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Combining ability studies for earliness and yield in pumpkin (*Cucurbita moschata*) in *kharif* season

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Abstract
Gene action, Combining ability variance derived by crossing eight diverse pumpkin parents were studied through half diallel analysis including 28 F_1 hybrids for earliness and yield components. Data was recorded for seventeen characters. The mean squares due to GCA were significant for all the seventeen characters. The ratio of σ^2GCA/ σ^2sca suggested that non additive gene action had greater role with inheritance of characters. Out eight parents P1, P2 and P3 was the best general combiner as it showed high GCA effect in desirable direction for most of the traits. The best promising hybrids regarding sca effects for yield and majority of yield traits were P_1 x P_2, P_1 x P_3, P_2 x P_3, P_2 x P_5, P_2 x P_8 and P_3 x P_4. Hence these crosses can be utilized in further heterosis breeding for improvement in pumpkin.

Keywords: Combining ability, gene action, earliness, yield components, pumpkin (*Cucurbita moschata*)

Introduction
Pumpkin (*Cucurbita moschata*) is an important cucurbitaceous vegetable crop of India and principal ingredient of several culinary vegetables utilized at the immature and mature fruit stage. The mature fruits are used as vegetable and the seeds are also consumed as fried nuts. The fruits are rich in carotene. Pumpkin is placed as high value vegetable owing to its high productivity, nutritive value, good storability, long period of availability, better transport qualities and extensive cultivation both in tropical and subtropical parts of our country. In recent, pumpkin improvement programme is focused on heterosis breeding. Identification of suitable parents with good combining ability and derivation of best F_1 hybrids having better specific combining ability are prerequisite for exploitation of heterosis in desirable direction. Diallel mating design is most frequently used to determine nature and magnitude of gene action by estimating genetic components, GCA and SCA variances and their effects in self and cross pollinated crops as similar reported by Ray *et al*. (2015) [10]. Aravindkumar (2005) [2] reported that the ratio of GCA and SCA variance indicated non- additive genetic variances for days to first male and female flower opening, vine length, number of branches per vine, fruit length, number of fruits per vine and total yield per vine, whereas additive gene effects were appeared to be important for the expression of flesh thickness and fruit girth. At present main emphasis is being given to develop F_1 hybrids in pumpkin. The identification and selection of potential parents based on their combining ability is very essential for hybrid development. Keeping this view, the present studies were undertaken to identify the genetic architecture of characters related to earliness and yield components.

Material and Methods
The experimental material comprised of 28 F_1, 1 standard check (MPH-1) and 8 parents viz., P_1 (RHRPK-18), P_2 (RHRPK-19-2), P_3 (RHRPK-12), P_4 (RHRPK-9), P_5 (RHRPK-10), P_6 (RHRPK-4), P_7 (RHRPK-6) and P_8 (RHRPK-17-2). The complete sets of 37 genotypes were evaluated in a randomized block design with two replications during *kharif* season, 2015 at the AICVIP, Rahuri. The F_1^s and parents comprised of five plants spaced at 5m apart in rows with plant to plant spacing of 1m were planted in each experimental plot. All the recommended cultural practices and plant protection measures were followed to grow a healthy crop. Observations were recorded on 5 randomly selected plants for seventeen characters viz., days required for first female flower, days required for first male flower, node number at which first female flower appeared, node number at which first male flower appeared, sex ratio, days required to first harvest, length of vine, number of branches, length of fruit, fruit diameter, length of pedicel, flesh thickness, fruit weight, number of fruits per vine, yield per vine,

yield per plot, yield per tonne. The ANOVA for the experiment (RBD) was estimated accordingly to Panse and Sukhatme (1989) [9]. The combining analysis was performed as per the Griffing (1956) [4], Model I Method II), where parents and F_1's were included under the experiment excluding reciprocals.

Results and Discussion

The analysis of variance for combining ability (Table 1) indicated that mean square due to GCA and SCA were highly significant for almost all the traits, which indicated variation in parents and crosses and significant combination of additive and non-additive effects in the expression of the characters. Uma and Haribabu (2005) [14], Mohanty (2000a) [6] and El-Adl *et al.* (2014) [3] also reported significant GCA and sca variances for yield and its components in pumpkin. Information regarding GCA effect of the parent is of prime importance as it helps in successful prediction of genetic potentiality of crosses. Estimates of general combining ability (GCA) effects of parents (Table 2) showed that the parents P_1, P_2 and P_3 was the best general combiner as it showed high GCA effect in desirable direction for most of the traits.

Table 1: Analysis of variance for combining ability in 8 x 8 diallel of pumpkin

S. No	Replication	Season	GCA	SCA	Error	σ²GCA	σ²sca	σ²GCA /σ²sca
			M.S.S	M.S.S	M.S.S			
1.	Days at which first female flower appeared	K	5.227 **	2.036 **	0.038	0.51	0.51	0.25
2.	Days at which first male flower appeared	K	4.537 **	2.083 **	0.038	0.44	2.04	0.22
3.	Node number for the first female flower appeared	K	3.440 **	0.965 **	0.013	0.34	0.95	0.35
4.	Node number for the first male flower appeared	K	0.862 **	0.846 **	0.013	0.08	0.83	0.10
5.	Sex ratio	K	15.781 **	11.234**	0.042	1.57	11.19	0.14
6.	Days required to first harvest	K	19.684 **	30.408 **	0.04	1.96	30.36	0.06
7.	Vine length (m)	K	1.083 **	0.605 **	0.003	0.10	0.60	0.17
8.	Number of branches per vine	K	2.856 **	1.250 **	0.004	0.28	1.24	0.22
9.	Fruit length (cm)	K	28.063 **	18.799 **	0.084	2.79	18.71	0.14
10.	Fruit diameter(cm)	K	3.518 **	7.818 **	0.007	0.35	7.81	0.04
11.	Length of pedicel (cm)	K	2.372 **	1.576 **	0	0.23	1.57	0.15
12.	Flesh thickness (cm)	K	0.981 **	0.415 **	0.003	0.09	0.41	0.23
13.	Fruit weight (kg)	K	0.368 **	0.376 **	0	0.03	0.37	0.09
14.	Fruits per vine	K	0.226 **	0.108 **	0	0.02	0.10	0.21
15.	Yield per vine (Kg)	K	12.621 **	4.044 **	0.001	1.26	4.04	0.31
16.	Yield per plot (kg)	K	315.533**	101.107**	0.02	31.55	101.08	0.31
17.	Yield per hectare (tonne)	K	50.471 **	16.180 **	0.003	5.52	16.29	0.33

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

Table 2: Estimates of general combining ability effects for different characters in 8x8 diallel of pumpkin

Source	Days at which first female flower appeared	Days at which first male flower appeared	Node number for the first female flower appeared	Node number for the first male flower appeared	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (kg)
P_1	-0.508 **	-0.219 **	-0.779 **	-0.347 **	1.568 **	0.695 **	0.059 **
P_2	-0.990 **	-1.062 **	-0.841 **	-0.454 **	1.607 **	0.789 **	0.248 **
P_3	-0.995 **	-0.947 **	-0.319 **	-0.183 **	2.044 **	0.492 **	0.292 **
P_4	0.215 **	0.369 **	0.066	0.259 **	-1.184 **	-0.119 **	-0.258 **
P_5	0.517 **	0.477 **	0.223 **	0.046	-0.989 **	-0.712 **	-0.001
P_6	0.789 **	0.698 **	0.627 **	0.345 **	-0.954 **	-0.669 **	-0.094 **
P_7	0.384 **	0.247 **	0.619 **	0.160 **	-2.619 **	-0.366 **	-0.148 **
P_8	0.589 **	0.438 **	0.402 **	0.173 **	0.529 **	-0.112 **	-0.099 **
S.E. (gi) ±	0.057	0.057	0.033	0.034	0.085	0.024	0.004
C.D. 5%	0.117	0.117	0.068	0.069	0.173	0.050	0.009
C.D. 1 %	0.156	0.157	0.092	0.093	0.233	0.067	0.012

Continue

Source	Flesh thickness (cm)	Fruits per vine	Yield per vine (kg)	Yield per plot (kg)	Yield per hactare (tonne)	Sex ratio	Length of pedicel (cm)	Days required to first harvest	Number of branches per vine	Vine length (m)
P_1	0.207 **	0.192 **	1.121 **	5.603 **	2.241 **	-0.347 **	0.504 **	-1.363 **	0.586 **	0.271 **
P_2	0.353 **	0.201 **	1.617 **	8.087 **	3.234 **	1.405 **	0.578 **	-1.925 **	0.738 **	0.393 **
P_3	0.487 **	0.090 **	1.243 **	6.217 **	2.486 **	1.937 **	0.587 **	-1.483 **	0.568 **	0.450 **
P_4	-0.206 **	0.039 **	-0.553 **	-2.765 **	-1.106 **	-1.414 **	-0.536 **	-0.007	-0.338 **	-0.025
P_5	-0.189 **	-0.110 **	-0.594 **	-2.971 **	-1.188 **	0.904 **	-0.357 **	0.727 **	-0.269 **	-0.358 **
P_6	-0.309 **	-0.183 **	-1.156 **	-5.781 **	-2.312 **	-1.032 **	-0.480 **	1.315 **	-0.588 **	-0.246 **
P_7	-0.329 **	-0.108 **	-0.921 **	-4.606 **	-1.842 **	-1.090 **	-0.287 **	1.436 **	-0.427 **	-0.341 **
P_8	-0.014	-0.119 **	-0.757 **	-3.785 **	-1.514 **	-0.363 **	-0.009	1.300 **	-0.270 **	-0.144 **
S.E. (gi) ±	0.015	0.002	0.008	0.041	0.016	0.060	0.087	0.059	0.0178	0.016
C.D. 5%	0.031	0.006	0.016	0.084	0.033	0.123	0.177	0.120	0.036	0.033
C.D. 1 %	0.041	0.008	0.022	0.112	0.045	0.165	0.238	0.161	0.048	0.044

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

The parents P1 (-0.50), P2 (-0.99) and P3 (-0.99) showed significantly negative GCA effects for days at which first female flower appeared in *kharif* season. The parental lines P1 (-0.21), P2 (-1.06) and P3 (-0.94) displayed significant negative GCA effects for days at which first male flower appeared. The parents P1 (-0.77), P2 (-0.84) and P3 (-0.31) recorded negative GCA effects for node number at which first female flower appeared. The parental lines P1 (-0.34), P2 (-0.45) and P3 (-0.18) showed negative GCA effects for node number at which first male flower appeared. The parents P4 (-1.414), P7 (-1.090), P6 (-1.032) P8 (-0.363) and P1 (-0.347) displayed significant negative GCA effects for sex ratio in *kharif* season. The parental lines P1 (-1.36), P2 (-1.92) and P3 (-1.48) recorded negative GCA effects for days required to first harvest. The parents P1 (0.27), P2 (0.39) and P3 (0.45) showed positive GCA effects for vine length. The parents P1 (0.58), P2 (0.73) and P3 (0.56) showed positive GCA effects for number of branches per vine. The parental lines P1 (1.56), P2 (1.60), P3 (2.04) and P8 (0.52) showed positive GCA effects for fruit length in *kharif*. The parents P1 (0.69), P2 (0.78) and P3 (0.49) showed positive GCA effects for fruit diameter. For the length of pedicel P1 (0.50), P2 (0.57) and P3 (0.58) recorded significant positive GCA effects. The parents P1 (0.20), P2 (0.35) and P3 (0.48) showed positive GCA effects for flesh thickness. The parental lines P1 (0.05), P2 (0.24) and P3 (0.29) recorded significant positive GCA effects for fruit weight. The parents P1 (0.19), P2 (0.20), P3 (0.09) and P4 (0.03) showed positive GCA effects for number of fruits per vine. The parental lines P1 (1.12), P2 (1.61) and P3 (1.24) showed positive GCA effects for yield per vine. The parents P1 (5.60), P2 (8.08) and P3 (6.21) showed positive significant GCA effect for yield per plot. The parental lines P1 (2.24), P2 (3.23) and P3 (2.48) showed positive GCA effects for yield per hectare. In general the parent P_1, P_2 and P_3 were found good general combiner for yield and yield contributing characters which are worth considering in future breeding programme. These parents with good GCA effect for a character also exhibits good per se performance. Similar findings for some characters were also reported by Islam *et al.* (2012) [5] in sponge gourd and Tiwari *et al*. (2001) [13] in bitter gourd.

The estimates of Specific combining ability (SCA) effects are given in Table 3. Maximum sca effects were exhibited by the cross P_1 x P_2 (1.21) followed by P_1 x P_3 (1.20) for vine length were identified as good specific combiner. Uma and Haribabu (2005) [14] reported significant sca effects for vine length in pumpkin. For number of primary branches, maximum sca effects were exhibited by P_1 x P_3 (2.83) followed by P_2 x P_8 (2.05), P_2 x P_5 (1.56), P_5 x P_6 (1.27) and (1.26). Significant sca effects for number of branches per vine were also reported by Mohanty (2000a) [6] in pumpkin. For sex ratio, highest negative and significant sca effects was observed in the cross P_1 x P_5 (-4.504) followed P_3 x P_8 (-4.291) and P_2 x P_4 (-4.268). Among the 28 crosses the cross P_1 x P_3 (-1.94) followed by P_1 x P_6 (-1.68) in *kharif* exhibited maximum and significant sca effects in desirable direction for days to first female flowering. Significant sca effects for days to first female flowering were also reported by Sirohi *et al.* (1986) [12] in pumpkin. For days to first male flowering, maximum sca effects were exhibited by P_1 x P_3 (-1.90) followed by cross P_6 x P_8 (-1.87) and P_2 x P_8 (-1.74) P_4 x P_8 in *kharif* season. For node to first female flowering, maximum negative and significant sca effects was observed in the cross P_1 x P_3 (-1.87) followed by cross P_5 x P_6 (-1.33) and cross P_1 x P_2 (-1.22) in *kharif.* Significant sca effects for node to first female flower was also reported by Aastik *et al.* (2009) [1]; Mohanty and Mishra (2000) [8] and Mohanty (2001a) [7] in pumpkin.

Table 3: Estimates of specific combining ability effects for different characters in 8x8 diallel of pumpkin

Source	Days at which first female flower appeared	Days at which first male flower appeared	Node number for the first female flower appeared	Node number for the first male flower appeared	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (kg)
1x2	-1.276	-1.607	-1.228	-1.372	5.097	3.942	0.828
1x3	-1.945	-1.902	-1.87	-1.143	9.935	5.639	0.935
1x4	-0.391	-0.383	0.145	0.091	-3.512	-1.15	-0.055
1x5	-0.607	-0.661	0.188	-0.627	-5.257	0.043	-0.009
1x6	-1.68	-0.977	0.384	0.25	2.408	0.46	-0.379
1x7	0.53	1.239	-0.808	0.074	-2.003	1.097	-0.5
1x8	-0.265	0.048	-0.231	0.402	1.1	-0.107	-0.565
2x3	-0.063	-0.559	-0.778	-0.686	4.201	3.245	0.086
2x4	-0.634	-0.185	0.807	0.387	-2.341	-2.244	-0.644
2x5	-1.165	-1.648	1.45	-0.615	4.739	4.099	0.409
2x6	0.162	1.281	-0.754	0.396	-0.456	-2.994	-0.153
2x7	-0.123	0.017	-0.286	-0.839	-0.542	-0.997	-0.573
2x8	-1.633	-1.744	-1.079	-0.742	6.186	3.249	0.417
3x4	-1.198	-1.255	-1.105	-0.999	2.412	4.053	0.572
3x5	-0.23	0.152	-0.222	-0.141	0.717	-0.754	-0.665
3x6	-0.567	-0.155	1.224	0.385	-1.643	-0.397	-0.217
3x7	0.163	-0.033	1.482	0.2	-5.229	-0.74	0.452
3x8	-1.292	-1.399	-1.051	-0.353	-0.851	-1.454	0.073
4x5	-1.425	-0.764	-0.367	0.132	1.62	0.257	1.015
4x6	-0.553	-0.915	-0.311	-1.176	-0.44	-0.756	-0.497
4x7	-1.198	-1.349	-0.073	-0.732	3.359	-1.089	-0.063
4x8	1.147	0.79	0.064	0.076	-4.773	1.797	-0.652
5x6	1.296	0.577	-1.338	-1.339	-2.135	0.807	1.286
5x7	1.726	0.373	-0.81	0.611	0.329	1.544	-0.87
5x8	0.211	-0.318	0.807	0.358	-4.593	0.98	-0.242
6x7	0.223	-0.178	0.666	-0.023	-2.806	0.461	0.508
6x8	-1.197	-1.874	-0.237	-0.22	-0.378	1.407	0.124

7x8	0.113	-0.618	0.211	-1.186	-2.229	-0.596	0.938
S.E.±	0.176	0.177	0.103	0.104	0.262	0.075	0.014
C.D.at5%	0.358	0.360	0.210	0.212	0.532	0.153	0.029
C.D. 1 %	0.481	0.483	0.283	0.285	0.714	0.205	0.038

Continue

Source	Flesh thickness (cm)	Fruits per vine	Yield per vine (kg)	Yield per plot (kg)	Yield per hactare (tonne)	Sex ratio	Length of pedicel (cm)	Days required to first harvest	Number of branches per vine	Vine length (m)
1x2	1.136	0.267	3.688*	18.442	7.378	5.575	2.073	-6.004	1.275	1.215
1x3	1.312	0.488	5.152*	25.759	10.304	6.293	2.625	-7.446	2.835	1.208
1x4	-0.325	-0.231	-1.226*	-6.129	-2.452	-2.956	-0.582	-0.758	-0.003	0.133
1x5	-0.067	-0.112	-0.528*	-2.641	-1.057	-4.504	0.688	-2.822	0.027	-0.409
1x6	-0.217	0.155	-0.416*	-2.078	-0.832	-2.468	0.362	-2.245	-0.304	0.204
1x7	-0.507	0.016	-1.364	-6.819	-2.728	-4.186	-1.482	-0.201	-0.23	-1.526
1x8	-0.562	-0.203	-2.391	-11.955	-4.782	-3.207	-0.439	-0.73	-0.426	0.192
2x3	0.262	0.154	0.885	4.426	1.772	0.891	0.86	-4.884	1.263	0.536
2x4	-0.306	-0.08	-2.192	-10.962	-4.384	-4.268	-0.326	-0.38	-0.37	-0.264
2x5	0.928	0.234	2.235	11.173	4.47	1.774	1.514	-2.859	1.56	0.679
2x6	-0.482	-0.208*	-1.254	-6.271	-2.507	-2.87	-1.512	-0.183	-0.546	-1.318
2x7	-0.713	-0.073*	-1.848	-9.24	-3.695	-2.772	-1.545	0.861	-0.842	-0.573
2x8	1.223	0.388*	2.823	14.113	5.646	3.041	1.817	-6.667	2.052	0.580
3x4	0.815	0.206*	2.47	12.35	4.941	2.41	1.005	-3.632	1.009	0.194
3x5	-0.631	-0.04*	-1.845	-9.223	-3.689	-0.118	-1.195	1.964	-0.83	-0.538
3x6	-0.076	-0.227*	-1.467	-7.337	-2.934	0.318	0.808	-0.625	-0.141	0.475
3x7	0.253	-0.387*	-0.719	-3.595	-1.438	-2.204	-0.244	-3.576	-0.163	-0.305
3x8	0.199	-0.226*	-0.934	-4.672	-1.868	-4.291	0.377	-3.309	-0.709	0.373
4x5	0.076	-0.484*	0.361	1.805	0.722	-1.487	0.248	-5.013	0.247	0.512
4x6	0.131	0.164*	-0.418	-2.089	-0.836	-0.871	0.372	-4.601	0.366	-0.775
4x7	0.226	0.239*	0.89	4.452	1.781	0.427	0.539	-1.887	0.704	0.770
4x8	-0.804	0.02**	-1.486	-7.429	-2.972	-3.12	-0.13	0.079	-0.367	-0.127
5x6	-0.11	-0.627*	-0.112	-0.558	-0.224	2.231	-0.247	-2.335	0.511	1.059
5x7	-0.261	0.088*	-1.526	-7.631	-3.052	0.969	-0.97	-1.456	-0.285	-0.146
5x8	-0.045	-0.011	-0.452	-2.258	-0.903	0.622	0.422	-1.655	0.404	-1.218
6x7	0.309	-0.139*	0.853	4.267	1.707	-1.795	1.123	-1.045	0.604	0.792
6x8	-0.115	-0.328*	-0.851	-4.257	-1.703	-0.442	-0.196	-1.238	-0.392	0.020
7x8	0.144	-0.388*	0.469	2.344	0.938	-0.184	0.001	-2.364	-0.354	1.015
S.E.±	0.047	0.009	0.025	0.126	0.050	0.186	0.087	0.181	0.054	0.050
C.D.at5%	0.095	0.018	0.051	0.257	0.103	0.378	0.177	0.368	0.110	0.102
C.D. 1 %	0.128	0.024	0.069	0.345	0.1385	0.508	0.238	0.493	0.148	0.137

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

For node to first male flowering, maximum negative and significant sca effects was observed in the cross P_1 x P_2 (-1.37) followed by P_5 x P_6 (-1.34), P_7 x P_8 (-1.18) and P_1 x P_3 (-1.14 and -1.20) in *kharif*. For number of fruits per vine, highest positive and significant sca effects was observed in the cross P_1 x P_3 (0.48) followed by P_2 x P_8 (0.38) and P_1 x P_2 (0.26) in *kharif* season. The significant sca effect for number of fruits per vine in pumpkin was also reported by Mohanty (2000a) [6] and Sirohi *et al.* (1985) [11]. For average fruit weight, highest positive and significant sca effects was observed in the cross P_5 x P_6 (1.28) in *kharif* season followed by cross P_4 x P_5 (1.01), P_7 x P_8 (0.93), P_1 x P_3 (0.93) and P_1 x P_2 (0.82). For fruit diameter, highest positive and significant sca effects was observed in the cross P_1 x P_3 (5.63) followed by P_2 x P_5 (4.09), P_3 x P_4 (4.05), P_1 x P_2 (3.94), P_2 x P_3 (3.24) and P_2 x P_8 (3.24) in *kharif* season. For fruit length, highest positive and significant sca effects was observed in the cross P_1 x P_3 (9.93) followed by P_1 x P_2 (5.09), P_2 x P_3 (4.20), P_2 x P_5 (4.73) and P_2 x P_8 (6.18). The cross P_1 x P_3 (1.31) followed by P_2 x P_8 (1.22) and P_1 x P_2 (1.13) exhibited positive and significant sca effects for flesh thickness. For length of pedicel, cross P_1 x P_3 (2.62) followed by P_1 x P_2 (2.07) P_2 x P_8 (1.81) and P_2 x P_5 (1.51) exhibited positive and significant sca effects for length of pedicel. The cross P_1 x P_3 (5.15) followed by P_1 x P_2 (3.68), P_2 x P_8 (2.82), P_3 x P_4 (2.47) and P_2 x P_5 (2.23) was recorded as good specific combiners for fruit yield per vine, possessing significantly high sca effects. For fruit yield per plot P_1 x P_3 (25.75) exhibited positive and significant sca effects followed by P_1 x P_2 (18.44), P_2 x P_8 (14.11), P_3 x P_4 (12.35) and P_2 x P_5 (11.17). For fruit yield per hectare the crosses P_1 x P_3 (10.30) followed by cross P_1 x P_2 (7.37), P_2 x P_8 (5.64), P_3 x P_4 (4.94) and P_2 x P_5 (4.47) was recorded as good specific combiners in both *kharif* season. For exploitation of the heterosis, the information on GCA effects should be supplemented with sca effects and hybrid performance. Heterosis in F_1^S indicates operation of non-additive gene effects, but it cannot give any idea about the relative magnitude of non-additive (dominance + epistasis) and additive gene action. Hence, analysis of combining ability is one of the potential tools for identifying prospective parents to develop commercial F_1 hybrids (Griffing, 1956) [4].

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