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Genetic studies on important horticultural traits using line × tester analysis in pomegranate

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ABSTRACT

An investigation was carried out to study the combining ability and gene action estimates for various plant growth and physico-chemical characteristics in pomegranate by following line × tester mating design which included five lines namely; Mridula, G-137, Kandhari Kabuli, Bhagwa and Ganesh and two testers *viz.,* NT-1 and MH-1. The study revealed higher dominance variance compared to the additive variance for majority of the traits except plant height, fruit weight, number of arils per fruit, days from full bloom to harvest, sugars content, titratable acidity and TSS: acid ratio indicating the major role of non-additive gene action for these characteristics. The present investigation identified the parent G-137 as a good general combiner for plant height, fruit weight, fruit size, number of arils per fruit, days from full bloom to harvest, fruit yield and titratable acidity, while Bhagwa was found to be the best general combiner for leaf area, fruit weight, number of arils per fruit, total sugars, reducing sugars and TSS: acid ratio on the basis of desirable significant GCA effects. The cross of G-137×NT-1 was a good specific combiner for most of the desirable traits *viz*; fruit weight, fruit size, number of arils per fruit, fruit yield and total sugars and Bhagwa×NT-1 cross was found to have significant positive specific combining ability effects for fruit weight, fruit size, days from full bloom to harvest and fruit yield.

Key words: *Punica granatum* L., combining ability, gene action, horticultural traits

INTRODUCTION

Pomegranate is considered to be a highly remunerative crop for subtropical and subtemperate regions of the world. It is famous for its arils which are attractive, juicy, sweet acidic and refreshing. Owing to its high nutritional value, strong antioxidant properties and chemo-preventive properties with medicinal value, it is considered as 'super fruit' (Hertog *et al*., 6). Pomegranate is also used for the patients suffering from diabetes (Syed, 15).The growing areas of pomegranate in the world range between 41 ºN and 42 ºS latitude (Hodgson, 7). Its plant can resist frost and can grow upto an altitude of 1600 m above mean sea level (Rana and Dwivedi, 14).

In India, pomegranate is grown both for domestic use and for export purposes. The wild pomegranate, grown in the belts of Himachal Pradesh is locally known as 'daru'. It is one of the fruits having high economic value in its growing region. Its seeds are mainly used after sun drying to prepare anardana, which is used as a souring agent in different preparations. It exhibits high level of acidity and field tolerance to bacterial blight (Jalikop *et al*., 8).

Keeping in view the increasing demand for pomegranate, due to its superior pharmacological and therapeutic properties and to meet the demands of local and international consumers, growers and exporters, well planned breeding efforts are required for the development of superior cultivars. Although, pomegranate have been characterized by various workers based on morphological, fruiting and biochemical traits in India (Khodabakhshian *et al*., 11; Ali *et al*., 2), but, to understand the ability of the cultivars or parents to combine with each other during hybridization programme, it is necessary to conduct combining ability studies. An allied methodology, combining ability analysis, divides phenotypic variation between progeny means, components due to additive inputs of discrete parents (general combining ability) and variation due to interactions between parents (specific combining ability) are able to measure the relative breeding value of parents This guarantees the nature and extent of different forms of gene action that are involved in quantitative trait expression. Therefore, the present study was conducted to select desirable parents and cross combinations by using line × tester mating design. This mating design provides information regarding the usefulness of male and female inbreds as parents for hybridization to generate segregating population which is expected to give superior segregants. The prevalence of additive gene action in a species necessitates mass selection and progeny selection in autogamous species, whereas, synthetic and composite breeding in case of allogamous species. In case of dominant

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and epistatic gene action, commercial exploitation of heterosis should be taken up.

MATERIALS AND METHODS

Five pomegranate genotypes, *viz.,* Mridula, G-137, Kandhari Kabuli,Bhagwa and Ganesh were used as female parents (lines) and two selections NT-1 (Naina Tikker, HP) and MH-1 (Mehlog, HP) were used as male parents (testers) in hybridization programme. The genotypes selected as lines are the commercially grown cultivars, whereas, the testers are locally grown wild pomegranate known as Daru. The crosses were made during 2012-2013, by using line × tester mating design at Pomegranate Block of Department of Fruit Science, Dr.YSPUHF, Nauni, Solan (HP). Three to four trees of above-named pomegranate cultivars were selected for hybridization work. The fruits from each cross were harvested separately. The progeny developed from hybrid seed behaved as segregating population, being highly heterozygous nature of tree crops. The seeds of each fruit were sown separately in the nursery beds. From each single plant four to five cuttings were taken and further propagated vegetatively to fix the heterosis. The plants obtained were homogenous and used for replication. Ten hybrids in three replications were evaluated for plant growth and physico-chemical traits according to Randomized Complete Block Design with three replications. Each single tree selected was considered as one replication. Various plant growth parameters like plant height and plant spread were measured using a measuring tape. Tree volume above ground was determined from the height and plant spread by following the method suggested by Westwood (16). The stem girth was measured with the help of digital vernier caliper and leaf area was recorded using digital leaf area meter (LICOR-3100A).

Duration of flowering was calculated by counting the days from date of opening of first flower to the date of opening of last flower in each hybrid. Fruit weight was measured with the help of weighing balance. Fruit size was measured in terms of fruit length and fruit breadth with digital vernier caliper. The data for number of arils per fruit was recorded by counting the average number of arils from the representative sample of three fruits in every hybrid, whereas, the aril : rind ratio was calculated by dividing weight of aril with the weight of rind. The days from full bloom to harvest were counted from date of full bloom to date of harvest and fruit yield was measured in kg per tree in each hybrid replication wise.

The analysis of biochemical traits was done by Lane and Eynon's volumetric method (A.O.A.C., 1).The determination of non-reducing sugars was done by subtracting reducing sugars from the total sugars and multiplying the difference with 0.95. Total soluble solids content in fruits was determined with Erma Hand Refractometer (0-32°Brix). The TSS: acid ratio was determined by dividing the value of per cent total soluble solids to the titratable acidity of the fruits. Analysis of data for general and specific combining ability was carried out as per the model suggested by Kempthorne (10) using software OPSTAT.

RESULTS AND DISCUSSION

The analysis of variance for combining ability (Table 1) revealed significant differences for majority of traits among crosses. Similar trend due to lines for mean sum of squares was observed. For majority of the traits under study except plant spread (N-S), stem girth, leaf area, duration of flowering, aril: rind ratio and biochemical traits, the mean sum of squares due to testers was significant. The mean sum of square was significant for all the characters except plant height, plant spread (N-S), duration of flowering, aril: rind ratio, days from full bloom to harvest and non-reducing sugars in line × tester interaction. The observations under study showed treatment differences, thus meeting prerequisite for line × tester analysis.

The dominant variance component (σ^2D) was greater than the additive variance component (σ^2A) for plant spread (N-S, E-W), tree volume, stem girth, leaf area, duration of flowering, fruit length, fruit breadth, aril: rind ratio, fruit yield, total sugars and TSS indicating the predominance of non-additive gene action governing the inheritance of these traits (Table 2). For the remaining traits the additive variance component (σ^2A) were more than the dominant variance component (σ^2D), indicated the role of additive gene action. Similar gene action findings were reported by various workers; Chua (3) in strawberry and Marin *et al.* (12) in papaya observed additive gene action for plant height. Non-additive gene action was observed for plant spread, tree volume, fruit weight, fruit size, aril : rind ratio and total soluble solids by Karale (9) in pomegranate; for leaf area, fruit yield and total sugars by Chua (3) in strawberry. For titratable acidity, Karale (9) reported non-additive gene action in pomegranate which was in contradiction with the present study. The additive gene action for titratable acidity and TSS: acid ratio revealed the dominance of high acidity to low acidity, as the local cultivar daru used as tester have more acidity than the cultivated genotypes. Variance ratio yields information on the nature of gene action and aids breeder in formulating suitable breeding strategies. It was observed that for plant spread (N-S), tree volume, stem girth, leaf area, duration of

Table 1. Analysis of variance for combining ability for various traits in pomegranate

Source of Variation		Replication	Cross	Line(s)	Tester(s)	Line × Tester	Error
Trait	df →	2	9	4	1	4	18
PH (m)		0.05	0.69*	0.86*	2.16*	0.15	0.15
PS(N-S) (m)		0.08	0.44*	0.77*	0.04	0.22	0.10
PS(E-W) (m)		0.01	0.49*	0.49*	0.35*	0.51*	0.05
TV (m^3)		1.11	11.64*	15.92*	6.25*	8.72*	1.37
SG (mm)		47.06*	52.31*	44.97*	18.95	67.99*	11.64
LA (cm^2)		0.76	13.53*	19.40*	0.77	10.86*	0.73
DF		2.53	18.26	9.28	36.30	22.72	10.09
FW (g)		355.63	7835.20*	7556.59*	22022.65*	4556.95*	150.92
FL (cm)		0.07	1.36*	1.56*	2.29*	0.93*	0.10
FB (cm)		0.02	1.57*	1.53*	2.93*	1.27*	0.10
NAF		828.40	21228.40*	30694.03*	31428.03*	9212.87*	762.44
A:R		0.007	0.01	0.01	0.005	0.02	0.008
DFBH		18.53	44.39*	47.12*	163.33*	11.92	7.61
FY (kg/tree)		0.23*	0.87*	0.65*	2.07*	0.80*	0.05
TS (%)		0.20	3.94*	6.61*	1.52	1.88*	0.43
RS (%)		0.13	2.01*	3.55*	1.39*	0.64*	0.16
NS (%)		0.39	0.44	0.49	0.003	2.01	0.48
TSS (°B)		0.13	1.08*	1.60*	0.43	0.71*	0.19
TA (%)		0.06	0.48*	0.94*	0.16*	0.09*	0.02
TSS/TA		1.16	11.07*	22.07*	0.03	2.82*	0.60

*Significant at 5% level of significance

flowering, fruit size, aril : rind ratio, fruit yield, total sugars and TSS the variance ratio was less than one which indicated the predominant role of non-additive gene action, therefore for these traits selection may be deferred to later generations. While, the other traits had variance ratio higher than one suggested the role of additive gene action, there by indicating the necessity of selection at early stages for the improvement of these traits. The results by Glala *et al.* (5) for variance ratio in muskmelon are in line with the present study.

GCA is owing to the activity of genes which are largely additive in their effects as well as additive×additive interactions. In the present study, the parental genotypes have recorded significant GCA effects in both positive as well as negative direction (Table 3). The significantly negative GCA effects are desirable for plant height; line G-137 and tester MH-1 were found to be good general combiners and the line Kandhari Kabuli and tester NT-1 were poor general combiners for this trait. Kandhari Kabuli was a good general combiner for plant spread, tree volume and stem girth. Bhagwa was a poor combiner for plant spread and tree volume and for stem girth G-137 was designated as poor combiner. For leaf area, Bhagwa was a good general combiner and the poor general combiners were Ganesh, Kandhari Kabuli and G-137. Similar results for plant height, plant spread and tree volume has also been reported by Karale (9) in pomegranate.

The GCA effects for fruit weight, fruit size and number of arils per fruit were observed highest in line G-137 and tester NT-1 and lowest in Mridula, Ganesh and MH-1.The study revealed non-significant GCA effects for the lines and testers, for duration of flowering and aril : rind ratio, indicating them as average general combiners. The data for days from full bloom to harvest revealed that the line G-137 and tester MH-1 were good general combiners, as the negative significant GCA effects are desirable and Ganesh and NT-1 were poor general combiners for this trait. For fruit yield, G-137 and NT-1 were considered as good general combiners whereas; Mridula, Kandhari Kabuli and MH-1 were designated as poor combiners. Various workers, Marin *et al*. (12) in papaya, and Masny *et al*. (13) in blackcurrant

Table 2. Estimates of genetic components of variance for different horticultural and quality traits in pomegranate.

Character (s)	σ^2GCA	σ^2SCA	σ^2A	σ^2D	σ^2A/ σ^2D (Variance ratio)
PH (m)	0.13	-0.01	0.26	-0.01	-26.00
PS(N-S) (m)	0.018	0.039	0.035	0.039	0.89
PS(E-W) (m)	-0.008	0.152	-0.017	0.152	-0.11
TV (m^3)	0.225	2.450	0.450	2.450	0.18
SG (mm)	-3.432	18.788	-6.865	18.788	-0.37
LA (cm^2)	-0.073	3.376	-0.147	3.376	-0.04
DF	0.007	4.209	0.014	4.209	0.003
FW (g)	973.587	1,472.012	1,947.175	1,472.012	1.32
FL (cm)	0.094	0.277	0.189	0.277	0.68
FB (cm)	0.091	0.390	0.183	0.390	0.46
NAF	2,080.778	2,816.810	4,161.556	2,816.810	1.48
A:R	-0.001	0.003	-0.002	0.003	-0.67
DFBH	8.887	1.436	17.773	1.436	12.37
FY (kg/tree)	0.053	0.250	0.106	0.250	0.42
TS (%)	0.208	0.485	0.415	0.485	0.86
RS (%)	0.174	0.157	0.349	0.157	2.22
NS (%)	-0.025	0.007	-0.049	0.007	-7.00
TSS (°B)	0.030	0.174	0.059	0.174	0.34
TA (%)	0.043	0.027	0.085	0.027	3.14
TSS/TA	0.784	0.740	1.568	0.740	2.12

PH = plant height,PS = plant spread, TV = tree volume, SG = stem girth, LA = leaf area, DF = duration of flowering, FW = fruit weight, FS = fruit size, FL = fruit length, FB = fruit breadth, NAF = number of arils per fruit, A:R = aril : rind ratio, DFBH = days from full bloom to harvest, FY = fruit yield, TSS = total soluble solids, TA = titratable acidity, TS = total sugars, RS = reducing sugars, NS = non-reducing sugars and TSS/TA = TSS : acid ratio

reported similar findings for fruit weight and fruit yield. For fruit size, the observations are supported by the findings of Karale (9) in pomegranate.

For biochemical traits namely total sugars, reducing sugars and TSS : acid ratio the parents Kandhari Kabuli and Bhagwa were found to be best general combiners and Mridula, G-137 and Ganesh as poor general combiners. Kandhari Kabuli was good general combiner and Mridula was a poor general combiner for total soluble solids. Mridula, G-137, Ganesh and NT-1 were found to be good general combiners, whereas, Kandhari Kabuli, Bhagwa and MH-1 poor general combiners for titratable acidity. Chua (3) reported similar results for total sugars and titratable acidity in strawberry. The findings contradicted Karale (9), because for TSS: acid ratio the GCA effects were found to be non-significant in pomegranate. Nevertheless, in the present analysis, the positive significant TSS : acid ratio may be due to the dominant effect of the daru (testers), which had higher value for the trait as observed by (Jalikop *et al.*, 8). All the lines and testers were considered as average general combiners for non-reducing sugars, because of non-significant GCA effects. The observations on TSS are in consonance with Karale (9) in pomegranate and Masny *et al.* (13) in strawberry. All these superior general combiners can be used in further breeding programmes.

In the present endeavour (Table 4), all the crosses showed non-significant SCA effects for plant height indicated them as average specific cross combiners. For plant spread, Kandhari Kabuli×*NT-1 (0.*30) in N-S direction and Bhagwa×NT-1 (0.36), Mridula×MH-1 (0.29), Kandhari Kabuli×NT-1 (0.26), and Ganesh×*MH-1 (0.18) in E-W direction were reported as good specific combiners, because they had positive SCA effects. T*he cross Bhagwa×NT-1 had high SCA effects and the parents showed poor×good GCA effects which indicated involvement of both additive and dominance gene action, thereby suggests reciprocal recurrent selection method is effective for the improvement of this trait. The data

Table 3. Estimates of GCA effects of parents for different traits in pomegranate.

Parent (s)	PH (m)	PS (m)		TV (m^3)	SG (mm)	LA (cm^2)	DF	FW (g)	FS		NAF	A:R	DFBH	FY (kg/ tree)	TSS (°B)	TA (%)	TS (%)	RS (%)	NS (%)	TSS/ TA
		N-S	E-W						FL (cm)	FB (cm)										
Line(s)																				
Mridula	0.17	0.03	0.21*	0.20	-1.38	0.62	0.20	-26.45*	-0.34*	-0.43*	-60.53*	-0.02	1.80	-0.29*	-0.64*	0.48*	-0.96*	-0.69*	-0.25	-2.01*
G-137	-0.48*	-0.35*	-0.31*	-1.63*	-2.87*	-0.72*	1.70	58.04*	0.77*	0.73*	96.63*	0.05	-4.53*	0.49*	-0.22	0.17*	-0.75*	-0.51*	-0.23	-1.07*
Kandhari Kabuli	0.50*	0.53*	0.36*	2.56*	4.45*	-1.20*	-1.13	-18.43*	0.13	0.09	-23.03*	-0.01	-0.53	-0.24*	0.71*	-0.42*	1.05*	0.63*	0.39	2.34*
Bhagwa	-0.25	-0.31*	-0.24*	-1.16*	-0.18	2.86*	-1.30	9.91*	0.004	0.14	51.97*	-0.06	0.63	0.17	0.29	-0.40*	1.23*	1.01*	0.21	1.75*
Ganesh	0.06	0.09	-0.03	0.04	-0.02	-1.56*	0.53	-23.06*	-0.56*	-0.53*	-65.03*	0.04	2.63*	-0.13	-0.14	0.18*	-0.57*	-0.45*	-0.12	-1.01*
Tester(s)																				
NT-1	0.27*	0.04	0.11*	0.46*	0.80	0.16	1.10	27.09*	0.28*	0.31*	32.38*	0.01	2.33*	0.26*	0.12	0.07*	0.23	0.22*	0.01	-0.03
MH-1	-0.27*	-0.04	-0.11*	-0.46*	-0.80	-0.16	-1.10	-27.09*	-0.28*	-0.31*	-32.38*	-0.01	-2.33*	-0.26*	-0.12	-0.07*	-0.23	-0.22*	-0.01	0.03
S.E. (gi) (lines)	0.14	0.12	0.09	0.43	1.25	0.31	1.16	4.49	0.12	0.12	10.08	0.03	1.01	0.08	0.16	0.05	0.24	0.15	0.25	0.28
S.E. (gj) (testers)	0.07	0.06	0.04	0.21	0.62	0.16	0.58	2.24	0.06	0.06	5.04	0.02	0.50	0.04	0.08	0.03	0.12	0.07	0.13	0.14
C.D. (gi) (lines)	0.30	0.24	0.18	0.90	2.62	0.66	2.44	9.43	0.25	0.25	21.18	0.07	2.12	0.17	0.33	0.11	0.50	0.31	0.53	0.59
C.D. (gj)(testers)	0.15	0.12	0.09	0.45	1.31	0.33	1.22	4.71	0.13	0.13	10.59	0.04	1.06	0.09	0.17	0.05	0.25	0.16	0.27	0.30

*Significant at 5% level of significance

Table 4. Estimates of SCA effects of hybrids for different traits in pomegranate.

Hybrid (s)	PH (m)	PS (m)		TV (m^3)	SG (mm)	LA (cm^2)	DF	FW (g)	FS		NAF	A:R	DFBH	FY (kg/ tree)	TSS (°B)	TA (%)	TS (%)	RS (%)	NS (%)	TSS/ TA
		N-S	E-W						FL (cm)	FB (cm)										
Mridula×NT-1	-0.10	-0.18	-0.29*	-1.01*	-1.09	1.05*	2.40	-8.64	-0.06	-0.04	35.13*	-0.01	1.00	-0.14	-0.29	0.17*	-0.35	-0.01	-0.33	-0.59
Mridula×MH-1	0.10	0.18	0.29*	1.01*	1.09	-1.05*	-2.40	8.64	0.06	0.04	-35.13*	0.01	-1.00	0.14	0.29	-0.17*	0.35	0.01	0.33	0.59
G-137×NT-1	0.15	-0.01	-0.15	-0.30	-2.31	-0.20	0.23	33.77*	0.38*	0.35*	31.97*	0.07	0.67	0.31*	0.26	-0.06	0.75*	0.29	0.44	0.18
G-137×MH-1	-0.15	0.01	0.15	0.30	2.31	0.20	-0.23	-33.77*	-0.38*	-0.35*	-31.97*	-0.07	-0.67	-0.31*	-0.26	0.06	-0.75*	-0.29	-0.44	-0.18
KK×NT-1	-0.07	0.30*	0.26*	1.87*	5.66*	1.54*	-2.93*	-23.06*	-0.51*	-0.53*	-36.37*	0.05	-0.67	-0.27*	0.46*	-0.15*	0.44	0.36*	0.07	1.09*
KK×MH-1	0.07	-0.30*	-0.26*	-1.87*	-5.66*	-1.54*	2.93*	23.06*	0.51*	0.53*	36.37*	-0.05	0.67	0.27*	-0.46*	0.15*	-0.44	-0.36*	-0.07	-1.09*
Bhagwa×NT-1	0.19	0.04	0.36*	0.45	-2.58	-0.54	-0.43	24.42*	0.41*	0.57*	-47.70*	-0.06	-2.17*	0.46*	-0.15	-0.06	-0.28	-0.27	-0.02	-0.11
Bhagwa×MH-1	-0.19	-0.04	-0.36*	-0.45	2.58	0.54	0.43	-24.42*	-0.41*	-0.57*	47.70*	0.06	2.17*	-0.46*	0.15	0.06	0.28	0.27	0.02	0.11
Ganesh×NT-1	-0.18	-0.14	-0.18*	-1.01*	0.32	-1.86*	0.73	26.49*	-0.22	-0.35*	16.97	-0.05	1.17	-0.36*	-0.29	0.09	-0.55*	-0.37*	-0.16	-0.56
Ganesh×MH-1	0.18	0.14	0.18*	1.01*	-0.32	1.86*	-0.73	-26.49*	0.22	0.35*	-16.97	0.05	-1.17	0.36*	0.29	-0.09	0.55*	0.37*	0.16	0.56
S.E. (sij)(crosses)	0.14	0.12	0.09	0.43	1.25	0.31	1.16	4.49	0.12	0.12	10.08	0.03	1.01	0.08	0.16	0.05	0.24	0.15	0.25	0.28
C.D.(sij)(crosses)	0.30	0.24	0.18	0.90	2.62	0.66	2.44	9.43	0.25	0.25	21.18	0.07	2.12	0.17	0.33	0.11	0.50	0.31	0.53	0.59

*Significant at 5% level of significance (KK = Kandhari Kabuli) showed that, the crosses Kandhari Kabuli×NT-1 (1.87), Mridula×*MH-1 (1.01) and Ganesh*×MH-1 (1.01) articulated significant positive SCA effects for tree volume, reported as good specific cross combinations. Among the above-mentioned crosses, in the cross combination Kandhari Kabuli×*NT-1*, the parents involved had good×*good* GCA effects indicated additive type of gene action and such crosses can be utilized by simple conventional method of breeding that is pedigree method. The significant positive SCA effects were observed in Kandhari Kabuli×NT-1 (5.66) represented as a best specific cross combiner for stem girth. The findings of plant height are in line with Chua (3), as he reported non-significant SCA effects in all the hybrids of strawberry for plant height. Similar results are also reported by Karale (9) in pomegranate for plant spread and tree volume.

In the case of duration of flowering, Kandhari Kabuli×MH-1 (2.93) had high positive significant SCA effects among all the crosses, indicating as best specific cross combination. For fruit weight and fruit size, the hybrids G-137×NT-1 (33.77), Ganesh×NT-1 (26.49), Kandhari Kabuli×MH-1 (23.06) and Bhagwa×NT-1 (24.42) identified as good specific combiners due to significant positive SCA effects. The parents involved in the hybrid G-137×NT-1 indicated to have good×good GCA effects for fruit weight and fruit size suggested additive gene action, so the selection process for these traits could be done in early stages. In the cross Ganesh×NT-1, parents designated as poor×good general combiners for fruit weight and fruit size,which stipulated non-additive gene action; meaning selection should be deferred to later stages. The data for number of arils per fruit revealed Bhagwa×MH-1 (47.70), Kandhari Kabuli×MH-1 (36.37), Mridula×NT-1 (35.13) and G-137×NT-1 (31.97) as good specific cross combiners. The cross combinations Bhagwa×MH-1 and Mridula×NT-1 had parents with good×poor and poor×good GCA effects, respectively for number of arils per fruit,which suggested the non-additive gene action, where the hybrid breeding method is successful for the development of the traits. The results are in consonance with the findings obtained by Zeinanloo *et al.* (17) in olive for fruit weight and fruit size.

Negative significant SCA effects were observed in Bhagwa×NT-1 (-2.17) which is desirable for the days from full bloom to harvest indicated as good specific cross combination. The crosses Bhagwa×NT-1 (0.46), Ganesh×MH-1 (0.36), G-137×NT-1 (0.31), and Kandhari Kabuli×MH-1 (0.27) indicated as good specific combiners for fruit yield. For both the traits days from full bloom to harvest and fruit yield Bhagwa×NT-1 had desirable SCA effects and the parents showed poor×good GCA effects, which indicated non-additive gene action. The parents in the cross G-137×NT-1 had good×good GCA effects stipulated additive gene action for fruit yield, thereby, indicating the role of conventional breeding methods to get stable high performance progenies. The findings for fruit yield are in close conformity with the observations of Masny *et al.* (13) in blackcurrant.

The data pertaining to biochemical traits showed that the crosses G-137×NT-1 (0.75) and Ganesh×MH-1 (0.55), had significant positive SCA effects, therefore, were found to be the best specific cross combiners for total sugars. For reducing sugars, the crosses having significant positive SCA effects were Ganesh×MH-1 (0.37) and Kandhari Kabuli×NT-1 (0.36) designated as good specific combiners. The cross combination Mridula×NT-1 involved parents having good×good GCA effects for reducing sugars. So they indicated additive gene action for these traits, hence pedigree method of conventional breeding can be used which can give stable progenies with high performance in the next generations. All the crosses for non-reducing sugars had non-significant SCA effects which reported them as average specific cross combiners. In case of total soluble solids, Kandhari Kabuli×NT-1 (0.46), for titratable acidity Mridula×NT-1 (0.17) and Kandhari Kabuli×MH-1 (0.15) were good specific combiners due to positive significant SCA effect, therefore, designated as a good specific cross combination. The hybrid Kandhari Kabuli×NT-1 showed good×good GCA effects for titratable acidity, therefore similar results i.e. additive gene action as that of reducing sugars were found. While, for TSS : acid ratio the cross combination Kandhari Kabuli×NT-1 (1.09) reported as a best specific combiner. The earlier study in strawberry by Chua (3) also observed similar results for total sugars and titratable acidity. For total soluble solids, earlier similar results have also been reported by Ciulca *et al.* (4) in strawberry.

The present research revealed that for most of the horticultural traits, the parents G-137 and Bhagwa were found to be promising based on GCA effects. So the breeder can use them in hybridization programme. The cross combinations G-137×NT-1 and Bhagwa×NT-1 based on the SCA effects were found superior for the desirable traits. These studies will pave the way for genetic analysis in fruit crops in general and pomegranate in particular.

AUTHORS' CONTRIBUTION

Conceptualization of research (Dogra R.K., Thakur D.S. and Rana V.S.); Designing of the experiments

(Dogra R.K., Thakur D.S and Rana V.S.); Contribution of experimental materials (Thakur D.S. and Rana V.S); Execution of field/lab experiments and data collection (Sharma A.); Analysis of data and interpretation (Dogra R.K. and Sharma A.); Preparation of the manuscript (Dogra R.K. and Sharma A.).

DECLARATION

The authors declare no conflict of interest

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