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RESEARCH ARTICLE

Gene Action Studies in Gynoecious Cucumber (*Cucumis sativum* L.) Lines under Mid Hill Conditions of Western Himalayas

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Genetic improvement of crop plants is a continuous process and plant breeders continuously strive for developing new varieties, which are high yielding and superior to the existing ones. The success of a breeding programme lies in the choice of appropriate parents and the breeding method followed. Therefore, the experiment was carried out involving gynoecious lines in cucumber at Palampur and Bajaura, to identify suitable parents and gather information on gene action. The line × tester analysis revealed significant differences due to lines, testers and line × tester interaction at both the locations for most of the traits, indicating appreciable diversity in the experimental material. Estimates of general combining ability effects, necessitates inclusion of lines G-3, G-1, Plp-Gy-1 and EC-5082 and the testers K-pap, Sel-75-2-10, K-90 and KL-1 for making crosses which was corroborated by the superiority of their cross combinations. The estimates of GCA and SCA variances pointed out that for majority of traits, non-additive gene action was in appreciable magnitude suggesting the exploitation of hybrid vigour in cucumber.

Key Words: Breeding, Cucumber, Gene action, Lines, Testers

Introduction

Cucumber (*Cucumis sativus* L.) is member of Cucurbitaceae family, which comprises 117 genera and 825 species in warmer parts of the world (Gopalakrishnan, 2007). Cucumber is a thermophillic and frost-susceptible crop, growing best at temperature above 20 ºC. Cucumber is thought to have originated in India (Harlan, 1975) because of the fact that *Cucumis sativus* var *hardwickii*, progenitor of cultivated cucumber is found in the Himalayan foothills of India. Today, cucumber is grown throughout the world in large commercial farms, glasshouses and small gardens.Its fruits are eaten at immature stage as refreshing salad vegetable and are said to have cooling effect, prevent constipation and are useful to jaundice patients. Globally, it is cultivated in 2,271,260 hectares areawith an annual production of 83,753,861 tonnes (Anonymous, 2017). Compared to this, the corresponding figures for India are 25,676 hectares and 1.61 lakh tons (Anonymous, 2017). Cucumber is both a leading commercial crop and popular home garden vegetable in low and mid hills of Himachal Pradesh and the crop brings lucrative returns to the hill farmers during July to October, when it is not produced in the adjoining plains.

After the first report of hybrid vigour in cucumber (Hayes and Jones, 1916), a large number of hybrids have been developed and almost ninety per cent of the total cucumber area planted is covered by hybrids in developed countries like USA, France, Germany, Netherlands, Russia and Japan. The development of hybrid cultivar became easy after gynoecious sex expression was obtained from a Korean cultivar. Gynoecious allele is dominant and cucumber hybrids involving gynoecious parent will bear high proportion of female flowers, resulting in earliness and good yield.The first gynoecious hybrid cultivar, 'Saprtan Dawn' was introduced in 1962 by CE Peterson.

Despite being home of cucumber, the work on breeding and improvement of cucumber has been rather limited in India. At national level, F_1 hybrid 'Pusa Sanyog' has been released by IARI, Katrain (Gill *et al*., 1973) by crossing gynoecious line, isolated from a Japanese variety 'Kaga Aomoga Fushinavi' with 'Green Long' of Naples, an Italian variety, which outyielded

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the recommended variety by 128.78 per cent. But this hybrid is confined to cooler and sub-tropical conditions. Dr. YS Parmar University of Horticulture and Forestry has also developed two hybrids KH-1 and KH-2 but under high rainfall areasthey perform poorly.

Development of new strains superior to the existing ones, with respect to yield and other desirable traits is one of the primary objectives of vegetable breeding. Higher productivity is the need of the hour, and can be met by adopting heterosis breeding. For exploitation of heterosis, choice of suitable parents is of utmost importance. The study of general combining ability (GCA) of parents and specific combining ability (SCA) of crosses provides information for selecting suitable parents and cross combinations, respectively.Of the different biometrical approaches now available to determine the genetic information from the performance of hybrids and to identify appropriate cross-combinations, the "Line × Tester" mating design as proposed by Kempthorne (1957) gives comparable estimate of the genetic make-up of genotypes.

For breeders, agro-ecological diversity of environments represents a double-edged sword. This diversity complicates breeding and testing of improved genotypes with adequate adaptation, but it also permits identification of extreme environmental conditions that guarantee selection pressure from important stresses (Ramagosa and Fox, 1993). Since the quantitative characters are considerably influenced by the environment, a study under different locations/ environments is likely to bring out genotype-environment interactions for precise estimates of the genetic variation and prediction of genetic advance under selection. Thus, the present investigation was undertaken to estimate the nature of combining ability and type of gene action with respect to yield and yield attributing traits in cucumber.

Materials and Methods

Description of locations

The present investigations were carried out at the Experimental Farms of the Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur and Hill Agricultural Research and Extension Centre, Bajaura, Kullu during *Kharif*, 2009.

The Palampur Experimental Farm is located at an elevation of about 1290.8 m above mean sea level with 32°8' North latitude and 76°3' East longitude, representing mid hill zone of Himachal Pradesh and has a sub-temperate climate with high rainfall (2,500 mm). The soil of this zone is silty clay loam with acidic reaction. The Bajaura Experimental Farm is situated at 31°8' North latitude and 77° East longitude at an elevation of 1,090 m above mean sea level. Bajaura falls under mid-hill, sub-humid zone (Zone-II) of the stateand is endowed with mild summer and cool winter with low monsoon rains. The soil of this location is sandy loam with high water-table.

Breeding material

The experimental material comprised of F_1 populations of 55 crosses, five gynoecious lines, 11 testers and two standard checks (Table 1). All the lines used as female parents were crossed to each of the testers by hand pollination in a line × tester model at Palampur. Simultaneously, parents were also maintained by selfing.

Experimental layout and cultural practices

The F_1 population of 55 crosses, 16 parents and two standard checks were grown in a completely randomized Block Design with three replications during summer-rainy seasons of 2009 in each environment. Seeds were sown in poly bags (size 6" × 3") on March 14 at Palampur and March 19, at Bajaura inside a poly-house and transplanted at 2-4 true leaf stage in the field on April 22, at Palampur and May 1 at Bajaura at an inter and intra-row spacing of 1.5 m and 0.5 m, respectively. The vines were staked within fortnight after transplanting. Recommended cultural operations were followed as per the package of practices for raising a healthy crop.

Data collection and statistical analysis

The agronomical and morphological traits investigated included: days to first female flower appearance, nodal position of first female flower, days taken to first picking, fruit length (cm), fruit diameter (cm), average fruit weight (g), number of marketable fruits per vine, marketable yield per vine (kg), harvest duration, number of primary branches per plant, vine length (m) and total soluble solids (%). Observations were recorded from five competitive plants in each entry and replication for the horticultural traits.The data recorded on 55 crosses along with 16 parents and two standard checks were subjected to analysis of variance, as per the model suggested by Panse and Sukhatme (1967).The variation among the hybrids was partitioned further into sources

Table 1. Germplasm of cucumber and their sources of procurement

S. No.	Genotype	Location
a) Lines		
1.	EC-5082	Regional Research Station, Indian Agriculture Research Institute, Katrain
2.	Plp-Gy-1 (Plp)	Department of Vegetable Science and Floriculture, CSK HPKV, Palampur
3.	G-1	Department of Vegetable Crops, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan
4.	G-3	-do-
5.	PCUCP-4	GB Pant University of Agriculture and Technology, Pantnagar, Uttrakhand
b) Testers		
1.	KL-1	Department of Vegetable Science and Floriculture, CSK HPKV, Palampur
2.	Khira Paprola (K-Pap)	-do-
3.	Japanese Long Green (JLG)	Regional Research Station, Indian Agricultural Institute, Katrain
4.	Poinsette	National Seeds Corporation, New Delhi
5.	DPC-1	Department of Vegetable Science and Floriculture, CSK HPKV, Palampur
6.	EC-173934	-do-
7.	Summer Green (SG)	-do-
8.	K-90	Department of Vegetable Crops, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan
9.	Sel-75-2-10	Department of Vegetable Science and Floriculture, CSK HPKV, Palampur
10.	K-75	Department of Vegetable Crops, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan
11.	KL-3	Department of Vegetable Science and Floriculture, CSK HPKV, Palampur
c) Checks		
1.	Solan Khira Hybrid-1	Department of Vegetable Crops, UHF, Solan
2.	Pusa Sanyog	Regional Research Station, IARI, Katrain

attributed to general combining ability (GCA) and specific combining ability (SCA) components in accordance with the procedure suggested by Kempthorne (1957). The per cent contribution of lines, testers and their interactions were calculated as per statistical procedures suggested by Singh and Chaudhary (1977).

Results and Discussion

Studies on combining ability

The combining ability studies evaluate the parental lines on the basis of their general combining ability (GCA) effects and the performance of these parents in specific cross combinations (SCA). General combining ability effects, being related to additive genetic effects, represent the fixable components of genetic variance and are used to classify the parents for the breeding behaviour in hybrid combinations, whereas, specific combining ability effects are related to non-fixable component of genetic variance (Hayman, 1960, Sprague, 1966).

Analysis of variance for combining ability

The analysis of variance for combining ability at pooled over environments (Table 2) revealed significant differences among hybrids for all the traits studied. Significant differences for mean sum of squares due to lines were observed for all the traits, when tested against mean sum of squares due to error. The mean sum of squares due to lines × environment and tester × environment were significant for all the traits, except nodal position of first female flower, fruit girth, number of primary branches and vine length in pooled analysis. Line × tester × environment interactions were found significant for all the traits against mean sum of squares due to error except fruit girth. The significance of mean squares due to lines × environment, testers × environment and (L vs T) × environment interactions for majority of the traits suggested that both parents as well as their interaction variances were influenced by the environment as also reported by Sudhakhar *et al.* (2005) and Sharma *et al*. (2006) with their set of breeding material and environment.

General combining ability (GCA) effects

The mean sum of squares due to lines and testers were significant for all the characters, hence GCA effects have been estimated for all the traits exhibiting significant mean sum of squares. The parents with general combining ability effects for different traits in pooled over environments have been presented in Table 3 and 4.

The results with regard to all the 16 parents for combining ability have been found to be variable as no single parent has exhibited significant GCA effects for all the traits. A perusal of GCA effects for earliness (days

Table 2. Analysis of variance for combining ability (pooled over environments) in cucumber

S. No.	Sources of variation	df	Days to first female flower appearance	Nodal position of first female flower	Days taken to first picking	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits per vine	Marketable yield per vine (kg)	Harvest duration	Number of primary branches	Vine length (m)	Total soluble solids (%)
1	Lines	4	30.739@**	1.705@**	12.675**	76.792@**	2.477@**	17509.700@**	15.123**	0.388**	91.159@**	0.787@**	2.920@**	0.875**
2	Testers	10	6.801**	0.401**	17.936**	87.221@**	2.804@**	4605.387**	22.592**	1.596**	1.482**	0.177**	0.990@**	0.246**
3	Line vs Tester	40	7.392**	0.831**	19.240**	18.573**	0.672**	3866.856**	11.216**	1.181**	24.737**	0.360**	0.334**	0.613**
4	Line ×Loc	4	32.099**	0.111	47.434**	5.421**	0.001	841.758**	1.187**	0.015	141.465**	0.001	0.002	0.630**
5	Tester ×Loc	10	2.740**	0.106	5.758**	3.678**	0.014	822.366**	1.166**	0.195**	32.140**	0.002	0.001	0.001
6	L vs T ×Loc	40	4.726**	0.285**	5.389**	3.158**	0.043	688.951**	1.964**	0.175**	17.730**	0.241**	0.058**	0.144**
	Error	216	0.233	0.060	0.343	0.356	0.020	12.115	0.042	0.002	0.407	0.093	0.011	0.030

* Significant at 5% level of significance when tested against MSS due to error
** Significant at 1% level of significance when tested against MSS due to error
@Significant at 5% level of significance when tested against MSS due to line x teste

Table 3. Estimates of general combining ability (GCA) effects of lines in F_1 generation at pooled over environments in cucumber

S.No.	Lines / Traits	EC-5082	Plp-Gy-1	G-1	G-3	PCUCP-4	SE (gi)±	SE (gi-gj) ±	CD(5%)
1	Days to first female flower appearance	-0.033	0.183**	-0.997**	-0.151*	0.998**	0.061	0.086	0.120
2	Nodal position of first female flower	0.184**	-0.044	-0.085**	0.004	-0.060**	0.026	0.037	0.051
3	Days taken to first picking	0.029	0.005	-0.377**	-0.227**	0.570**	0.072	0.101	0.140
4	Fruit length (cm)	1.043**	0.471**	0.570**	-1.190**	-0.893**	0.079	0.111	0.154
5	Fruit girth (cm)	-0.299**	0.156**	-0.030	0.064**	0.109**	0.019	0.026	0.037
6	Average fruit weight (g)	3.065**	-1.117**	-3.989**	4.177**	-2.136**	0.423	0.598	0.829
7	Marketable fruits per vine	0.047*	-0.015	0.591**	-0.027	-0.596**	0.023	0.033	0.046
8	Marketable yield per vine (kg)	0.040**	-0.007	0.054**	0.048**	-0.132**	0.004	0.006	0.008
9	Harvest duration	0.662**	0.094	-1.010**	2.224**	-1.969**	0.069	0.098	0.136
10	Number of primary branches	-0.042	0.047	0.128**	-0.081**	-0.052	0.031	0.044	0.060
11	Vine length (m)	0.040**	0.031**	-0.022**	-0.018**	-0.031**	0.006	0.008	0.011
12	Total soluble solids (%)	0.019	0.067**	-0.025	0.025	-0.086**	0.017	0.024	0.034

* Significant at 5% level of significance
** Significant at 1% level of significance

Table 4. Estimates of general combining ability (GCA) effects of Testers in F_1 generation at pooled over environments in cucumber

S. No.	Lines / Traits	KL-1	K-PAP	JLG	Poinsette	DPC-1	EC-173934	SG	K-90	Sel-75-2-10	K-75	KL-3	SE (gj)+	SE (gi-gj) +	CD (5%)
1	Days to first female flower appearance	0.282**	-0.898**	-0.598**	-0.272**	0.486**	0.265**	-0.234**	0.248**	-0.656**	0.309**	1.069**	0.091	0.128	0.178
2	Nodal position of first female flower	0.075	-0.143**	0.091*	-0.091*	0.000	-0.059	0.129**	0.091*	-0.004	-0.020	-0.070	0.039	0.055	0.076
3	Days taken to first picking	1.098**	-1.705**	-0.585**	-0.338**	-0.182	-0.164	0.141	0.448**	-0.687**	0.695**	1.279**	0.106	0.150	0.208
4	Fruit length (cm)	2.237**	-0.041	3.423**	-0.872**	-1.345**	-1.020**	-0.443**	-0.715**	-0.825**	-0.732**	0.334**	0.117	0.165	0.229
5	Fruit girth (cm)	-0.273**	0.236**	-0.464**	-0.065*	0.043	0.223**	-0.204**	0.092**	0.102**	-0.253**	0.563**	0.028	0.039	0.054
6	Average fruit weight (g)	4.422**	12.094**	-15.205**	-12.151**	-4.695**	4.290**	5.258**	15.007**	-8.427**	-12.198**	11.604**	0.627	0.887	1.230
7	Marketable fruits per vine	0.137**	1.650**	-0.057	-1.358**	0.355**	0.188**	0.045	-0.427**	1.189**	0.237**	-1.960**	0.035	0.049	0.068
8	Marketable yield per vine (kg)	0.106**	0.442**	-0.175**	-0.389**	0.008	0.092**	0.086**	0.080**	0.147**	-0.108**	-0.289**	0.006	0.009	0.012
9	Harvest duration	0.806**	2.776**	-1.467**	-3.811**	0.355**	0.378**	0.095	0.661**	0.759**	-2.563**	2.011**	0.103**	0.145	0.201
10	Number of primary branches	0.019	0.045	0.022	-0.234**	-0.051	0.061	-0.004	0.043	0.089	0.023	-0.012	0.046	0.065	0.090
11	Vine length (m)	0.042**	-0.071**	0.114**	-0.215**	0.010	-0.047**	-0.055**	0.084**	0.053**	0.039**	0.047**	0.008	0.012	0.016
12	Total soluble solids (%)	-0.021	-0.065*	-0.060*	0.061*	-0.022	0.066**	0.027	0.118**	0.184**	-0.141**	-0.146**	0.025	0.036	0.050

* Significant at 5% level of significance
** Significant at 1% level of significance

to first female flower appearance, nodal position of first female flower and days taken to first picking) revealed that G-1 and G-3 among lines and K-pap, JLG and Poinsette among testers with significant negative GCA effects were the best combiners across environments.

G-1, G-3 and EC-5082 among lines and K-pap, Sel-75-2-10, KL-1, EC-173934, SG and K-90 among testers exhibited the highest positive GCA effects for marketable yield per vine across the environments. Of these lines and testers, G-3, EC-5082, K-90, Sel-75-2-10, K-pap, SG, KL-1 and EC-173934 were also found to be best combiners for average fruit weight, marketable fruits per vine and fruit size (fruit length and fruit girth), thereby suggesting close association between GCA of the lines and testers for fruit yield with fruit number, fruit weight, and fruit size.

For plant growth characters, G-1 and Plp-Gy-1 among lines and KL-1, JLG, K-90 and Sel-75-2-10 among testers for number of primary branches and vine length were good combiners. For total soluble solids, Plp-Gy-1, K-90 and Sel-75-2-10 were observed good general combiners over the environments. Different parents expressing high desirable GCA in respect of yield and component traits have been reported by different workers by using different genetic materials and locations (Singh and Sharma 2006, Tiwari and Singh 2016 and Malav *et al*. 2018).

Additive parental effects as measured by GCA effects are of practical use to the breeders since non-allelic interactions are unpredictable. On the basis of present investigations for GCA effects, it may be concluded that the parents *viz.,* EC-5082, G-1, G-3, KL-1, K-Pap, Summer Green, K-90 and Sel-75-2-10 are good general combiners for yield and its component traits and may be utilized in hybridization programmes for getting transgressive segregants.

Specific combining ability (SCA) effects

Variances due to line × tester × location interaction was non-significant for fruit girth in pooled analysis. Consequently, SCA effects of the traits showing non-significant variances were not estimated. The specific combining ability (SCA) effects estimated for different traits have been presented in Table 5. No single cross could reveal significant SCA for all the traits. Majority of the cross combinations exhibiting desirable SCA effects, had at least one of the parents as good or average general combiner. Similar views have also been expressed by earlier researchers (Singh and Sharma 2006, Munshi *et al.,* 2006 and Yadav*et al.* 2007).

The cross combinations Plp × K-Pap, G-3 × Poinsette and G-1 × K-75 can be exploited to isolate transgressive segregants in early generations as they involve both parents with high GCA effects for earliness and marketable yield per vine, respectively. Similarly, in other cross combinations involving one good and other poor or average combiner may give desirable transgressive segregants in the later generations if the additive effect of one parent and complementary epistatic effects (if present in the cross) act in same direction and maximize the desirable plant attributes as reported by Sharma (1999).

In few cross combinations *viz.* PCUCP-4 × KL-3 (earliness), PCUCP-4 × JLG (marketable yield per vine) and PCUCP-4 × K-Pap (total soluble solids), although significant SCA effects were observed but these hybrids had both the parents as poor general combiners. This might be due to parental lines used in the present study had origin from the diverse genetic background and hence exhibited high SCA effects. These observations corroborate the views of Krishna Prasad and Singh (1994) who opined that, it is not necessary that parents having higher estimates of GCA effects would also give higher estimates of SCA effects, usually the highest estimates of SCA effects are obtained from crosses involving diverse parents. Both parents with high GCA effects when crossed had probably low magnitude of non-additive gene effects resulting in small degree of SCA effects. Therefore, recurrent selection for specific combining ability could be followed in the segregating generations, on the assumption that an important part of heterosis results from the non-linear interaction of genes at different loci from interaction between alleles at the same locus or from both causes in combination.

On the basis of present study for GCA and SCA effects, it may be concluded that cross combinations Plp-Gy-1 × K-pap, G-1 × K-pap, Plp-Gy-1 × K-90, G-1 × K-90 and G-3 × Sel-75-2-10 came out to be the best specific combiners for yield and yield contributing traits. Similar findings for identification of superior parental lines, tester and hybrids based on GCA and SCA effects for fruit yield and morphological characters in cucumber were reported by Kumar *et al.* (2013), Golabadi *et al.* (2015) and Tak *et al*. (2017).

Table 5. Estimates of specific combining ability (SCA) effects of crosses in F_1 generation in cucumber (pooled over environments)

S. No.	Traits Crosses	Days to first female flower appearance	Nodal position of first female flower	Days taken to first picking	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits per vine	Marketable yield per vine (kg)	Harvest duration	Number of primary branches	Vine length (m)	Total soluble solids (%)
1	EC-5082 × KL-1	0.700**	-0.159	0.260	0.684**	-	-58.490**	-0.263**	-0.750**	-7.774**	0.154	0.028	-0.250**
2	EC-5082 × K-pap	-0.286	-0.418**	-1.128**	-1.709**	-	-1.293	-0.944**	-0.184**	-1.187**	-0.320**	-0.024	0.010
3	EC-5082 × JLG	1.226**	-0.071	2.415**	-3.483**	-	-23.385**	-1.639**	-0.552**	-4.306**	0.069	-0.050**	-0.011
4	EC-5082 × Poinsette	-1.387**	0.138	0.255	-0.529*	-	-23.665**	-1.004**	-0.431**	-4.462**	0.025	0.127**	0.051
5	EC-5082 × DPC-1	1.566**	0.272**	2.037**	-1.102**	-	22.841**	-0.201**	0.241**	-1.267**	-0.057	-0.063**	0.074
6	EC-5082 × EC-173934	-0.757**	-0.073	-1.307**	0.936**	-	5.511**	2.001**	0.470**	1.822**	0.405**	0.104**	0.086
7	EC-5082 × SG	-0.784**	-0.119	-1.504**	-1.925**	-	10.478**	0.936**	0.315**	0.632**	0.286**	0.011	-0.065
8	EC-5082 × K-90	-0.435*	0.078	-0.461	2.554**	-	15.992**	0.484**	0.178**	4.233**	-0.119	-0.022	0.145*
9	EC-5082 × Sel-75-2-10	-1.257**	0.258**	-2.286**	1.541**	-	18.645**	-0.758**	0.095**	2.302**	0.002	-0.107**	0.078
10	EC-5082 × K-75	0.452*	0.055	0.582*	1.194**	-	7.229**	1.569**	0.420**	7.290**	-0.348**	0.098**	-0.197**
11	EC-5082 × KL-3	0.963**	0.039	1.138**	1.839**	-	26.137**	-0.182*	0.197**	2.717**	-0.097	-0.101**	0.079
12	Plp × KL-1	-0.016	-0.378**	-0.716**	0.427	-	6.215**	0.058	0.146**	4.322**	0.175	-0.028	0.125*
13	Plp × K-pap	-0.835**	-0.160	-0.774**	0.496	-	24.179**	0.755**	0.475**	0.394	0.208*	0.052**	-0.051
14	Plp × JLG	0.727**	0.135	0.693**	2.862**	-	-18.218**	0.881**	-0.067**	2.984**	0.119	0.052**	-0.201**
15	Plp × Poinsette	0.799**	0.249**	0.863**	-0.718**	-	31.166**	1.406**	0.612**	4.106**	0.318**	-0.014	0.103
16	Plp × DPC-1	-0.386	0.032	0.493*	0.295	-	42.723**	0.415**	0.553**	3.717**	0.143	0.056**	-0.097
17	Plp × EC-173934	-0.186	0.211*	0.272	-0.826**	-	4.410**	-0.819**	-0.126**	-0.195	0.158	-0.027	0.023
18	Plp × SG	-0.416*	0.029	0.245	0.624*	-	-4.443**	-1.434**	-0.366**	2.200**	-0.328**	0.031	0.046
19	Plp × K-90	1.768**	0.032	1.354**	-1.192**	-	-23.818**	-1.333**	-0.525**	-7.921**	-0.208*	-0.018	0.030
20	Plp × Sel-75-2-10	0.560**	0.037	1.245**	-0.187	-	-28.350**	-1.209**	-0.602**	-6.074**	-0.420**	-0.157**	-0.004
21	PlP × K-75	-2.012**	-0.200*	-3.671**	-0.695**	-	-21.596**	-0.079	-0.254**	-3.317**	0.063	-0.053**	-0.095
22	Plp × KL-3	-0.002	0.012	-0.005	-1.086**	-	-12.266**	1.360**	0.152**	-0.216	-0.228*	0.106**	0.120*
23	G-1 × KL-1	-0.670**	-0.175*	-0.442	1.669**	-	18.930**	0.056	0.237**	3.093**	0.194	-0.158**	0.060
24	G-1 × K-pap	-0.336	-0.124	-1.472**	0.430	-	20.739**	-0.081	0.134**	0.128	0.137	0.145**	-0.029
25	G-1 × JLG	0.711**	-0.102	1.265**	-0.517*	-	-19.626**	-0.498**	-0.337**	-5.135**	-0.100	0.005	0.099
26	G-1 × Poinsette	0.384	-0.171*	0.161	-0.652*	-	1.710	-1.908**	-0.327**	-2.790**	-0.261*	-0.045*	-0.105
27	G-1 × DPC-1	-0.791**	-0.025	-1.331**	0.164	-	-11.978**	1.159**	0.085**	-0.264	-0.085	0.064**	0.028
28	G-1 × EC-173934	0.008	0.151	0.667**	-0.050	-	20.876**	-1.430**	-0.052**	2.521**	-0.339**	-0.064**	-0.110
29	G-1 × SG	0.347	-0.015	-0.818**	0.482	-	4.140**	0.921**	0.264**	0.248	0.092	-0.006	0.046
30	G-1 × K-90	0.086	-0.103	0.541*	-1.063**	-	9.642**	0.537**	0.276**	2.738**	0.228*	-0.075**	-0.012
31	G-1 × Sel-75-2-10	1.102**	0.334**	2.010**	-1.349**	-	-24.920**	-0.535**	-0.438**	0.390	-0.167	0.133**	0.001
32	G-1 × K-75	-0.553**	0.098	-0.457	0.007	-	-0.993	2.994**	0.559**	2.128**	0.399**	0.040*	0.287**
33	G-1 × KL-3	-0.289	0.133	-0.123	0.877**	-	-18.520**	-1.214**	-0.400**	-3.057**	-0.097	-0.040*	-0.265**
34	G-3 × KL-1	-0.183	0.074	0.369	-1.121**	-	16.727**	0.364**	0.264**	0.362	0.044	0.067**	0.077
35	G-3 × K-pap	0.748**	0.512**	0.766**	0.057	-	-28.724**	0.473**	-0.225**	1.722**	0.135	-0.075**	-0.229**
36	G-3 × JLG	-1.302**	0.249**	-1.642**	-0.724**	-	19.047**	-0.708**	0.062**	0.632**	-0.467**	0.000	0.186**
37	G-3 × Poinsette	-1.545**	-0.265**	-2.047**	1.092**	-	5.480**	0.392**	0.117**	3.476**	-0.244*	-0.080**	-0.139*
38	G-3 × DPC-1	-0.775**	0.007	-1.428**	0.846**	-	-31.834**	0.937**	-0.217**	3.810**	0.181	-0.075**	-0.006
39	G-3 × EC-173934	0.196	-0.291**	-1.223**	-0.165	-	-24.215**	-1.466**	-0.562**	-8.462**	-0.264**	-0.068**	-0.110
40	G-3 × SG	0.501*	0.521**	1.531**	-0.825**	-	15.235**	0.307**	0.228**	3.321**	-0.083	0.001	0.049
41	G-3 × K-90	-0.789**	-0.441**	-1.862**	0.275	-	12.082**	1.359**	0.454**	3.754**	0.157	0.071**	0.038
42	G-3 × Sel-75-2-10	0.066	-0.347**	-0.473*	0.416	-	13.535**	1.424**	0.473**	0.282	0.341**	-0.019	0.001
43	G-3 × K-75	1.971**	-0.051	3.615**	0.897**	-	8.440**	-2.640**	-0.447**	-6.772**	0.057	0.076**	0.097
44	G-3 × KL-3	1.113**	0.032	2.393**	-0.748**	-	-5.773**	-0.443**	-0.147**	-2.125**	0.142	0.104**	0.035
45	PCUCP-4 × KL-1	0.169	0.639**	0.528*	-1.658**	-	16.619**	-0.214**	0.103**	-0.003	-0.568**	0.091**	-0.012
46	PCUCP-4 × K-pap	0.710**	0.190*	2.608**	0.726**	-	-14.901**	-0.203**	-0.201**	-1.057**	-0.160	-0.098**	0.299**
47	PCUCP-4 × JLG	-1.361**	-0.210*	-2.731**	1.862**	-	42.182**	1.964**	0.894**	5.825**	0.380**	-0.006	-0.073
48	PCUCP-4 × Poinsette	1.750**	0.048	0.768**	0.807**	-	-14.691**	1.114**	0.029*	-0.331	0.162	0.013	0.089
49	PCUCP-4 × DPC-1	0.386	-0.286**	0.228	-0.203	-	-21.751**	-2.311**	-0.663**	-5.997**	-0.181	0.018	0.001
50	PCUCP-4 × EC-173934	0.739**	0.003	1.592**	0.104	-	-6.582**	1.715**	0.270**	4.314**	0.041	0.055**	0.111
51	PCUCP-4 × SG	0.352	-0.415**	0.547*	1.644**	-	-25.410**	-0.731**	-0.441**	-6.401**	0.033	-0.037*	-0.076
52	PCUCP-4 × K-90	-0.630**	0.434**	0.428	-0.575*	-	-13.898**	-1.048**	-0.383**	-2.803**	-0.058	0.044*	-0.201**
53	PCUCP-4 × Sel-75-2-10	-0.472*	-0.283**	-0.496*	-0.422	-	21.090**	1.078**	0.473**	3.100**	0.243*	0.150**	-0.077
54	PCUCP-4 × K-75	0.143	0.097	-0.069	-1.404**	-	6.919**	-1.844**	-0.279**	0.671**	-0.171	-0.161**	-0.092
55	PCUCP-4 × KL-3	-1.786**	-0.216*	-3.403**	-0.882**	-	10.422**	0.479**	0.199**	2.681**	0.280**	-0.069**	0.030
	SE (Sij)±	0.203	0.087	0.237	0.261	-	1.403	0.078	0.014	0.230	0.102	0.018	0.057
	SE(sij-skl)±	0.287	0.123	0.336	0.369	-	1.984	0.110	0.020	0.325	0.145	0.026	0.081
	CD (5%)	0.397	0.170	0.465	0.511	-	2.749	0.152	0.027	0.450	0.201	0.036	0.112

* Significant at 5% level of significance

** Significant at 1% level of significance

Gene action

After the identification of appropriate parents and potential crosses, the next important step in a dynamic breeding programme is with respect to adoption of suitable breeding methodology for the purposeful management of generated variability which largely depends upon the type of gene action in the population for the traits under genetic improvement (Sprague 1966). The nature of gene action has been inferred from the estimates of GCA and SCA variances, which are presented in Table 6 for pooled analysis.

A perusal of the values indicated that the estimates of σ^2_{sca} were higher as compared to σ^2_{gca} (average) for all the traits studied, similarly reported by Pradhan *et al*. (2016), Bhutia *et al*. (2017) and Naik *et al.* (2018). It indicates predominant role of non-additive gene action, which means hybrid vigour could better be exploited for these traits. The results of analysis of variance for combining ability were also confirmed from the study of additive (σ^2A) and dominant (σ^2D) components of variance. In all the traits studied, where SCA variances were higher than GCA values, dominant components of variance (σ^2D) were also higher than the additive components (σ^2A) indicating the role of non-additive gene action. For fruit length, though SCA variances were higher but the value of σ^2D was low. This might be attributed to the fact that statistically GCA variance is the additive portion of the variability, but it also includes additive × additive and higher order of epistatic interaction.The results of present study are in accordance with the earlier researchers for the traits related to marketable yield and fruit size (Singh and Sharma, 2006, Munshi *et al*., 2006 and Yadav *et al*., 2007).

The results obtained in this study lead to the conclusion that the hybrids were less stable over the environments as compared to the lines and testers. Conclusively, it may be stated that non-additive gene action governs the traits studied and thus, hybrid vigour could better be exploited for these traits.

Proportional contribution of lines, testers and their interactions

In pooled analysis, the per cent contribution of line × tester interactions were found to be greater than the individual contribution of lines and testers for all the traits except fruit length, fruit girth, vine length and total soluble solids where per cent contribution of testers was greater than individual contribution of lines and line × tester interactions.

Table 6.Estimates of genetic components of variance and proportional (%) contribution of lines, testers and their interactions in cucumber (pooled over environments)

Components S. No.	Traits	σ^2 GCA (Average)	σ^2 GCA × Env.	σ^2 SCA	σ^2 SCA × Env.	σ^2 A	σ^2 D	Heritability (%) (Narrow sense)	Genetic Advance 5%	% Contribution of Lines (%)	Testers (%)	Interaction (%)
1	Days to first female flower appearance	0.317	0.70	1.090	1.50	1.268	2.179	27.790	0.750	26.548	20.105	53.347
2	Nodal position of first female flower	0.001	0.03	0.071	0.07	0.002	0.142	2.770	0.020	12.744	9.443	77.814
3	Days taken to first picking	0.051	1.29	2.930	1.68	0.206	5.860	5.420	0.190	4.403	24.661	70.937
4	Fruit length (cm)	1.123	0.10	1.827	0.94	4.493	3.653	54.110	2.270	18.404	48.634	32.961
5	Fruit girth (cm)	0.038	0.09	0.084	0.10	0.151	0.169	45.890	0.380	15.683	45.907	38.409
6	Average fruit weight (g)	27.371	14.00	581.863	228.11	109.483	1163.726	11.390	5.330	1.789	19.974	78.237
7	Marketable fruits per vine	0.197	0.07	1.954	0.64	0.787	3.909	13.920	0.420	5.662	37.286	57.053
8	Marketable yield per vine (kg)	0.004	0.01	0.197	0.06	0.016	0.394	4.330	0.040	2.456	24.455	73.089
9	Harvest duration	0.522	4.23	19.152	5.69	2.089	38.303	2.830	0.260	10.618	17.323	72.059
10	Number of primary branches	0.002	0.01	0.063	0.05	0.007	0.127	7.870	0.040	8.907	10.191	80.902
11	Vine length (m)	0.002	0.01	0.008	0.02	0.010	0.016	22.630	0.100	5.992	53.235	40.773
12	Total soluble solids (%)	0.003	0.01	0.016	0.04	0.013	0.032	3.510	0.020	10.234	69.426	52.982

After having an insight into the GCA and SCA effects and variances as well as additive (σ^2A) and dominant (σ^2D) components of variance, it may be worthwhile to effect improvement in cucumber by developing superior open-pollinated varieties through selection in segregating population for the traits associated with earliness, fruit length and fruit girth. Alternatively, exploitation of hybrid vigour or reciprocal recurrent selection, which capitalizes on both additive and non-additive variances, might be more effective for marketable fruits per vine, marketable yield per vine, average fruit weight, number of primary branches, harvest duration and vine length, which had either high or equal dominant (σ^2D) components of variance to that of additive (σ^2A) components.The hybrids in cucumber are likely to dominate on account of the gynoecious lines and the relatively ease in producing hybrid seed commercially. The inclusion of gynoecious lines in heterosis and gene action study may lead to conclusion quite contrary to the ones obtained with mostly monoecious lines.

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Conflict of Interest

The authors declared that they have no conflict of interest.

Contribution of authors

MS performed hybridization programme, field evaluation and statistical analysis. AV contributed in statistical analysis and manuscript writing. YS participated in all steps of evaluation and data compiling.

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