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Genetic architecture and trait relationship in segregating populations of sweet pepper (*Capsicum annuum*) under shade house conditions*

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Sweet pepper (*Capsicum annuum* L.) is an annual herbaceous vegetable crop with specific identity also known as bell pepper, *shimla mirch*, green pepper and capsicum. It is one of the most popular and highly remunerative crop grown for fresh fruit throughout the world. Increase in demand and the area under cultivation necessitates improved varieties in this crop. Development of good inbred lines is the basic need for the development of improved varieties. The potential inbreds can also be helpful in exploiting the genetic and cytoplasmic male sterility available in this crop. Hence, an attempt was made to isolate such inbred lines which have desirable horticultural traits, better quality coupled with high yield potential, by taking the leading commercial hybrids having good export potential.

The gain from selection in a crop breeding programme depends on the amount of variability for the economic characters in the population. The selection process is complicated by the complex nature of yield by interplaying with its component characters. A better understanding of the contribution of each trait in building-up the genetic make-up of the crop may be obtained through correlation. The path coefficient analysis further elucidates the intrinsic nature of association of component traits by determining direct and indirect contribution of these traits to yield. The present investigation was therefore, undertaken to assess the magnitude of variability and to determine the nature and magnitude of correlation among different traits and their direct and indirect effects on fruit yield in segregating populations of sweet pepper.

The present investigation was conducted during 2008–09 at the Main Agriculture Research Station (MARS), Saidapur farm, UAS, Dharwad. The experimental material comprised F_2 populations of commercial sweet pepper hybrids 'Golden Summer' and 'Orobelle'. These two F_2 populations were grown in an unreplicated yield trial under shade house with misting facility. Seedlings were raised in trays by using the coco peat as media and 35-day-old seedlings were used for transplanting in shade house.

Land area inside the shade house was thoroughly dug to a depth of 20–25 cm and soil brought to fine tilth. Then beds of convenient size (length 31.5 cm, width 1 m and height of 15 cm) were prepared out of mixture of red soil + farmyard manure + vermicompost (1 kg/m^2) and neem cake (200 g/m^2). The beds were separated 50 cm apart to enable easy cultural operation, like spraying, harvesting etc. Pinching, irrigation, fertilizer application, weeding and plant protection measures were carried out from time to time. Observations were carried out on 500 plants in each F_2 population for 16 characters, viz plant height at maturity, plant stem girth, fruits/plant, fruit weight, fruit length, fruit diameter, fruit shape index, fruit surface area, fruit volume, stalk length, fruit pericarp thickness, seeds/fruit, locules/fruit, total soluble solids, fruit shelf life, fruit yield/plant.

The phenotypic and genotypic coefficient of variation was computed according to Burton and Devane (1953). The heritability and genetic advance as per cent of mean was worked out as per the method of Hanson *et al.* (1956) and Robinson *et al.* (1949), respectively. Other genetic parameters path analysis were calculated following the method suggested by Wright (1921).

Wide variation was observed for most of the characters (Table 1). Both the populations showed higher mean and wide range of values for all the 16 characters studied. Phenotypic coefficient of variation (PCV) was more than their genotypic coefficient of variation (GCV) for all the traits indicating influence of environment on expression of these traits.

*Short note

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Table 1 Genetic variability parameters for different quantitative traits in F_2 populations of sweet pepper hybrids 'Golden Summer'and 'Orobelle'

Traits	hybrids	Mean	Range	PV	GV	PCV	GCV	h²	GA	GAM
PHT	GS	138.26	46–235	1076.76	465.82	23.73	15.61	43.26	29.24	21.15
	OR	134.42	65–233	873.44	358.70	21.99	14.09	41.07	25.00	18.60
PSG	GS	2.84	0.90–5.00	0.55	0.17	17.11	9.45	30.48	0.47	10.74
	OR	3.23	1.10–5.10	0.42	0.13	14.05	7.72	30.14	0.40	8.73
FPP	GS	8.08	4.0–16.0	3.97	1.73	24.66	16.30	43.70	1.79	22.20
	OR	7.63	4.0–16.0	3.43	1.31	24.28	15.02	38.29	1.46	19.15
FW	GS	110.91	40–236.67	1242.21	806.53	31.78	25.61	64.93	47.14	42.50
	OR	140.72	33.33–270	1817.77	1217.45	30.30	24.80	66.97	58.82	41.80
FL	GS	7.84	3.8–11.2	1.60	1.33	16.16	14.69	82.64	2.16	27.51
	OR	7.21	2.93–10.87	1.52	0.80	17.11	12.44	52.87	1.34	18.63
FD	GS	6.15	3.53–8.6	0.70	0.28	13.63	8.59	39.73	0.69	11.15
	OR	7.27	4.27–10.3	1.29	0.99	15.63	13.67	76.49	1.79	24.63
FSI	GS	1.29	0.69–2.1	0.05	0.04	17.43	14.72	71.31	0.33	25.60
	OR	1.01	0.55–1.58	0.03	0.02	16.81	13.68	66.24	0.23	22.94
FSA	GS	76.22	29.82–138.71	333.89	205.86	23.97	18.82	61.65	23.21	30.45
	OR	83.47	23.03–149.68	526.60	323.60	27.49	21.55	61.45	29.05	34.80
FV	GS	79.24	18.34–196.83	764.18	459.95	34.89	27.06	60.19	34.28	43.25
	OR	103.77	18.37–240.17	1751.22	1164.67	40.33	32.89	66.51	57.33	55.25
STL	GS	3.55	1.4–6.1	0.56	0.26	21.01	14.44	47.24	0.73	20.45
	OR	3.95	1.6–7.03	1.05	0.86	25.95	23.43	81.51	1.72	43.58
PTN	GS	0.49	0.2–0.83	0.0097	0.01	20.03	17.33	74.89	0.15	30.90
	OR	0.51	0.23–.87	0.01	0.01	22.81	20.32	79.36	0.19	37.28
SPF	GS	121.44	14–261.66	2443.26	1486.76	40.70	31.75	60.85	61.96	51.02
	OR	125.38	0–321.67	4158.17	1740.41	51.43	33.27	41.86	55.60	44.35
FLC	GS	3.28	2–5.67	0.40	0.14	19.21	11.35	34.93	0.45	13.82
	OR	3.53	2.0–6.0	0.51	0.39	20.33	17.67	75.54	1.12	31.64
TSS	GS	6.53	3.56–9	0.81	0.19	13.75	6.74	24.04	0.44	6.81
	OR	6.35	2.9–9.76	1.60	1.09	19.90	16.46	68.47	1.78	28.07
FSL	GS	6.56	4–10	1.27	0.06	17.21	3.84	4.99	0.12	1.77
	OR	6.73	3.0–10.0	1.46	0.09	17.97	4.38	5.94	0.15	2.20
YPP	GS	661.92	240–1740	77505.00	27188.33	42.06	24.91	35.07	201.18	30.39
	OR	817.68	260–1640	90995.13	28163.52	36.89	20.52	30.95	192.32	23.52

PHT, Plant height at maturity; PSG, plant stem girth; FPP, fruits/plant; FW, fruit weight; FL, fruit length; FD, fruit diameter; FSI, fruit shape index; FSA, fruit surface area; FV, fruit volume; STL, stalk length; PTN, fruit pericarp thickness; SPF, seeds/fruit; FLC, locules/fruit; TSS, total soluble solids; FSL, fruit shelf-life; YPP, fruit yield /plant

However, higher PCV and GCV were observed for fruit weight, fruit volume, seeds/fruits and fruit yield/plant. Similar observations were also made by Manju and Sreelathakumary (2002), Sreelathakumary and Rajamony (2004), Yadwad (2004), Singh *et al.* (2009). Thus, the major portion of variation for the economically important characters was contributed by genotypic components, indicating the possibility of improving these traits by adopting proper selection methods. For the characters fruit surface area, pedicel length and pericarp thickness, the population 'Orobelle' recorded high PCV and GCV, but the population 'Golden summer' showed high PCV coupled with moderate GCV.

Heritability coupled with genetic advance is more effective and reliable in predicting the results and the effect of selection. High heritability coupled with high genetic advances as percentage of mean was recorded for the characters fruit weight, fruit shape index, fruit surface area, fruit volume and pericarp thickness in both the F_2 populations. However, for the character fruit diameter, fruit stalk length and number of locules/fruit, the population 'Orobelle' showed high heritability and genetic advances as percentage of mean. Whereas 'Golden Summer' showed the moderate heritability coupled with high genetic advances as percentage of mean for the same characters. But for the characters fruit length and seeds/fruit the population 'Golden summer' showed high heritability and genetic advances as percentage of mean. Whereas 'Orobelle' showed moderate heritability coupled with high genetic advances as percentage of mean. This is in accordance with the reports made by Sonia *et al.* (2007) and Sharma *et al*. (2010) in their study on 25 and 23 diverse genotypes of bell pepper, respectively. Hence, these fruit

Table 2 Phenotypic correlations among different quantitative traits in the F_2 population of sweet pepper hybrids 'Golden Summer' and 'Orobelle'

		PHT	PSG	FPP	FWT	FLT	FDM	FSI	FSA	FVM	STLT	PTN	SPF	FLC	TSS	FSL	YPP
PHT	GS	1	0.430**	0.069	0.261**	0.222*	0.151	0.081	0.235*	0.216*	0.226*	0.086	0.041	0.031	0.006	0.07	0.218*
	O	1	0.197*	–0.037	0.148	0.132	0.076	0.081	0.126	0.124	0.103	0.093	0.044	0.075	0.115	0.065	0.146
PSG	GS		1	0.029	0.220*	0.193*	0.273**	–0.029	0.279**	0.292**	0.146	0.208*	0.037	–0.058	–0.03	0.051	0.13
	O		1	0.012	0.169	0.094	0.171	–0.062	0.159	0.179	0.006	0.068	0.1	0.052	–0.024	–0.075	0.157
FPP	GS			1	–0.014	0.055	0.002	0.053	0.04	0.033	0.044	0.124	0.002	–0.004	–0.036	–0.03	0.555**
	O			1	–0.191*	–0.049	–0.123	0.063	–0.102	–0.122	–0.063	–0.157	–0.129	–0.086	0.06	–0.079	0.469**
FW	GS				1	0.490**	0.610**	–0.02	0.676**	0.702**	0.290**	0.181	0.388**	0.134	–0.068	0.099	0.743**
	O				1	0.609**	0.608**	0.056	0.707**	0.692**	0.225*	0.287**	0.503**	0.094	–0.071	0.038	0.731**
FL	GS					1	0.325**	0.655**	0.851**	0.693**	0.280**	0.218*	0.133	–0.075	–0.081	0.112	0.400**
	O					1	0.526**	0.556**	0.876**	0.751**	0.104	0.190*	0.415**	–0.089	–0.02	–0.002	0.489**
FD	GS						1	–0.486**	0.766**	0.887**	0.332**	0.213*	0.280**	0.099	–0.082	0.11	0.443**
	O						1	–0.398**	0.861**	0.931**	0.1	0.168	0.302**	0.052	0.032	0.055	0.441**
FSI	GS							1	0.169	–0.064	–0.021	0.04	–0.1	–0.163	–0.015	0.02	0.027
	O							1	0.099	–0.094	0.022	0.035	0.152	–0.147	–0.044	–0.054	0.092
FSA	GS								1	0.966**	0.372**	0.261**	0.251**	0.015	–0.099	0.137	0.525**
	O								1	0.974**	0.14	0.209*	0.416**	–0.013	0.005	0.026	0.536**
FV	GS									1	0.372**	0.255**	0.282**	0.055	–0.1	0.138	0.539**
	O									1	0.163	0.200*	0.386**	0.025	0.021	0.034	0.510**
STL	GS										1	0.171	0.15	0.225*	–0.085	0.013	0.257**
	O										1	0.132	0.257**	0.052	–0.065	–0.023	0.129
PTN	GS											1	0.061	–0.08	–0.083	0.039	0.209*
	O											1	0.267**	0.037	–0.014	0.103	0.156
SPF	GS												1	0.039	0.045	0.01	0.295**
	O												1	0.122	–0.061	0.021	0.330**
FLC	GS													1	0.042	0.025	0.096
	O													1	–0.033	0.041	0.031
TSS	GS														1	0.044	–0.075
	O														1	–0.075	–0.003
FSL	GS															1	0.057
	O															1	–0.001
YPP	GS																1
YPP	O																1

* Significant at 5% level of probability, ** Significant at 1% level of probability

PHT, Plant height at maturity; PSG, plant stem girth; FPP, fruits/plant; FW, fruit weight; FL, fruit length; FD, fruit diameter; FSI, fruit shape index;

FSA, fruit surface area; FV, fruit volume; STL, stalk length; PTN, fruit pericarp thickness; SPF, seeds/fruit; FLC, locules/fruit; TSS, total soluble solids; FSL, fruit shelf-life; YPP, fruit yield /plant

Table 3 Direct and indirect effects of different quantitative traits on fruit yield in F_2 population of sweet pepper hybrids 'Golden Summer' and' Orobelle'

		PHT	PSG	FPP	FWT	FLT	FDM	FSI	FSA	FVM	STLT	PTN	SPF	FLC	TSS	FSL	r
PHT	GS	–0.0029	–0.0248	0.0394	0.1929	–0.0551	–0.0693	–0.0117	0.1382	0.0049	0.0068	0.0016	0.0002	–0.0004	0.0001	0.0002	0.2200*
	O	0.0426	–0.0002	–0.0253	0.1267	–0.0485	0.0015	0.0117	0.0670	–0.0266	–0.0025	0.0014	–0.0004	0.0006	0.0014	0.0006	0.1500
PSG	GS	–0.0012	–0.0577	0.0169	0.1632	–0.0476	–0.1248	0.0044	0.1612	0.0065	0.0045	0.0038	0.0002	0.0008	–0.0002	0.0001	0.1300
	O	0.0085	–0.0008	0.0063	0.1435	–0.0336	0.0032	–0.0088	0.0824	–0.0399	–0.0002	0.0011	–0.0011	0.0005	–0.0002	–0.0008	0.1600
FPP	GS	0.0002	–0.0017	0.5625	–0.0074	–0.0125	0.0000	–0.0073	0.0230	0.0007	0.0012	0.0022	0.0000	0.0000	–0.0003	–0.0001	0.5600**
	O	–0.0017	0.0000	0.6323	–0.1604	0.0186	–0.0023	0.0088	–0.0515	0.0266	0.0015	–0.0025	0.0014	–0.0008	0.0007	–0.0008	0.4700**
FW	GS	–0.0008	–0.0127	–0.0056	0.7419	–0.1228	–0.2820	0.0029	0.3914	0.0157	0.0086	0.0033	0.0019	–0.0017	–0.0005	0.0002	0.7400**
	O	0.0064	–0.0001	–0.1201	0.8443	–0.2274	0.0115	0.0088	0.3657	–0.1529	–0.0055	0.0044	–0.0054	0.0008	–0.0009	0.0004	0.7300**
FL	GS	–0.0006	–0.0110	0.0281	0.3635	–0.2505	–0.1526	–0.0953	0.4893	0.0154	0.0083	0.0040	0.0006	0.0009	–0.0006	0.0003	0.4000**
	O	0.0055	–0.0001	–0.0316	0.5150	–0.3728	0.0100	0.0821	0.4532	–0.1662	–0.0025	0.0029	–0.0045	–0.0008	–0.0002	0.0000	0.4900**
FD	GS	–0.0004	–0.0156	0.0000	0.4525	–0.0827	–0.4623	0.0718	0.4432	0.0199	0.0098	0.0038	0.0014	–0.0013	–0.0006	0.0003	0.4400**
	O	0.0034	–0.0001	–0.0759	0.5150	–0.1976	0.0188	–0.0587	0.4429	–0.2061	–0.0025	0.0026	–0.0032	0.0005	0.0004	0.0005	0.4400**
FSI	GS	–0.0020	0.0017	0.0281	–0.0148	–0.1628	0.2265	–0.1465	0.0979	–0.0013	–0.0006	0.0007	–0.0005	0.0021	–0.0001	0.0000	0.0300
	O	0.0034	0.0001	0.0379	0.0507	–0.2088	–0.0075	0.1467	0.0515	0.0199	–0.0005	0.0006	–0.0016	–0.0014	–0.0005	–0.0005	0.0900
FSA	GS	–0.0007	–0.0161	0.0225	0.5045	–0.2129	–0.3560	–0.0249	0.5756	0.0217	0.0110	0.0047	0.0012	–0.0003	–0.0007	0.0003	0.5300**
	O	0.0055	–0.0001	–0.0632	0.5995	–0.3281	0.0161	0.0147	0.5150	–0.2150	–0.0035	0.0032	–0.0045	–0.0001	0.0001	0.0003	0.5400**
FV	GS	–0.0006	–0.0167	–0.0169	0.5193	–0.1729	–0.4115	0.0088	0.5584	0.0224	0.0110	0.0046	0.0014	–0.0006	–0.0007	0.0003	0.5400**
	O	0.0051	–0.0002	–0.0759	0.5826	–0.2796	0.0175	0.0132	0.4996	–0.2216	–0.0040	0.0031	–0.0042	0.0003	0.0002	0.0003	0.5100**
STL	GS	–0.0007	–0.0086	0.2250	0.2151	–0.0101	–0.1526	0.0029	0.2130	0.0083	0.0298	0.0031	0.0007	–0.0028	–0.0006	0.0000	0.2600**
	O	0.0043	0.0000	–0.0379	0.1858	–0.0373	0.0019	0.0029	0.0721	–0.0355	–0.0248	0.0020	–0.0028	0.0005	–0.0009	–0.0002	0.1300
PTN	GS	–0.0003	–0.0121	0.0675	0.1335	–0.0551	–0.0971	–0.0059	0.1497	–0.0056	0.0051	0.0182	0.0003	0.0010	–0.0006	0.0001	0.2100*
	O	0.0038	–0.0001	–0.1012	0.2449	–0.0708	0.0032	0.0059	0.1082	–0.0443	–0.0032	0.0153	–0.0029	0.0004	–0.0001	0.0010	0.1600
SPF	GS	–0.0001	–0.0023	0.0000	0.2893	–0.0326	–0.1294	0.0147	0.1439	0.0063	0.0045	0.0011	0.0049	–0.0005	0.0003	0.0000	0.3000**
	O	0.0017	–0.0001	–0.0822	0.4222	–0.1566	0.0056	0.0220	0.2163	–0.0864	–0.0065	0.0041	–0.0108	0.0011	–0.0007	0.0002	0.3300**
FLC	GS	–0.0001	0.0035	0.0000	0.0964	0.0175	–0.0462	0.0235	0.0115	0.0011	0.0065	–0.0015	0.0002	–0.0128	0.0003	0.0000	0.1000
	O	0.0300	0.0000	–0.0569	0.0760	0.0336	0.0009	–0.0220	–0.0052	–0.0066	–0.0012	0.0006	–0.0013	0.0092	–0.0004	0.0004	0.0300
TSS	GS	0.0000	0.0017	–0.0225	–0.0519	0.0200	0.0370	0.0029	–0.0576	–0.0022	–0.0027	–0.0015	0.0002	–0.0005	0.0069	0.0001	–0.0700
	O	0.0047	0.0000	0.0379	–0.0591	0.0075	0.0006	–0.0059	0.0052	–0.0044	0.0017	–0.0002	0.0006	–0.0003	0.0124	–0.0007	–0.0030
FSL	GS	–0.0002	–0.0029	–0.0169	0.0742	–0.0276	–0.0509	–0.0029	0.0806	0.0031	0.0003	0.0007	0.0000	–0.0003	0.0003	0.0023	0.0600
	O	0.0026	0.0001	–0.0506	0.0338	0.0000	0.0009	–0.0073	0.0155	–0.0066	0.0005	0.0015	–0.0002	0.0004	–0.0009	0.0105	–0.0010

Diagonal values: Direct effect, Off-diagonal value – Indirect effects

PHT, Plant height at maturity; PSG, plant stem girth; FPP, fruits/plant; FW, fruit weight; FL, fruit length; FD, fruit diameter; FSI, fruit shape index; FSA, fruit surface area; FV, fruit volume; STL, stalk length; PTN, fruit pericarp thickness; SPF, seeds/fruit; FLC, locules/fruit; TSS, total soluble solids; FSL, fruit shelf-life; YPP, fruit yield /plant

related characters could be improved by simple selection as they are represented merely due to additive gene action.

All the fruit and fruit-related characters showed significant positive correlation with fruit yield/plant and also among themselves (Table 2), except the characters fruit shape index, number of locules/fruit and fruit stalk length in both the populations. High correlation was observed for fruit weight, followed by number of fruits/plant, fruit surface area, fruit volume, fruit diameter, fruit length, pericarp thickness and seeds/fruit. Similar results of positive association of both fruit weight and fruits/plant with yield have been reported by Sharma *et al*. (2010) in sweet pepper. Results obtained from path analysis revealed the existence of high positive direct effect of fruit weight on yield, followed by fruits/plant and fruit surface area in both the F_2 populations of hybrids 'Golden Summer' and 'Orobelle' (Table 3). This is in accordance with the observations of Nazir *et al.* (2005), who were of the opinion that mean fruit weight and fruits/plant have a similar direct contribution to yield allowing the possibility of obtaining large fruited varieties through breeding. However, the character fruit length and fruit diameter in the F_2 population of the hybrid 'Golden Summer' and fruit length in the population 'Orobelle' although showed high negative direct effect on yield, their contribution towards yield was significant and positive because of the high indirect effect of fruit weight and fruit surface area.

The results revealed that there was considerable variation for the 16 characters studied in both the F_2 population. The PCV and GCV were higher for most of the characters, viz fruit weight, fruit surface area, fruit volume, seeds/fruit and fruit yield/plant. High heritability and genetic advances as percentage of mean was observed for fruit weight, fruit shape index, fruit surface area, fruit volume and pericarp thickness. Significant and positive correlation was recorded for fruit weight, number of fruits/plant, fruit surface area, fruit volume, fruit diameter, fruit length and seeds/fruits with yield as well as among themselves. Path analysis indicated that fruit weight, fruits/plant and fruit surface area should be considered during selection process, as these fruit-related characters contribute directly towards the yield.

SUMMARY

A study was conducted during 2008–09 to estimate the variability, heritability, genetic advance, correlation coefficient and path coefficient analysis in 2 F_2 population produced by selfing of leading commercial hybrids 'Golden Summer' and 'Orobelle' sweet pepper (*Capsicum annuum* L.) on 16 different characters including morphological, fruit-related and quality parameters. Wide variation was observed for most of the characters as evident by high phenotypic coefficient of variation and genotypic coefficient of variation values. Selection strategy for yield improvement should rely on fruit weight, fruits/plant, fruit length, fruit surface area, fruit volume and seeds/fruit during selection process, as these characters contribute directly towards the yield.

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