	TSS : acid ratio		1.16	11.07*	22.07*	0.03	2.82*	0.60

\*Significant at 5% level of significance

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**Title of Thesis** : **Gene action and combining ability studies in Pomegranate (*Punica granatum L.*)**  
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**ABSTRACT**

The present investigation entitled “**Gene action and combining ability studies in Pomegranate (*Punica granatum L.*)**” was conducted at Pomegranate Block of Department of Fruit Science, Dr Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh during 2018-2019. The experimental material comprised of ten hybrids, developed by crossing five lines namely, Mridula, G-137, Kandhari Kabuli, Bhagwa, Ganesh and two testers viz., NT-1, MH-1 in a line × tester mating design. The experiment was laid out in a Randomized Complete Block Design. The observations recorded during the investigation were plant height (m), plant spread (m), tree volume (m<sup>3</sup>), stem girth (mm), leaf area (cm<sup>2</sup>), date of opening of first flower, date of full bloom, date of opening of last flower, duration of flowering, fruit weight (g), fruit size (cm), fruit shape, number of arils per fruit, aril : rind ratio, colour of aril, days from full bloom to harvest, fruit yield (kg/tree), total sugars (%), reducing sugars (%), non-reducing sugars (%), TSS (°B), titratable acidity (%) and TSS : acid ratio. The results revealed that, for most of desirable horticultural traits, the two lines G-137 and Bhagwa were found to be the best general combiners on the basis of general combining ability effects. The hybrids G-137 × NT-1 and Bhagwa × NT-1 were the best specific combiners according to the specific combining ability studies. The dominance variance was higher than the additive variance for plant spread, tree volume, stem girth, leaf area, duration of flowering, fruit size, aril : rind ratio, fruit yield, total sugars and TSS indicating the role of non-additive gene action. The remaining traits having dominance variance less than additive variance suggested the predominant role of additive gene action. The traits viz., plant spread, tree volume, stem girth, leaf area, duration of flowering, fruit size, aril : rind ratio, fruit yield, total sugars and TSS having variance ratio less than one also indicated non-additive gene action. The other traits having variance ratio more than one indicated the role of additive gene action.

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