Int. J. Indust. Entomol. Vol. 24, No. 1, 2012, pp. 7~16

International Journal of
Industrial Entomology

Studies on the Manifestation of Hybrid vigour and Combining Ability in Polyvoltine x Bivoltine (cross breed) Hybrids of Mulberry Silkworm *Bombyx mori* L.

S. V. Seshagiri[1,]*, S. Sankar Naik[2], J. Seetharamulu[1], A.K. Goel[1], and P. J. Raju[1]

[1]*Andhra Pradesh State Sericulture Research and Development Institute, Kirikera – 515 211, Hindupur, Andhra Pradesh, India*
[2]*Department of Sericulture, Sri Krishnadevaraya University, Anantapur – 515 055, Andhra Pradesh, India.*

(Received 28 September 2011; Accepted 20 February 2012)

To meet the local requirement *i.e.* the tropical stress of Andhra Pradesh and marginal farmers, twenty four new hybrid combinations were tested in Line x Tester method involving eight newly developed polyvoltine oval lines *viz.*, MSO1, MSO2, MSO3, MSO4, MSO5, MSO6, MSO7 and MSO8 and three bivoltine silkworm breeds *viz.*, APS12, APS45 and APS8 as testers. These hybrids were reared to evaluate their performance. Data for eight economically important metric traits *viz.*, fecundity, cocoon yield per 10,000 larvae by number, cocoon yield per 10,000 larvae by weight, survival rate, cocoon weight, cocoon shell weight, cocoon shell ratio and filament length was recorded. General combining ability (gca), specific combining ability (sca) and heterosis were analyzed. Further, the relative merit of the hybrids for all the traits under study was also assessed adopting Evaluation Index method. Based on combining ability effects, heterosis and evaluation index, five hybrid combinations *viz.*, MSO3 x APS45, MSO1 x APS12, MSO7 x APS8, MSO2 x APS45 and MSO1 x APS45 were selected for further evaluation in different seasons.

Key words: Silkworm, Hybrid combinations, Performance data, Combining ability, Evaluation index.

*To whom the correspondence addressed
Andhra Pradesh State Sericulture Research and Development Institute (APSSRDI), Kirikera – 515 211, Hindupur, Andhra Pradesh, India
Tel: +094410 26695, 91 8556 247428;
E-mail: seshu_apssrdi@rediffmail.com

Introduction

Breeding as an important tool has been utilized by many breeders which has also played a vital role in increasing the productivity in sericulture. Aim of most of the breeding programmes is to improve the yield potential and qualitative parameters of the breeds/ hybrids over the existing ones. The silkworm, *Bombyx mori* L. offers one of the very important insects of choice with large number of strains which is best exemplified for utilization of heterosis by crossing them in different combinations (Datta and Nagaraju, 1987). In fact, silkworm crop is the only exception where hybrids are invariably used (Yokoyama, 1979). The systematic rearing of F1 hybrids was undertaken for the first time in Japan after establishing the superiority of hybrids (Toyama, 1905). A new era came into existence with the exploitation of '*heterosis*' which has increased the productivity of silk contributing to the development and expansion of sericulture industry. However, there is always a scope of improvement of genetic traits and identification of superior hybrids through estimation of heterosis by combining ability studies (Rao *et al.*, 1968).

The recent trend of global silk production centered mainly in tropical countries. India is the second largest producer of silk in the world next to China and more than ninety percent of the silk produced mainly by cross breeds (polyvoltine x bivoltine). In spite of continuous efforts for the development of sericulture through various breeding programs many hybrids have been developed by the breeders (Rao *et al.*, 2004; Seshagiri *et al.*, 2011), still there exists a wide gap between domestic requirement and production in India. To fulfill the gap and to face global competitiveness in silk production there is a need to develop more productive breeds or hybrids with quantitative and qualitative merit. Very limited number of polyvoltine cross breeds are available with all desired traits, which are not sufficient to meet the demand. The polyvoltine race, Pure Mysore (PM) is ruling the Indian Sericulture Industry for more than 50 years. At this juncture, there is a need for the development of quantitatively and qualitatively superior polyvoltine breeds and hybrids with high genetic plasticity to cater various climatic conditions of tropical countries. In the present study, an attempt was made to know the general combining ability of the new genotypes, specific combining ability and heterosis of their hybrids under Line x Tester programme in order to identify potential parents and to adjudicate the best hybrids for commercial exploitation at farmer's level.

Materials and Methods

In the present study, eight newly evolved polyvoltine breeds *viz*., MSO1, MSO2, MSO3, MSO4, MSO5, MSO6, MSO7 and MSO8 were tested with three productive superior bivoltine breeds *viz.,* APS12, APS45 and APS8. Twenty four hybrid combinations were prepared and tested under Line x Tester mating design. All the hybrid combinations along with their parents were reared in three replications following standard rearing techniques (Krishnaswami, 1973). Three hundred larvae were retained after 3rd moult in each replication. The data pertaining to eight economic traits *viz.,* fecundity, cocoon yield per 10,000 larvae by number, cocoon yield per 10,000 larvae by weight (kg), survival rate (%), cocoon weight (g), cocoon shell weight (g), cocoon shell ratio (%) and filament length (m) were recorded. The data was analysed using "INDOSTAT" software package. Analysis of variance (ANOVA) was carried out to study the overall differences between genotypes. The estimates of General Combining Ability (gca), Specific Combining Ability (sca), Mid parental heterosis (MPH) and Better parental heterosis (BPH) were also calculated (Kempthorne, 1957) to understand the combining ability and heterosis.

Table 1. Mean Performance of Poly x Bivoltine hybrids of silkworm, *Bombyx mori* L

S. No.	Hybrid / Combination	Fecundity (No.)	Yield /10,000 larvae		Pupation (%)	Cocoon weight (g)	Shell weight (g)	Shell ratio (%)	Filament length (m)
			No.	Wt. (kg)					
1	MSO1 x APS12	512	9539	17.798	94.02	1.888	0.353	18.70	937
2	MSO1 x APS45	502	9550	17.753	94.70	1.890	0.351	18.59	923
3	MSO1 x APS8	481	9122	16.195	89.56	1.788	0.323	18.08	834
4	MSO2 x APS12	469	9111	15.072	90.27	1.668	0.296	17.75	734
5	MSO2 x APS45	506	9533	17.784	94.45	1.875	0.351	18.72	953
6	MSO2 x APS8	482	9267	16.015	91.92	1.753	0.297	16.95	776
7	MSO3 x APS12	471	9383	16.855	92.73	1.833	0.337	18.38	825
8	MSO3 x APS45	516	9567	18.324	94.60	1.945	0.369	18.97	979
9	MSO3 x APS8	477	9250	16.243	90.32	1.765	0.321	18.17	805
10	MSO4 x APS12	457	9100	14.969	89.67	1.650	0.275	16.64	777
11	MSO4 x APS45	481	9222	15.354	90.88	1.676	0.277	16.51	763
12	MSO4 x APS8	487	9200	14.339	91.02	1.569	0.253	16.14	727
13	MSO5 x APS12	487	9422	15.798	93.20	1.748	0.277	15.84	701
14	MSO5 x APS45	454	9178	15.900	90.56	1.736	0.269	15.49	734
15	MSO5 x APS8	498	9211	15.983	91.12	1.742	0.284	16.32	812
16	MSO6 x APS12	494	9111	16.015	90.53	1.767	0.284	16.09	773
17	MSO6 x APS45	485	9322	15.351	92.23	1.654	0.274	16.58	759
18	MSO6 x APS8	484	9145	14.642	90.52	1.610	0.272	16.88	740
19	MSO7 x APS12	498	9189	15.676	90.73	1.714	0.279	16.30	715
20	MSO7 x APS45	474	9256	15.409	91.25	1.690	0.276	16.31	757
21	MSO7 x APS8	510	9495	17.794	94.19	1.887	0.360	19.08	926
22	MSO8 x APS12	492	9322	15.527	92.57	1.675	0.283	16.90	761
23	MSO8 x APS45	487	9022	14.692	88.96	1.651	0.278	16.85	740
24	MSO8 x APS8	473	9045	15.113	89.55	1.685	0.288	17.09	770

Table 2. ANOVA for combining ability of genetic traits in Poly x Bivoltine hybrids of silkworm

Source of Variation	D.f.	Fecundity	Yield /10,000 larvae		Survival rate	Cocoon weight	Shell weight	Shell ratio	Filament length
			No.	Wt.					
Replications	2	204.07	26272.46667	0.026	2.70	0.001	0.000	0.48	447.58
Treatments	34	800.186**	95155.0431**	8.782**	10.582**	0.093**	0.006**	4.070**	18011.94**
Parents	10	792.721**	79648.897**	7.394**	10.451**	0.116**	0.009**	5.561**	2683.03**
Parents vs. Hybrids	1	689.2367*	479618.0525**	136.051**	46.40**	1.328**	0.032**	0.659**	121377.35**
Hybrids	23	808.255**	85181.063**	3.852**	9.082**	0.030**	0.004**	3.570**	20182.55**
Lines	7	488.046*	96518.064**	7.156*	7.941**	0.060*	0.008*	8.197**	29119.82
Testers	2	67.17	77934.59722	1.674**	7.62	0.009*	0.0003**	0.313*	14799.50
Line * Tester	14	1074.2301**	80547.772**	2.511**	9.860**	0.018**	0.0019**	1.722**	16482.91**
Error	68	107.27	12317.46667	0.03	1.32	0.000	0.000	0.08	221.07

* Significant ($P<0.05$); ** Significant ($P<0.01$)

Table 3. Percent contribution for genetic traits in silkworm, *Bombyx mori* L.

Source	Fecundity	Yield per 10,000 Larvae		Survival Rate	Cocoon Weight	Shell Weight	Shell Ratio	Filament Length
		No.	Wt. (Kg)					
Lines	78.38	34.48	46.54	66.61	31.25	31.78	29.36	43.91
Testers	10.90	7.96	3.78	26.09	22.70	55.36	59.88	6.38
Lines x Testers	10.72	57.56	49.68	7.30	46.05	12.86	10.76	49.71

Multiple Trait Evaluation Index Method

Evaluation index over multiple traits was calculated for each hybrid for all the traits as per the following formula which is suggested by Mano *et al*. (1993).

$$\text{Evaluation Index} = \frac{A-B}{C}\times 10+50$$

Where,

A = Value obtained for a trait by the specific hybrid

B = Overall mean value of particular trait over all the hybrids

C = Standard deviation of the trait over all the hybrids

10 = Constant used for change of scale

50 = Constant used for change of origin

Based on the average Evaluation Index value ranks were assigned to all the hybrid combinations. Evaluation Index, number of traits with positive SCA, number of traits with positive mid parent heterosis (MPH), number of traits with positive better parent heterosis (BPH) and total score of positive SCA, MPH and BPH exhibited by each of the twenty four hybrid combinations were compiled for ultimate identification of promising hybrids (Goel, 2008).

Results

The mean rearing performance data and ANOVA pertaining to eight economic traits of the twenty four hybrid combinations are presented in Table 1 and 2 respectively. Perusal of the data revealed that fecundity ranged from 454 eggs/laying (MSO5 x APS45) to 516 eggs/laying (MSO3 x APS45), yield per 10000 larvae by number varied from a minimum of 9022 (MSO8 x APS45) to a maximum 9567 (MSO3 x APS45), minimum yield per 10000 larvae by weight of 14.339 kg was recorded in MSO4 x APS8 with a maximum of 18.324 kg in MSO3 x APS45, survival rate ranged from 88.96% (MSO8 x APS45) to 94.70% (MSO1 x APS45), Cocoon weight varied from 1.569 g (MSO4 x APS8) to 1.945 g (MSO3 x APS45), Shell weight ranged from 0.253 g (MSO4 x APS8) to 0.369 g (MSO3 x APS45) and the Shell ratio was recorded to be minimum in MSO5 x APS45 (15.49%) with a maximum of 19.08% in MSO7 x APS8. The Filament length varied from a minimum of 701 m (MSO5 x APS12) to a maximum of 979 m (MSO3 x APS45). The ANOVA for combining ability revealed significant differences for general combining ability (gca) and specific combining ability (sca) indicating the genetic diversity of the parental breeds/ hybrids.

Contribution for genetic traits

The data (Table 3) revealed that contribution of lines was more for the traits of fecundity (78.38%) and survivability (66.61%) where as testers contribution was

Table 4. General combining ability effects of lines and testers

Parents	Fecundity	Yield per 10,000 Larvae		Survival Rate	Cocoon Weight	Shell Weight	Shell Ratio	Filament Length
		No.	Wt.					
Lines								
MSO1	12.208 **	129.778 **	1.218 **	1.076 **	0.111 **	0.041 **	1.228 **	98.125 **
MSO2	-0.903	15.000	0.270 **	0.33	0.023 **	0.014 **	0.568 **	18.681 **
MSO3	0.319	140.889 **	1.138 **	1.249 **	0.103 **	0.041 **	1.272 **	66.014 **
MSO4	-10.792	-96.111	-1.139	-1.053	-0.113	-0.032	-0.732	-44.764
MSO5	-6.903	-3.444	-0.137	-0.06	-0.002	-0.025	-1.344	-51.208
MSO6	1.208	-81.222	-0.694	-0.59	-0.067	-0.024	-0.709	-42.542
MSO7	7.542 *	39.222	0.263 **	0.372	0.019 **	0.004 *	0.002	-0.986
MSO8	-2.681	-144.111	-0.92	-1.323	-0.074	-0.018	-0.284	-43.319
SE	3.452	36.995	0.060	0.382	0.003	0.002	0.095	4.956
CD at 5%	6.949	74.466	0.122	0.769	0.006	0.003	0.191	9.976
CD at 1%	9.277	99.405	0.163	1.027	0.008	0.005	0.255	13.317
Testers								
APS12	-1.750	-0.931	-0.065	0.077*	-0.002	-0.003	-0.124	-23.583
APS45	1.583	57.444 *	0.291 **	0.521 *	0.020 **	0.004 **	0.024	25.917 **
APS8	0.167	-56.514	-0.225	-0.598	-0.019	-0.002	0.100	-2.333
SE	2.114	22.654	0.037	0.234	0.002	0.001	0.058	3.035
CD at 5%	4.256	45.601	0.075	0.471	0.004	0.002	0.117	6.109
CD at 1%	5.681	60.873	0.100	0.629	0.005	0.003	0.156	8.155

* Significant (P< 0.05) ; ** Significant (P< 0.01)

Table 5. Specific combining ability effects in Poly x Bivoltine hybrids of silkworm for genetic traits

Hybrid combination	Fecundity	Yield per 10,000 Larvae		Pupation	Cocoon Weight	Shell Weight	Shell Ratio	Filament Length
		No.	Wt.					
MSO1 x APS12	15.417*	136.264 *	0.614 **	1.186	0.034 **	0.013 **	0.372 *	62.583 **
MSO1 x APS45	2.083	88.889	0.214 *	1.419 *	0.015 **	0.004	0.103	-0.917
MSO1 x APS8	-17.500	-225.153	-0.828	-2.605	-0.049	-0.018	-0.476	-61.667
MSO2 x APS12	-14.806	-176.625	-1.163	-1.822	-0.097	-0.016	0.076	-61.639
MSO2 x APS45	18.861 **	187.000 **	1.193 *	1.915 **	0.088 **	0.032 **	0.897 **	108.194 **
MSO2 x APS8	-4.056	-10.375	-0.03	-0.093	0.010	-0.016	-0.972	-46.556
MSO3x APS12	-18.694	-36.181	-0.249	-0.227	-0.015	-0.002	0.034	-26.639
MSO3 x APS45	27.972 **	94.444	0.865 **	1.149	0.078 **	0.023 **	0.446 **	86.861 **
MSO3 x APS8	-9.278	-58.264	-0.616	-0.922	-0.063	-0.02	-0.48	-60.222
MSO4 x APS12	-14.917	-65.847	0.155	-0.715	0.019 **	0.011 **	0.462 **	44.472 **
MSO4 x APS45	3.417	-12.889	0.172	-0.269	0.025 **	0.003	-0.003	-18.028
MSO4 x APS8	11.5	78.736	-0.327	0.984	-0.044	-0.014	-0.459	-26.444
MSO5 x APS12	8.861	152.819 *	-0.031	1.498 *	0.008	0.002	0.081	-24.75
MSO5 x APS45	-27.472	-149.889	-0.284	-1.589	-0.027	-0.012	-0.421	-40.583
MSO5x APS8	18.611 **	-2.931	0.315 *	0.090	0.019 **	0.009 **	0.340 *	65.333 **
MSO6 x APS12	8.417	-80.736	0.744 **	-0.645	0.092 **	0.010 **	-0.301	39.250 **
MSO6 x APS45	-4.25	72.222	-0.276	0.618	-0.043	-0.007	0.04	-24.25
MSO6 x APS8	-4.167	8.514	-0.468	0.027	-0.049	-0.004	0.261	-15
MSO7 x APS12	5.75	-123.181	-0.552	-1.407	-0.048	-0.023	-0.802	-60.639
MSO7 x APS45	-21.917	-114.889	-1.175	-1.324	-0.094	-0.034	-0.941	-68.139

Table 5. Continued

Hybrid combination	Fecundity	Yield per 10,000 Larvae		Pupation	Cocoon Weight	Shell Weight	Shell Ratio	Filament Length
		No.	Wt.					
MSO7 x APS8	16.167 **	238.069 **	1.727 **	2.732 **	0.142 **	0.056 **	1.743 **	128.778 **
MSO8 x APS12	9.972	193.486 **	0.481 **	2.132 **	0.007	0.003	0.078	27.361 **
MSO8 x APS45	1.306	-164.889	-0.709	-1.919	-0.04	-0.009	-0.121	-43.139
MSO8 x APS8	-11.278	-28.597	0.228 *	-0.213	0.033 **	0.006 *	0.043	15.778
Std. Error	5.980	64.077	0.105	0.662	0.054	0.003	0.164	8.584
CD at 5%	12.04	128.979	0.211	1.333	0.011	0.006	0.330	17.279
CD at 1%	16.07	172.174	0.282	1.779	0.014	0.008	0.441	23.066

* Significant ($P< 0.05$) ; ** Significant ($P< 0.01$)

Table 6. Mid parent heterosis (MPH) among Poly x Bivoltine hybrids for various genetic traits

Hybrid combination	Fecundity	Yield per 10,000 Larvae		Pupation	Cocoon Weight	Shell Weight	Shell Ratio	Filament Length
		No.	Wt.					
MSO1 x APS12	3.40*	4.76**	24.57**	5.02**	18.19**	18.66**	1.53	23.69**
MSO1 x APS45	2.45	4.81**	23.27**	5.28**	17.81**	19.50**	2.38*	23.55**
MSO1 x APS8	-0.48	0.86	14.12**	-0.08	12.29**	12.33**	0.77	16.07**
MSO2 x APS12	-4.9	0.25	5.12**	0.98	4.45**	0.62	-2.4	-2.72
MSO2 x APS45	3.69*	4.82**	23.06**	5.16**	16.89**	20.76**	4.48**	28.15**
MSO2 x APS8	0.07	2.15*	12.66**	2.04*	10.46**	4.63**	-4.41	7.67**
MSO3x APS12	-5.38	2.74**	16.33**	3.29**	14.00**	12.47**	-0.27	6.92**
MSO3 x APS45	5.88**	4.74**	25.48**	4.83**	20.63**	24.73**	4.29**	30.07**
MSO3 x APS8	-0.69	2.57**	13.44**	1.66	10.34**	10.47**	0.78	10.98**
MSO4 x APS12	-6.39	0.80	5.61**	1.3	3.81**	-5.02	-7.2	4.74**
MSO4 x APS45	-0.93	1.97*	7.37**	1.82	5.09**	-4.1	-7.57	4.47**
MSO4 x APS8	1.85	2.47**	1.76	2.33*	-0.86	-10.39	-8.63	3.49*
MSO5 x APS12	-0.88	3.79**	10.45**	4.34**	9.76**	-5.84	-13.13	-6.03
MSO5 x APS45	-6.62	1.04	10.28**	0.91	8.47**	-7.57	-13.8	-0.11
MSO5x APS8	4.00*	2.15*	12.49**	1.90*	9.74**	-0.06	-8.06	14.91**
MSO6 x APS12	0.34	0.52	11.85**	1.63	10.77**	-3.07	-11.3	2.23
MSO6 x APS45	-0.51	2.79**	6.37**	3.06**	3.21**	-5.35	-7.22	1.79
MSO6 x APS8	0.59	1.57	2.95**	1.51	1.24**	-4.23	-4.43	3.18*
MSO7 x APS12	-0.66	0.55	7.80**	0.92	6.43**	-6.52	-11.33	-5.9
MSO7 x APS45	-4.53	1.21	5.14**	1.04	4.46**	-6.76	-9.95	1.02
MSO7 x APS8	4.26**	4.59**	23.17**	4.66**	17.57**	24.35**	6.52**	28.42**
MSO8 x APS12	0.17	3.65**	9.72**	4.78**	5.44**	-4.23	-8.07	1.72
MSO8 x APS45	0.14	0.25	2.99**	0.22	3.41**	-4.79	-6.98	0.32
MSO8 x APS8	-1.39	1.25	7.52**	1.25	6.40**	0.64	-4.54	8.68**

* Significant ($P<0.05$) ; ** Significant ($P<0.01$)

recorded to be higher for shell weight (55.36%) and shell ratio (59.88%). The interaction of lines x testers contributed more for the traits of yield per 10000 larvae by number (57.56%), yield per 10000 larvae by weight (49.68%), cocoon weight (46.05%) and filament length (49.71%).

General Combining Ability (gca) and Specific Combining Ability (sca)

The gca data (Table 4) revealed that the line MSO1 exhibited significant gca effects for all the traits studied followed by MSO3 for seven traits except fecundity. Among testers only two testers recorded significant positive gca effects.

Table 7. Better parent heterosis (BPH) in silkworm hybrid combinations for the quantitative genetic traits

Hybrid combination	Fecundity	Yield per 10,000 Larvae		Pupation	Cocoon Weight	Shell Weight	Shell Ratio	Filament Length
		No.	Wt.					
MSO1 x APS12	-0.39	3.00 **	11.37 **	2.52 *	4.50 **	-2.13	-6.31	18.45 **
MSO1 x APS45	-0.33	3.12 **	9.53 **	3.26 **	3.81 **	0.66	-4.32	19.86 **
MSO1 x APS8	-1.9	-1.5	2.57 **	-2.35	-0.46	-5.27	-4.86	15.19 **
MSO2 x APS12	-8.81	-1.26	-5.69	-1.29	-7.66	-17.93	-11.1	-7.29
MSO2 x APS45	0.40	3.31 **	9.72 **	3.28 **	2.98 **	0.75	-3.64	23.71 **
MSO2 x APS8	-1.83	-0.07	1.62	-0.14	-2.1	-12.79	-10.95	7.39 **
MSO3x APS12	-9.33	0.77	5.47 **	0.52	1.29 **	-6.65	-7.78	3.12 *
MSO3 x APS45	2.45	2.80 **	13.05 **	2.49 *	6.81 **	4.34 **	-2.33	27.09 **
MSO3 x APS8	-2.65	-0.06	3.40 **	-0.96	-1.71	-6.25	-4.65	9.34 **
MSO4 x APS12	-10.76	-0.18	-6.25	-0.38	-8.77	-23.11	-15.68	-1.9
MSO4 x APS45	-4.63	1.04	-5.27	0.61	-7.96	-21.77	-14.96	-0.91
MSO4 x APS8	-0.68	0.79	-9.19	0.76	-12.66	-25.88	-15.09	1.87
MSO5 x APS12	-5.38	2.35 *	-1.15	2.09 *	-3.21	-23.2	-20.65	-11.46
MSO5 x APS45	-9.99	-0.3	-1.9	-0.81	-4.69	-24.03	-20.27	-4.67
MSO5x APS8	1.56	0.06	1.22	-0.19	-2.99	-16.7	-14.1	13.83 **
MSO6 x APS12	-3.89	-0.73	0.21	-0.31	-2.16	-21.16	-19.39	-2.27
MSO6 x APS45	-3.77	1.57	-5.29	1.57	-9.15	-22.43	-14.62	-1.43
MSO6 x APS8	-1.43	-0.36	-7.27	-0.31	-10.36	-20.41	-11.17	2.59
MSO7 x APS12	-3.18	-1.49	-1.91	-1.86	-5.13	-22.46	-18.33	-9.65
MSO7 x APS45	-6.02	-0.78	-4.94	-1.29	-7.21	-22.05	-16.01	-1.73
MSO7 x APS8	4.01 *	1.79	12.69 **	1.88	5.07 **	5.47 **	0.37	27.09 **
MSO8 x APS12	-4.34	3.15 **	-2.84	3.60 **	-7.25	-21.53	-15.36	-3.88
MSO8 x APS45	-3.44	-0.17	-9.36	-0.43	-9.35	-21.39	-13.27	-3.98
MSO8 x APS8	-3.67	0.08	-4.29	0.22	-6.18	-15.72	-10.09	7.99

Significant (P<0.05) ; ** Significant (P<0.01)

The tester APS45 exhibited significant gca effects for six out of eight traits studied followed by APS12, which exhibited significant positive gca effect for survival rate only.

The magnitude of sca effects (Table 5) varied considerably among hybrid combinations exhibiting both positive and negative effects indicating the genetic diversity of the parental lines. Five hybrids *viz*., MSO3 x APS45, MSO1 x APS12, MSO7 x APS8, MSO2 x APS45 and MSO1 x APS45 expressed significant sca effects for all the traits studied followed by MSO1 x APS45 and MSO5 x APS8 for seven traits.

Mid parent heterosis (MPH) and Better Parent Heterosis (BPH)

The expression of MPH (Table 6) among 24 Poly x Bivoltine hybrids varied to a greater extent and majority of the hybrids expressed significant hybrid vigour for yield per 10000 larvae by number, yield per 10000 larvae by weight, cocoon weight and filament length. Five hybrids *viz*., MSO3 x APS45, MSO1 x APS12, MSO7 x APS8, MSO2 x APS45 and MSO1 x APS45 manifested significant MPH for all the eight traits studied followed by two hybrids for seven traits and eight hybrids with significant positive MPH for six traits.

The BPH (Table 7) among 24 hybrid combinations varied to a greater extent. The majority of the hybrids expressed significant BPH for yield per 10000 larvae by number, yield per 10000 larvae by weight, cocoon weight and filament length. Two hybrids *viz*., MSO3 x APS45 and MSO7 x APS8 manifested significant BPH for all the eight traits studied followed by one hybrid (MSO2 x APS45) for six traits.

Evaluation Index (EI)

The evaluation indices of the hybrid combinations (Table 8) for eight traits revealed that among the hybrid, MSO3 x APS45 ranked on top with a highest EI of 69.37 followed by MSO1 x APS12 (65.50), MSO7 x APS8 (65.42), MSO2 x APS45 (65.28), MSO1 x APS45 (64.85), MSO3 x APS12 (55.57), MSO3 x APS8 (50.54)

Table 8. Evaluation index (EI) values of Poly x Bivoltine hybrids

Hybrid combination	Fecundity	Yield per 10,000 Larvae		Survival Rate	Cocoon Weight	Shell Weight	Shell Ratio	Filament Length	Avg. EI
		No.	Wt.						
MSO1 x APS12	66.35	66.34	66.19	63.66	64.81	65.48	63.79	67.40	65.50
MSO1 x APS45	60.02	67.01	65.78	67.56	65.09	64.98	62.72	65.61	64.85
MSO1 x APS8	46.70	40.69	51.54	37.98	54.50	56.60	58.02	54.26	50.04
MSO2 x APS12	38.88	40.03	41.27	42.08	42.16	48.46	54.89	41.43	43.65
MSO2 x APS45	62.34	65.99	66.06	66.12	63.54	64.88	63.93	69.39	65.28
MSO2 x APS8	47.13	49.57	49.89	51.54	50.87	48.76	47.44	46.83	49.00
MSO3 x APS12	39.84	56.74	57.99	56.20	59.20	60.70	60.81	53.07	55.57
MSO3 x APS45	68.89	68.04	71.00	67.00	70.73	70.25	66.30	72.71	69.37
MSO3 x APS8	43.96	48.56	51.97	42.37	52.18	55.88	58.88	50.52	50.54
MSO4 x APS12	31.28	39.33	40.33	38.60	40.24	42.04	44.58	46.89	40.41
MSO4 x APS45	46.28	46.86	43.85	45.61	42.97	42.73	43.40	45.21	44.61
MSO4 x APS8	50.51	45.48	34.57	46.37	31.89	35.67	39.90	40.54	40.62
MSO5 x APS12	50.08	59.15	47.91	58.93	50.44	42.78	37.13	37.22	47.95
MSO5 x APS45	29.16	44.13	48.84	43.73	49.13	40.34	33.82	41.51	41.33
MSO5 x APS8	57.48	46.16	49.60	46.95	49.82	44.99	41.62	51.42	48.50
MSO6 x APS12	54.94	40.01	49.89	43.55	52.40	45.02	39.49	46.49	46.47
MSO6 x APS45	49.03	53.01	43.82	53.37	40.74	41.99	44.01	44.70	46.33
MSO6 x APS8	48.18	42.08	37.34	43.53	36.15	41.24	46.82	42.28	42.20
MSO7 x APS12	57.27	44.81	46.79	44.70	46.86	43.50	41.42	39.05	45.55
MSO7 x APS45	41.84	48.91	44.35	47.73	44.38	42.39	41.54	44.40	44.44
MSO7 x APS8	65.09	63.61	66.15	64.62	64.75	67.55	67.29	65.91	65.42
MSO8 x APS12	53.46	53.01	45.43	55.31	42.90	44.60	46.96	44.87	48.32
MSO8 x APS45	50.08	34.56	37.80	34.56	40.36	43.12	46.51	42.19	41.15
MSO8 x APS8	41.21	35.93	41.65	37.94	43.90	46.05	48.73	46.10	42.69

and MSO1 x APS8 (50.04).

Selection of Promising Hybrid Combinations:
On the basis of number of traits with positive of specific combining ability (sca), Mid Parent Heterosis (MPH), Better Parent Heterosis (BPH) and average evaluation index value scored by each of the twenty four hybrid combinations were reviewed (Table 9) to finally select the promising hybrids. Maximum total score of 24 positive traits for SCA, MPH and BPH was observed in two hybrids *viz*., MSO3 x APS45 (EI - 69.37; Score -24) and MSO7 x APS8 (EI - 65.62; Score -24) followed by MSO2 x APS45 (EI - 69.37; Score - 22), MSO1 x APS12 (EI - 65.50; Score-21) and MSO1 x APS45 (EI - 64.85; Score-20). These hybrids were adjudicated as promising and chosen for further laboratory evaluation during different seasons for subsequent identification of most promising and stable combinations.

Discussion

In the present study, analysis of variance computed for

Table 9. Selection of promising hybrid combinations based on SCA, MPH, BPH and EI

Hybrid combination	Total number of positive traits obtained			Total Score	Average EI	Rank
	SCA	MPH	BPH			
MSO1 x APS12	8	8	5	21	65.50	2
MSO1 x APS45	7	8	5	20	64.85	5
MSO1 x APS8	0	6	2	8	50.04	8
MSO2 x APS12	1	5	0	6	43.65	18
MSO2 x APS45	8	8	6	22	65.28	4
MSO2 x APS8	1	7	2	10	49.00	9
MSO3 x APS12	1	6	5	12	55.57	6
MSO3 x APS45	8	8	8	24	69.37	1
MSO3 x APS8	0	7	2	9	50.54	7
MSO4 x APS12	5	5	0	10	40.41	24
MSO4 x APS45	4	5	2	11	44.61	16
MSO4 x APS8	3	5	3	11	40.62	23
MSO5 x APS12	6	4	2	12	47.95	12
MSO5 x APS45	0	4	1	5	41.33	21
MSO5 x APS8	7	6	4	17	48.50	10
MSO6 x APS12	5	6	1	12	46.47	13
MSO6 x APS45	3	5	2	10	46.33	14
MSO6 x APS8	3	6	1	10	42.20	20
MSO7 x APS12	1	4	0	5	45.55	15
MSO7 x APS45	0	5	0	5	44.44	17
MSO7 x APS8	8	8	8	24	65.62	3
MSO8 x APS12	8	6	2	16	48.32	11
MSO8 x APS45	2	6	0	8	41.15	22
MSO8 x APS8	5	6	3	14	42.69	19

SCA= Specific Combining Ability; MPH= Mid Parent Heterosis; BPH= Better Parent Heterosis; EI= Evaluation Index

combining ability revealed that highly significant variances due to crosses, lines and lines x testers observed among lines indicating the presence of both additive and non-additive gene action for the expression of these traits and also establishes the existence of genotypic differences for all the traits. In the present study, the contribution of lines was recorded to be higher for the traits *viz*., fecundity, survivability, which indicates the maternal effect on the traits. The testers contribution was observed to be more for the traits of shell weight and shell ratio. The interaction of lines x testers together contributed more for the traits like yield per 10000 larvae by number, yield per 10000 larvae by weight, cocoon weight and filament length. The results are in conformity with that of Ragavendra Rao *et al*. (2002).

The parental lines possessing high general combining ability (gca) are preferred for population development and for initiation of pedigree breeding as it is heritable which can be fixed. The general combining ability effects of eight lines and three testers pertaining to eight traits revealed that the line MSO1 was found to be best general combiner by virtue of significant positive effects for all the traits studied followed by MSO3 for seven traits. Among testers, APS45 exhibited significant gca effects for six out of eight traits studied indicating major role of additive gene action for the expression of these traits. The positive gca indicate their superiority and ability to combine with most of the breeds and are expected to produce promising hybrids. The identification of lines, MSO1 and MSO3 based on gca effects corroborate with the findings of Lakshmi (2008) and Goel (2008).

The magnitude of specific combining ability is another aspect to be evaluated in the hybrids to estimate their superiority. In the present investigation the sca effects varied considerably among F_1 hybrids. The sca effects of the hybrids revealed the importance of both additive and non-additive gene action for the eight traits studied. Among the twenty four F_1 hybrids analyzed, five hybrids *viz*., MSO3 x APS45, MSO1 x APS12, MSO7 x APS8, MSO2 x APS45 and MSO1 x APS45 recorded significant positive sca effects for all the traits under study reflecting the interaction of alleles, additive and non additive gene action and dominant effects expressed by genes, which play major role in the expression of hybrid vigour which is in conformity with the studies of Goel (2008), Malik *et al.* (1998), Sudhakara Rao *et al*. (2005). The present study support the predominant role of non-additive gene action for the traits fecundity, cocoon yield per 10,000 larvae by number, cocoon yield per 10,000 larvae by weight, survival rate, cocoon weight, shell weight and cocoon shell ratio in majority of the combinations as observed by Ravindra Singh *et al*. (2005).

The operation of additive x dominance interaction in the derived hybrids showing significant sca effects involving good x poor general combiners is well established as in the case of MSO1 x APS12 where in, MSO1 a good combiner while APS12 is a poor combiner. In contrast to gca effects, which are related to additive x additive gene interaction which reflects flexible genetic variation (Griffing, 1956). The sca effects related to dominance and epistasis components of variance represents non-flexible genetic variation in nature (Simmonds, 1979).

The exploitation of heterosis is an important step towards achieving desirable economic effects in the hybrids. The hybrid combination MSO3 x APS45 recorded highly significant positive ($P<0.01$) desirable mid parent and better parent heterosis for eight and five traits respectively followed by MSO1 x APS12 with significant positive MPH for seven traits and BPH for five traits. The present findings are in agreement with Nanjundaswamy (1997). The hybrids derived in the present study showed positive heterosis for most of the traits and over dominance for only some traits which corroborate the findings of Satenahalli *et al*. (1989) and Raju, (1990) which is ascribed to the allelic interaction.

The multiple trait evaluation of the twenty four hybrid combinations revealed that the combination MSO3 x APS45 ranked first followed by MSO1 x APS12. These observations confirm the established fact as observed by Ramesh Babu *et al*. (2002) that superiority of one or a couple of characters may not reflect the overall merit of the hybrid. Since the comprehensive merit of the hybrid over a range of traits depends on relative superiority of many individual traits, selection needs to be based on multiple traits contributing to overall silk output. Based on multiple traits and performance of the each of the hybrid combinations, the hybrids *viz.,* MSO3 x APS45, MSO7 x APS8, MSO2 x APS45, MSO1 x APS12 and MSO1 x APS45 were considered as potential hybrids and selected for further laboratory evaluation for the ultimate identification to the regions of tropical stress of Andhra Pradesh.

References

Datta RK, Nagaraju J (1987) Genetic engineering and tropical sericulture. Indian Silk 26, 9-12.

Eisen EJ, Horstgen-Schwark G, Saxton AM, Bandy TR (1983) Genetic interpretation and analysis of diallel crosses with animals. Theor Appl Genet 65, 17-23.

Falconer DS (1983) Introduction to quantitative genetics. Oliver and Boyd, Edinburgh, U.K.

Goel AK (2008) Breeding for the development of inbred lines and their heterotic effects on economic traits of silkworm, (*Bombyx mori* L.), Ph.D. thesis, University of Mysore, Mysore.

Griffing B (1956) Concepts on general and specific combining ability in relation to diallel crossing systems. Aust J Biol Sci 9, 463-493.

Harada C (1961) On the heterosis of quantitative characters in silkworm. Bull. Seric Expt Stn 17, 50-52.

Kempthorne O (1957) An Introduction to Genetic statistics. pp. 208 - 341, John Wiley and Sons, Inc, London.

Krishnaswami S, Narasimhann MN, Suryanarayana SK, Kumararaj S (1973) Silkworm rearing In: Manual on Sericulture, UN Food and Agriculture Organization, Rome, 2, 54-88.

Lakshmi H (2008) Studies on development of bivoltine hybrids of silkworm, *Bombyx mori* L. for tropical conditions of Andhra Pradesh. Ph.D. thesis, University of Mysore, Mysore.

Malik GN, Masoodi MA, Kamili AS, Sofi AM (1998) Studies on heterosis in some bivoltine silkworm (*Bombyx mori* L.) crosses. J Seric 6, 47-49.

Mano Y, Nirmal Kumar S, Basavaraja HK, Mal Reddy N, Datta RK (1993) A new method to select promising silkworm breeds / combinations. Indian Silk 31, 53.

Nanjundaswamy L (1997) Studies on the combining ability in silkworm, *Bombyx mori* L. Ph.D Thesis, University of Mysore, Mysore, India.

Raghavendra Rao D, Singh R, Premalatha V, Kariappa BK, Rekha M, Jayaswal KP (2002) Manifestation of hybrid vigour and combining ability in polyvoltine x bivoltine hybrid of silkworm, *Bombyx mori* L. Int J Indust Entomol 4, 23-30.

Raju PJ (1990) Studies on the hybridization and synthesis of new breeds of silkworm, *Bombyx mori* L. Ph.D. Thesis, University of Mysore, Mysore.

Ramesh Babu M, Chandrashekharaiah, Lakshmi H, Prasad J (2002) Multiple trait evaluation of bivoltine hybrids of silkworm (*Bombyx mori* L.). Int J Indust. Entomol 5, 37-43.

Rao NGP, Rana VKS, Tripati DP (1968) Line x Tester analysis of combining ability in sorghum. Ind J Genet and Plant Breeding, 28, 231-238.

Rao CGP, Chandrashekharaiah, Ibrahim Basha K, Seshagiri SV, Ramesh C, Nagaraju H (2004) Identification of superior polyvoltine hybrids (Poly x bivoltine) of silkworm, *Bombyx mori* L. Int J Indust Entomol 8, 43-49.

Ravindra Singh, Sharma SD, Raghavendra Rao D, Chandrashekaran K, Basavaraja HK, Kariappa BK (2005) Line x Tester and heterosis analysis in silkworm, *Bombyx mori* L. Indian J Seric 44, 92-99.

Satenahalli SB, Govindan R, Goud JV (1989) Heterosis studies for some quantitative traits in silkworm, *Bombyx mori* L. Indian J Seric 28, 100-102.

Seshagiri SV, Sankar Naik S, Goel AK, Raju PJ (2011) Identification of potential crossbreeds of mulberry silkworm, *Bombyx mori* L. and their performance under tropical stress. Int J Indust Entomol 22, 45-49.

Shull GH (1909) A pure line method of corn breeding. Amer Breed Assoc. Rept. 5, 51-59.

Simmonds NW (1979) Principles of crop improvement. Longman Inc, New York.

Sudhakara Rao P, Datta RK, Basavaraja HK, Vijayakumari KM, Rekha M (2005) Evaluation of combining ability for certain quantitative traits through diallel crosses in the silkworm, *Bombyx mori* L. Indian J Seric 44, 75-81.

Toyama K (1905) Sericulture in Siam. Dainihon Sanshi Keinko pp. 24-26.

Yokoyama T (1979) Silkworm selection and hybridization. In: Genetics in relation to insect management. Working Papers. pp. 71- 83. The Rockfeller Foundation Management.