Research Journal of AGRICULTURAL AND ENVIRONMENTAL SCIENCES

ISSN: 2394-0638

www.rjaes.com Volume-1, Issue-2, Nov-Dec-2014, Res.J.Agr.Env.Sci Copyrights@2014

Research Article *Open Access*

Received: 03/11/2014 *Revised: 10/12/2014* *Accepted: 12/12/2014*

STUDIES ON THE MANIFESTATION OF HYBRID VIGOUR AND COMBINING ABILITY IN BIVOLTINE HYBRIDS OF MULBERRY SILKWORM, *BOMBYX MORI* L. TOLERANT TO *BM*NPV

L. Vijaya Lakshmi[1], P. Sujathamma[2] and V. Sivaprasad[3]

[1]Dept. of Sericulture, Sri Padmavathi Mahila Viswa Vidyalayam, Tirupathi-517 502, Andhra Pradesh, India.
[2]Dept. of Sericulture, Sri Padmavathi Mahila Viswa Vidyalayam, Tirupathi-517 502, Andhra Pradesh, India.
[3]Central Sericulture Research and Training Institute, Sri Rampura-, Mysore-570 008, Karnataka, India.

ABSTRACT: The combining ability studies of the ten newly developed bivoltine silkworm breeds five each of oval and peanut tolerant to *Bm*NPV which are genetically divergent and their F_1 and RF_1 hybrids were utilized in complete diallel cross technique. The parental lines and their hybrids over twelve economic traits were subjected to ANOVA and general combining ability of parents and specific combining ability, heterosis and over-dominance of hybrids were studied. Superior hybrid combinations were identified based on their merit of multiple trait evaluation index values of the twelve economic traits.

Key words: Bivoltine silkworm breeds/ hybrids, *Bm*NPV, combining ability, diallel, multiple traits evaluation index.

***Corresponding author:** L. Vijaya Lakshmi, Dept. of Sericulture, Sri Padmavathi Mahila Viswa Vidyalayam, Tirupathi-517 502, Andhra Pradesh, India: Email: Vijaya.lingari@gmail.com

INTRODUCTION

Combing ability has been extensively studied in plants/animals to identify the promising parents and hybrids for designing and formulating efficient breeding plans [1]. The advent of biometrical genetics made it possible for identification of several silkworm hybrids by employing the methods of "Diallel cross technique" and "Line x Tester" analysis for meticulous understanding of the mechanism of heterosis, over dominance, general and specific combining abilities. The diallel cross system is one of the best approaches for the study of combining ability in bivoltine silkworm [2]. In this study the combining ability and heterosis was studied involving the newly evolved 10 lines tolerant to *Bm*NPV (5 each of oval and peanut) for identifying the promising hybrid combinations by employing full diallel cross system (10 x 10).

MATERIALS AND METHODS

Five each of bivoltine oval and peanut lines *viz*., BNR1, BNR3, BNR5, BNR7 and BNR9 and BNR2, BNR4, BNR6, BNR8 and BNR10 twenty five hybrids were utilized to study general combining ability effects, specific combining ability effects, heterosis and over dominance. All the hybrids and their parents were reared in three replications with 300 freshly moult out III instar larvae and reared up to spinning. The data pertaining to twelve economic traits were recorded and analyzed by the standard statistical procedure of Diallel analysis [2] and multiple trait evaluation index method.

RESULTS AND DISCUSSION

Mean data on the performance pertaining to twelve quantitative traits of ten parental breeds and their hybrids are presented in Tables 1 and 2 respectively. The evaluation index value is given in Tables 3. The details of gca effects and results of analysis of variance are presented in Table 4 and 5. Similarly, the results of analysis of variance of gca and sca of hybrids are presented in Table 6. The data regarding specific combining ability, heterosis and over dominance are presented in Tables 7, 8 and 9.

Table 1. Mean performance of parental lines

Breed	Fecun-dity (No.)	Yield /10,000 Larvae		Survival Rate (%)	Cocoon Weight (g)	Shell Weight (g)	Shell Ratio (%)	Fila-ment Length (m)	NBFL (m)	Raw Silk (%)	Denier (d)	Neat-ness (p)
		No.	Wt. (kg)									
BNR1	508	8795	14.66	83.13	1.545	0.335	21.65	751	684	15.81	2.37	89
BNR3	530	8619	14.63	82.90	1.533	0.332	21.63	744	664	14.97	2.28	90
BNR5	486	8714	13.84	82.14	1.519	0.315	20.71	684	624	14.05	2.39	91
BNR7	490	8578	13.76	81.13	1.511	0.329	21.74	785	700	15.83	2.38	90
BNR9	507	8962	14.91	83.36	1.563	0.343	21.92	813	742	15.59	2.37	90
BNR2	517	8723	15.05	83.66	1.564	0.333	21.29	722	645	15.42	2.27	89
BNR4	487	8483	14.39	81.93	1.528	0.320	20.96	671	612	15.64	2.29	88
BNR6	518	8403	14.15	81.30	1.517	0.332	21.91	656	585	16.12	2.38	90
BNR8	488	8650	14.28	83.16	1.493	0.328	21.95	723	659	15.64	2.35	90
BNR10	477	8760	16.30	84.30	1.677	0.342	20.38	749	682	15.30	2.34	90
Avg	501	8669	14.60	82.70	1.545	0.331	21.41	730	660	15.44	2.34	90
CV (%)	3.48	1.85	5.03	1.25	3.32	2.60	2.60	6.79	6.92	3.75	1.90	1.0

NBFL: Non-breakable filament length; Avg: Average; CV: Coefficient of variation

Fecundity: The trait varied from a low of 477 eggs/laying in BNR10 to the highest of 530 eggs/laying in BNR3 shows the diverse genetic constitution of the evolved lines. Among the hybrid combinations *viz*., BNR1 x BNR6 (532 eggs/laying) followed by BNR9 x BNR4 (521 eggs / laying) established their superiority over others. The higher fecundity observed in the new hybrids suggest the superiority of the hybrids over the pure lines and are in agreement with that of [3]. The results of gca showed non –significant values for three breeds and highly significant ($p<0.01$) values for two lines namely BNR3 (11.248) and BNR6 (21.081). Likewise, except for four hybrids, non-significant values for sca were recorded for most of the hybrids. Further, highly significant ($p<0.01$) heterosis observed for five hybrids. Lower magnitude of over dominance was observed that ranged from 8.75 % (BNR9 x BNR10) to 11.31 % (BNR1 x BNR6).

Cocoon yield per 10,000 larvae by number: Five lines *viz*., BNR9, BNR1, BNR10, BNR2 and BNR5 were found to exhibit higher mean values than the overall average (8669) value reflecting their genetic endowment which is in conformity with the findings of [4 and 5]. Among the hybrids combinations it varied to a greater extent with a minimum of 7378 (BNR5 x BNR2) to a maximum of 9851 (BNR9 x BNR4). The results indicated highly significant ($P<0.01$) positive gca effects in BNR6 and BNR3. The highly significant ($P<0.01$) sca was revealed in seven hybrid combinations. Seven hybrid combinations exhibited significant ($P<0.05$) and three highly significant ($P<0.01$) positive heterosis. With regard to over dominance, ten hybrids exhibited non-significant positive values. Wide range of heterosis and over dominance that was observed has established the superiority of the new combinations and is in agreement with the findings of [3, 5, 6, 7, 8, 9, and10].

Cocoon yield per 10,000 larvae by weight: The results indicated positive gca effects for ten parental lines while only one line (BNR6) revealed highly significant ($p<0.01$) positive value for gca. The highly significant ($p<0.01$) sca effect observed in three hybrids revealed superiority for sca. Significant ($p<0.05$) and highly significant ($p<0.01$) variations were observed for heterosis and over dominance for majority of the hybrids that reflect their genetic diversity. Wide range of heterosis and over dominance observed establish the superiority of the new combinations and is in support of the findings of [3, 4, 6, 7, 8, 9, 11 and 12]. The high estimates of sca variance compared to gca variance for the trait is suggestive of the role of non-additive gene action as observed by [13].

Table 2. Mean performance of new hybrid combinations (oval x peanut)

Combination	Fecun-dity (No.)	Yield /10,000 Larvae		Survival Rate (%)	Cocoon Weight (g)	Shell Weight (g)	Shell Ratio (%)	Fila-ment Length (m)	NBFL (m)	Raw Silk (%)	Denier (d)	Neat-ness (p)
		No.	Wt. (kg)									
BNR1 X BNR2	517	9497	16.30	92.20	1.804	0.395	21.90	972	853	18.07	2.36	94
BNR1 X BNR4	445	9545	15.14	92.67	1.670	0.317	19.00	831	710	17.10	2.33	88
BNR1 X BNR6	532	9624	17.44	93.43	1.900	0.388	20.43	1061	916	18.31	2.37	91
BNR1 X BNR8	431	8382	13.98	81.38	1.740	0.371	21.37	793	678	17.28	2.31	88
BNR1 X BNR10	432	9047	13.18	87.83	1.544	0.310	20.13	800	683	17.28	2.25	88
BNR3 X BNR2	504	9780	17.37	95.59	1.852	0.365	19.71	821	701	16.19	2.26	90
BNR3 X BNR4	462	8919	14.06	86.59	1.672	0.308	18.42	796	681	17.04	2.30	90
BNR3 X BNR6	437	9466	17.34	91.90	1.887	0.395	20.91	1029	879	18.71	2.37	94
BNR3 X BNR8	509	9627	17.15	93.47	1.870	0.393	21.03	1018	870	18.44	2.35	94
BNR3 X BNR10	460	8803	14.43	85.47	1.732	0.330	19.03	820	700	16.63	2.27	89
BNR5 X BNR2	446	7378	11.15	71.63	1.633	0.312	19.13	828	707	17.20	2.24	90
BNR5 X BNR4	432	9363	14.09	90.90	1.589	0.288	18.08	794	678	16.20	2.27	89
BNR5 X BNR6	490	9703	17.68	94.20	1.904	0.400	21.04	969	827	18.22	2.35	94
BNR5 X BNR8	441	8722	15.38	84.68	1.869	0.313	16.74	815	696	15.00	2.28	88
BNR5 X BNR10	444	8312	12.60	91.90	1.624	0.301	18.57	861	735	16.64	2.24	88
BNR7 X BNR2	489	9562	17.15	91.90	1.900	0.403	21.24	991	846	18.26	2.34	93
BNR7 X BNR4	456	8793	14.11	91.90	1.702	0.356	20.89	824	704	17.10	2.29	89
BNR7 X BNR6	494	9545	16.90	91.90	1.845	0.375	20.34	1031	880	17.77	2.35	92
BNR7 X BNR8	445	8175	14.12	91.90	1.860	0.380	20.52	881	753	17.27	2.27	89
BNR7 X BNR10	461	7849	13.51	91.90	1.790	0.353	20.05	848	724	16.11	2.23	89
BNR9 X BNR2	465	8638	14.38	91.90	1.698	0.347	20.58	953	814	17.47	2.28	90
BNR9 X BNR4	521	9851	18.27	96.27	1.931	0.400	20.72	1047	895	18.99	2.37	91
BNR9 X BNR6	447	8607	14.28	91.90	1.779	0.309	17.40	856	731	14.78	2.30	90
BNR9 X BNR8	455	9493	17.55	91.90	1.976	0.396	20.04	1079	921	18.20	2.39	91
BNR9 X BNR10	514	9449	17.71	91.90	1.884	0.376	19.96	1109	947	18.57	2.36	92
Avg	469	9045	15.41	90.29	1.786	0.355	19.89	913	781	17.31	2.31	90
CV (%)	6.83	7.30	12.63	5.72	6.65	10.77	6.52	11.69	11.81	6.33	2.14	2

NBFL: Non-breakable filament length; Avg: Average; SD: Standard deviation; CV: Coefficient of variation

Pupation rate: The estimation of gca revealed highly significant (p<0.01) positive values for three parental lines *viz*., BNR3, BNR6 and BNR8. Four hybrids *viz*., BNR7 x BNR2 (4.231), BNR7 x BNR6 (3.435), BNR9 x BNR4 (3.232) and BNR9 x BNR10 (4.221) were found to exhibit highly significant (p<0.01) sca effect indicate their superiority. Positive heterosis and over dominance values observed for the trait indicate the genetic diversity among which the combinations *viz*., BNR7 x BNR8 (18.35 %), BNR9 x BNR6 (9.27 %) for heterosis and BNR5 x BNR6 (4.32 %), BNR9 x BNR4 (4.09%) and BNR9 x BNR10 (4.30 %) for over dominance reflect their superiority and support the findings of [9 and14].

Cocoon weight: Most of the hybrids recorded higher values for the trait compared to their parents which are in conformity with [5, 8, 11, 12, 15, 16, 17, 18, and 19]. Four hybrids recorded highly significant (p<0.01) differences suggesting their superiority and operation of both additive and non-additive gene action which are in agreement with the findings of [20-23]. Highly significant (p<0.01) values for heterosis in fifteen hybrids and over dominance in ten hybrids indicate the superiority of the hybrids over the others. The magnitude of heterosis exhibited by the different hybrids could be either due to the additive gene action or dominant hypothesis as observed by [24-27].

Table 3. Evaluation Index of new hybrid combinations (oval x peanut)

Combination	Fecun-dity	Yield /10,000 Larvae		Survival Rate	Cocoon Weight	Shell Weight	Shell Ratio	Fila-ment Length	NBFL	Raw Silk	Denier	Neat-ness	Avg. EI
		No.	Wt.										
BNR1 X BNR2	65.00	56.84	54.55	53.70	51.53	60.40	65.50	55.52	57.74	56.90	61.29	67.64	58.89
BNR1 X BNR4	42.60	57.57	48.61	54.61	40.24	40.08	43.15	42.34	42.34	48.09	54.13	39.05	46.07
BNR1 X BNR6	69.75	58.77	60.40	56.09	59.60	58.54	54.15	63.87	64.62	59.12	63.16	52.85	60.08
BNR1 X BNR8	38.06	39.95	42.65	32.74	46.13	54.19	61.45	38.78	38.80	49.72	49.65	39.05	44.26
BNR1 X BNR10	38.31	50.03	38.54	45.24	29.55	38.25	51.88	39.40	39.33	49.73	37.91	39.71	41.49
BNR3 X BNR2	60.74	61.14	60.08	60.27	55.51	52.48	48.60	41.37	41.31	39.71	39.37	47.59	50.68
BNR3 X BNR4	47.91	48.08	43.08	42.83	40.37	37.67	38.69	39.06	39.09	47.51	47.93	47.92	43.34
BNR3 X BNR6	39.93	56.37	59.90	53.12	58.52	60.26	57.87	60.87	60.57	62.80	62.49	67.64	58.36
BNR3 X BNR8	62.57	58.82	58.94	56.16	57.08	59.94	58.84	59.80	59.60	60.27	57.76	67.64	59.78
BNR3 X BNR10	47.08	46.33	44.97	40.66	45.44	43.39	43.35	41.31	41.25	43.73	42.89	44.64	43.75
BNR5 X BNR2	42.78	24.74	28.09	13.85	37.09	38.80	44.16	42.03	41.95	48.99	35.46	47.27	37.10
BNR5 X BNR4	38.51	54.81	43.22	51.19	33.35	32.29	36.03	38.80	38.83	39.83	42.89	42.99	41.06
BNR5 X BNR6	56.40	59.96	61.67	57.58	59.90	61.79	58.87	55.25	55.01	58.24	57.76	66.00	59.04
BNR5 X BNR8	41.18	45.10	49.87	39.13	56.95	38.92	25.73	40.76	40.82	28.88	44.24	39.71	40.94
BNR5 X BNR10	42.15	38.89	35.57	53.12	36.36	35.73	39.82	45.14	45.04	43.81	37.00	38.39	40.92
BNR7 X BNR2	56.30	57.83	58.93	53.12	59.56	62.52	60.47	57.30	57.06	58.63	56.40	64.35	58.54
BNR7 X BNR4	45.79	46.18	43.32	53.12	42.89	50.05	57.72	41.62	41.59	48.05	45.60	43.65	46.63
BNR7 X BNR6	57.65	57.57	57.64	53.12	54.94	55.06	53.46	61.02	60.69	54.16	57.76	56.14	56.60
BNR7 X BNR8	42.57	36.81	43.39	53.12	56.23	56.54	54.84	46.99	46.94	49.62	41.54	41.35	47.50
BNR7 X BNR10	47.46	31.87	40.21	53.12	50.30	49.53	51.22	43.91	43.85	38.99	33.43	41.68	43.80
BNR9 X BNR2	48.71	43.84	44.68	53.12	42.60	47.92	55.32	53.74	53.52	51.42	44.24	46.28	48.78
BNR9 X BNR4	66.08	62.21	64.70	61.58	62.19	61.68	56.41	62.59	62.35	65.33	62.49	50.88	61.54
BNR9 X BNR6	43.09	43.37	44.18	53.12	49.38	37.92	30.79	44.64	44.56	26.84	48.30	46.28	42.71
BNR9 X BNR8	45.48	56.79	60.97	53.12	66.02	60.63	51.14	65.54	65.19	58.10	66.54	55.15	58.72
BNR9 X BNR10	63.89	56.11	61.83	53.12	58.27	55.42	50.53	68.36	67.95	61.51	59.78	56.14	59.41

Avg EI: Average Evaluation Index

Table 4. General combining ability of parental lines

Breed	Fecun-dity (No.)	Yield /10,000 Larvae		Pupation Rate (%)	Cocoon Weight (g)	Shell Weight (g)	Shell Ratio (%)	Fila-ment Length (m)	NBFL (m)	Raw Silk (%)	Denier (d)	Neat-ness (p)
		No.	Wt. (kg)									
BNR1	-5.215	60.369	-0.077	0.862	-0.031 *	0.004	0.609 *	-5.93	-8.149	-0.16	0.004	0.229
BNR3	11.248 **	223.666**	0.228	2.397 **	-0.034 *	0.001	0.466 *	-30.279 **	-2.365	0.03	0.002	-0.441 **
BNR5	-9.419 **	-61.437	-0.852 **	-0.424	-0.061 **	-0.015	-0.153	-39.179**	-26.417 **	-0.270 **	-0.008 **	-0.101
BNR7	2.646	12.109	0.034	0.292	-0.011	-0.005	-0.175	-11.28	-19.073 **	-0.087	-0.008 **	0.379 **
BNR9	-7.854 *	-143.533	-0.019	-2.245 **	0.015	-0.002	-0.268	-8.794	10.273	0.135	0.003	0.202
BNR2	5.794	55.953	-0.249	0.819	0.013	0.007**	0.217	18.076	7.404	0.041	0.000	-0.281 *
BNR4	3.331	-32.04	0.286	-1.086	0.062 **	0.005	-0.440 *	24.758 *	-1.229	0.117	-0.009 **	0.315 *
BNR6	21.081**	212.280**	0.911 **	3.158 **	0.045 **	0.007**	-0.15	47.055**	13.238	-0.251 **	0.007 *	-0.215
BNR8	-5.53	-315.446	-0.083	3.434**	0.035 *	0.007**	-0.031	3.288	15.889 *	0.191 *	0.011 **	-0.085
BNR10	-16.085 **	-11.92	-0.18	-0.339	-0.032 *	-0.007**	-0.077	2.286	10.427	0.254 **	-0.002	-0.001

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

Table 5. Analysis of variance for parental lines and hybrids

Source of Variation	DF	Fecundity (No.)	Yield /10,000 Larvae		Pupation Rate (%)	Cocoon Weight (g)	Shell Weight (g)	Shell Ratio (%)	Filament Length (m)	NBFL (m)	Raw Silk (%)	Denier (d)	Neatness (p)
			No.	Wt. (kg)									
Replicates	2	2354.984*	1792.735	7.162*	13.264	0.006	0.000	0.942	2213.65*	1560.15 *	0.193	0.002 *	0.172
Treatments	54	2624.074**	7531.672**	6.955**	106.314**	0.064**	0.004**	5.908**	2218.47**	1860.06 **	2.871 *	0.005 **	8.343 **
Parents	9	2111.348**	3123.374**	6.941**	58.137**	0.072**	0.004**	3.622**	3021.05**	2574.63 **	5.006 *	0.006 **	3.050 **
Hybrids	44	2756.535**	8602.100**	6.949**	118.471**	0.064**	0.004**	6.504**	2062.56**	1705.85 **	2.645 *	0.004 **	8.667 **
Parent Vs Hybrids	1	1410.385**	5545.529	7.362*	4.986	0.000	0.000	0.228	1827.197	9197.57 **	3.788 **	0.025 **	27.120 **
F1's	44	2664.933 *	8311.800 **	6.370 **	112.191 *	0.057 **	0.004 **	6.164 **	1739.92 **	1378.16 **	2.465 *	0.005 **	8.353 **
Reciprocals	44	2631.551 *	71705.04	7.042 **	6.759	0.067 **	0.004**	3.480 **	2842.92 **	2070.67 **	2.740 *	0.003 **	6.329 **
F1 *Vs* Reciprocals	1	1621.290 **	3854.5	24.105 **	57.982 *	0.080 **	0.003 *	45.362 **	9.62	63.693	6.418 *	0.002	125.393 **
Error	198	482.174	1547.2	1.345	11.066	0.01	0.000	1.42	493.16	3376.198	0.477	0.001	1.061
Total	299	1281.999	2525.1	3.308	27.888	0.029	0.002	2.699	1164.97	8498.668	1.268	0.002	3.466

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

Table 6. 'ANOVA' of gca, sca and reciprocal effect for economic characters

Source of Variation	DF	Fecundity (No.)	Yield /10,000 Larvae		Pupation Rate (%)	Cocoon Weight (g)	Shell Weight (g)	Shell Ratio (%)	Filament Length (m)	NBFL (m)	Raw Silk (%)	Denier (d)	Neatness (p)
			No.	Wt (kg)									
gca	9	145.69**	3027.108**	2.399**	47.368**	0.019**	0.001**	1.312**	7815.273**	4070.967 *	0.678 **	0.001 **	1.496 **
sca	45	7590.000	2406.647**	2.302**	33.059**	0.022**	0.001**	2.101**	7309.933**	5674.324 *	0.924 **	0.002 **	1.910 **
Reciprocal	45	1562.326**	2863.023**	2.092**	42.325**	0.019**	0.001**	1.203**	7405.204**	7151.529 *	1.046 **	0.001 **	3.909 **
Error	198	165.622	8313.396	0.528	5.096	0.003	0.000	0.462	1584.227	1125.399	0.159	0	0.354
gca variance		107.256	1881.156	0.156	3.523	0.0014	0.000	0.071	519.254	147.278	0.026	0	0.057
sca variance		593.470	1637.421	1.774	27.956	0.0189	0.001	1.639	5725.706	4548.924	0.765	0.002	1.557
Predictability Ratio		0.18073	0.11492	0.08787	0.12601	0.07299	0.03429	0.04324	0.09069	0.032	0.034	0.02	0.037

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

Shell weight: The estimation of gca revealed significantly (p<0.01) higher values for three breeds *viz*., BNR2, BNR6 and BNR8 (0.007). Nine hybrids were found to exhibit highly significant (p<0.01) sca. The higher values for sca and reciprocal effects observed in the new hybrids can be ascribed to additive gene action and support the findings of [11, 27, 28, 29]. Highly significant (p<0.01) values were observed for thirteen and eight hybrids for heterosis and over dominance respectively. These findings are in conformity with [11, 15 and 17].

Cocoon shell ratio: The significant (p<0.05) gca effects recorded for the trait for two lines with values that ranged from 0.609 (BNR1) to 0.466 (BNR3) indicate that they are good general combiners. The sca estimated revealed a wide range of values ranging from the lowest significant (p<0.05) value of 0.398 (BNR9 x BNR2) to highest significant (p<0.01) value of 0.958 (BNR3 x BNR8). Operation of non-additive gene action is ascribed to the trait as higher sca was observed than gca which is in conformity with the observations made by [13, 30, 31 and 32] and in contrary to the findings of [33, 34, 35 and 36].

Table 7. Specific combining ability effects of oval x peanut combinations

Hybrid combination	Fecundity (No.)	Yield /10,000 Larvae		Survival Rate (%)	Cocoon Weight (g)	Shell Weight (g)	Shell Ratio (%)	Filament Length (m)	NBFL (m)	Raw Silk (%)	Denier (d)	Neatness (p)
		No.	Wt (kg)									
BNR1 X BNR2	21.662*	115.83*	0.747	1.046	0.005	0.004	0.096	39.027	4.148	-0.538	0.016	-0.079
BNR1 X BNR4	-12.116	143.303*	0.800	1.396	0.055	-0.004	-0.959	7.861	68.162**	0.702**	0.053	1.458 **
BNR1 X BNR6	51.496**	200.736**	2.404**	1.832	0.269**	0.049**	-0.535	107.677*	-32.52	0.478**	0.003	-1.312
BNR1 X BNR8	-22.632	-454.143	-1.341	-4.448	0.006	0.003	0.097	-19.971	21.548**	-0.064	0.022	0.625 **
BNR1 X BNR10	-4.904	-3.547	-0.416	0.091	-0.030	-0.017	-0.714	-97.461	-68.171	0.416 *	-0.011	-1.025
BNR3 X BNR2	-4.238	264.287**	0.197	2.738*	-0.051	-0.032	-1.278	-86.177	-65.83	-0.493	-0.012	-0.642
BNR3 X BNR4	-6.682	-334.539	-0.447	-3.311	-0.009	-0.029	-1.608	-18.302	-35.816	-0.819	-0.014	-0.739
BNR3 X BNR6	-16.016	-16.03	1.217*	-0.341	0.153*	0.027**	-0.389	124.524**	-15.669	-0.408	-0.001	0.258
BNR3 X BNR8	-7.754	8.747	0.108	-0.022	0.046	0.025*	0.958**	28.748	-34.805	-0.25	-0.031	0.261
BNR3 X BNR10	-15.749	-213.018	-0.081	-2.011	0.102*	0.007	-0.873	-20.759	-19.271	0.082	-0.001	0.545 **
BNR5 X BNR2	8.79	-778.522	-0.575	-7.153	0.040	-0.002	-0.666	26.958	-47.508	0.805**	-0.008	-0.182
BNR5 X BNR4	-20.099	67.802	-1.224	0.787	0.127*	-0.041	-1.019	-54.449	0.257	-0.632	-0.011	-0.779
BNR5 X BNR6	11.179	247.548**	1.353*	2.411*	0.055	0.015*	0.225	32.805	-27.143	-0.828	-0.041	-0.915
BNR5 X BNR8	14.273	-157.129	1.104	-1.44	0.172**	-0.004	-2.218	-44.131	-21.451	-0.359	-0.021	-0.945
BNR5 X BNR10	-25.666	-255.007	-0.528	-3.576	-0.039	-0.014	-0.393	-12.864	11.437 *	-0.015	0.006	-0.562
BNR7 X BNR2	-5.332	334.915**	1.293*	4.231**	0.179**	0.048**	0.612**	109.815*	11.771 *	0.112	-0.021	-0.395
BNR7 X BNR4	-28.554	-226.428	0.27	-3.868	0.062	0.025*	0.689**	-19.103	-55.753	0.101	-0.017	-1.492
BNR7 X BNR6	43.223**	237.427**	-0.172	3.435**	-0.074	-0.028	-0.705	-56.248	-6.641	1.063**	0.012	1.771 **
BNR7 X BNR8	-18.293	-439.914	-0.426	-5.807	0.033	0.001	-0.303	-15.475	-52.999	-0.925	-0.046	-1.392
BNR7 X BNR10	2.546	-538.079	0.027	-7.896	0.095*	0.024*	0.428*	7.313	-82.406	-0.865	-0.04	-0.075
BNR9 X BNR2	-21.499	-324.215	-0.31	-5.125	0.005	0.008	0.398*	19.945	5.46	-0.563	0.040	0.448 *
BNR9 X BNR4	33.279*	299.878**	2.632**	3.232**	0.220**	0.047**	0.018	127.89**	-21.375	-0.338	0.00	-0.749
BNR9 X BNR6	-46.777	-399.559	-0.81	-5.384	-0.041	-0.018	-0.377	-94.228	-30.729	-0.161	-0.03	-0.085
BNR9 X BNR8	1.04	97.301	-1.028	1.480	-0.103*	-0.044	-1.458	-46.923	-52.385	-0.447	-0.032	-0.349
BNR9 X BNR10	53.879**	259.211**	1.949**	4.221**	0.115*	0.021*	-0.213	116.039**	19.857 *	0.348 *	0.004	-0.899

NBFL= Non-breakable filament length; * Significant ($p < 0.05$); ** Significant ($p < 0.01$)

Filament length: The significant ($p<0.05$ to $p<0.01$) variations for this trait was observed for eleven hybrids for heterosis with values ranging from 12.08 % (BNR9 x BNR8) and 26.47 % (BNR7 x BNR6) and over dominance for six hybrids ranging from 11.69 % (BNR3 x BNR6) to 20.78 % (BNR7 x BNR6) showing their superiority. These results are in conformity with the findings of [11 and 24]. As gca is greater than sca for the trait, additive gene action was predominant for the trait as observed by [33, 34 and 35] and in contrary to [37 and 38] who reported the operation of non-additive gene action. The difference in the observations could be attributed to the genetic makeup of the new genotypes involved.

Non-breakable filament length: Highly significant variations ($p<0.01$) observed for gca, sca and reciprocal effects among the hybrids can be attributed to their genetic variability. The estimation of gca revealed significant ($p<0.05$) value for the breed BNR8 (15.889). The higher values for sca observed in the new hybrids can be ascribed to additive gene action. With regard to the heterosis and over dominance, highly significant ($p<0.01$) values were observed for two and five hybrids respectively.

Table 8. Heterosis in oval x peanut combinations

Hybrid combination	Fecundity (No.)	Yield /10,000 Larvae		Survival Rate (%)	Cocoon Weight (g)	Shell Weight (g)	Shell Ratio (%)	Filament Length (m)	NBFL (m)	Raw Silk (%)	Denier (d)	Neatness (p)
		No.	Wt. (kg)									
BNR1 X BNR2	10.91**	2.08*	9.7	1.73	13.42**	17.92**	3.42	7.6	5.43	7.31 *	2.78 **	-0.52
BNR1 X BNR4	-7.87*	0.85	-2.69	0.52	4.43	-7.99	-12.04**	-9.56	32.62 **	8.26 *	3.69 **	4.83 **
BNR1 X BNR6	11.98**	4.76**	20.46**	4.39	26.45**	21.23**	-4.10	19.10**	-10.72	0.39	2.14 **	-0.15
BNR1 X BNR8	12.69**	-11.25**	-13.86**	-11.55*	7.16	2.09	-4.55	-16.60**	12.75 *	4.82	4.09 **	1.94 *
BNR1 X BNR10	-8.64*	-2.94	-9.14	-3.27	1.32	-4.82	-5.97	-13.94**	-15.89 **	-1.07	1.17	-1.64
BNR3 X BNR2	6.41	3.22*	15.58*	3.91	17.60**	12.59**	-4.70	-8.34	-7.44	-0.34	2.45 **	-1.49
BNR3 X BNR4	-5.7	-7.44*	-10.62*	-7.44**	5.61	-7.71	-12.71**	-12.63	7.57	-1.21	-0.86	-1.78
BNR3 X BNR6	-9.43*	1.15*	18.36*	1.15	26.98**	27.69**	0.50	16.51**	-2.99	-1.2	-1.94 *	1.51
BNR3 X BNR8	1.81	0.12	4.55	0.12	16.33**	11.53**	-3.94	7.85	-13.70 *	-13.60 **	-3.04 **	0.75
BNR3 X BNR10	-4.09	-7.26*	-1.7	-7.26**	14.93**	4.76	-9.03	-11.01*	-15.56 **	-7.22 *	0.57	0.37
BNR5 X BNR2	3.50	-20.26**	-16.08**	-20.26**	1.91	-3.81	-6.04	-3.97	-4.17	12.52 **	0.54	-0.37
BNR5 X BNR4	-9.81	-0.54	0.74	-0.54	-1.39	-14.09**	-13.04**	-9.63	21.16 **	16.19 **	-0.58	0.37
BNR5 X BNR6	3.89	6.20**	37.06**	6.20*	25.72	29.25**	2.68	14.03*	-0.03	11.96 **	-3.04 **	0.38
BNR5 X BNR8	-9.90**	-7.15*	4.97	-7.15**	14.26**	-11.49**	-22.42**	-5.73	-1.02	18.01 **	-1.27	-0.82
BNR5 X BNR10	-5.2	-10.33**	-2.55	-13.33**	5.83	-4.80	-9.85	-3.07	9.37	12.47 **	0.94	-0.37
BNR7 X BNR2	6.07	2.55*	24.93**	3.35	30.13**	40.95**	8.31	19.78**	-4.81	2.95	-1.09	0.22
BNR7 X BNR4	-4.77	-7.29*	-2.22	-12.40**	15.90**	20.14**	4.23	-2.31	5.48	-2.94	-2.01 *	-0.74
BNR7 X BNR6	4.92	3.66*	26.22**	4.89	34.50**	38.21**	3.02	26.47**	3.97	6.92 *	-0.98	6.04 **
BNR7 X BNR8	-8.84	-13.63**	-6.46	18.35**	24.60**	20.84**	-1.52	0.65	-14.26 *	-17.58 **	-2.01 *	-1.05
BNR7 X BNR10	-1.39	-15.98**	0.96	-23.61	28.54**	27.58**	0.99	-0.64	-8.76	-8.60 **	-1.79 *	-1.78
BNR9 X BNR2	0.9	-6.83*	-0.15	-11.21**	4.23	2.13	-1.74	4.19	1.49	0.36	4.36 **	-1.49
BNR9 X BNR4	8.93**	4.44**	21.00**	4.95	17.88**	14.31**	-3.03	12.56	18.19 *	2.23	0.43	-0.74
BNR9 X BNR6	-4.89	-5.98	1.88	9.27**	9.36*	-6.98	-13.52**	-5.15	-0.09	-2.04	-2.92 **	1.43
BNR9 X BNR8	-6.83	0.86	11.26*	1.94	18.88**	7.39	-9.58*	12.08*	-22.27 **	-12.66 **	-2.58 **	-0.3
BNR9 X BNR10	9.99**	1.72*	26.08**	5.04	20.64**	13.58**	-5.76	17.85**	-9.41	-3.23	-0.96	-0.3

NBFL= Non-breakable filament length; * Significant (p< 0.05); ** Significant (p< 0.01)

Raw silk recovery percentage: The raw silk recovery percentage varied among the newly evolved lines with highly significant (p<0.01) variations observed in BNR10 (0.254) suggesting its superiority compared to other lines. Non-additive gene action was found to be in operation for the trait as evidenced from greater sca compared to gca and corroborate with the findings of [13 and 39]. High heterosis was recorded for raw silk percentage in bivoltine hybrids as observed by [40]. The highly significant (p<0.01) variation observed for five hybrids for heterosis with values ranging from 11.96 % (BNR5 x BNR6) to 18.01 % (BNR5 x BNR8) establish their superiority over other combinations.

Table 9. Over-dominance in oval x peanut combinations

Hybrid combination	Fecundity (No.)	Yield /10,000 Larvae		Survival Rate (%)	Cocoon Weight (g)	Shell Weight (g)	Shell Ratio (%)	Filament Length (m)	NBFL (m)	Raw Silk (%)	Denier (d)	Neatness (p)
		No.	Wt. (kg)									
BNR1 x BNR2	9.43*	1.01	5.85	0.33	9.3	15.72**	-1.83	4.68	-3.78	2.65	1.93*	-0.52
BNR1 x BNR4	-9.89**	0.20	-3.7	0.20	0.14	-8.9	-14.82**	-10.47	4.79	3.43	1.90*	4.83**
BNR1 x BNR6	11.31**	2.36	13.24*	1.67	24.12**	13.63**	-8.42	14.28*	-12.68*	-2.09	-1.74*	-1.64
BNR1 x BNR8	-16.22**	-11.64**	-18.06**	-11.64**	1.35	-3.8	-4.92	-18.55**	12.57*	-2.25	2.01*	1.49
BNR1 x BNR10	-8.67*	-3.78	-14.39*	-4.43	0.82	-9.11	-9.75*	-14.04*	-16.69**	-5.9	0.94	-1.64
BNR3 x BNR2	3.52	0.36	10.32	1.03	12.16*	10.99*	-7.55	-10.1	-23.20**	-12.32**	-2.25**	-2.50**
BNR3 x BNR4	-6.45	-8.48*	-10.69	-8.48**	0.23	-11.55*	-13.57**	-12.80*	-22.74**	-13.18**	-2.95**	-2.80**
BNR3 x BNR6	-10.19**	-2.87	10.1	-2.87	25.97**	23.56**	-1.91	12.69*	-13.75*	-11.37**	-1.94*	-1.03
BNR3 x BNR8	-0.95	-1.21	0.53	-1.21	8.91	1.9	-6.42	4.48	-21.68**	-14.77**	-4.81**	-0.74
BNR3 x BNR10	-5.48	-9.67**	-8.35	-9.67**	14.26**	3.34	-10.74*	-11.85	-23.97**	-10.28**	-3.03**	-0.66
BNR5 x BNR2	-3.95	-20.67**	-22.13**	-20.67**	-1.08	-4.94	-7.49	-5.71	-5.68	-0.5	-1.16	-0.37
BNR5 x BNR4	-12.54**	-1.71	-10.38	-1.71	-4.77	-17.46**	13.48**	-12.78*	6.56	2.88	-1.44	0.37
BNR5 x BNR6	2.37	4.32	30.49**	4.32	22.52**	24.75**	1.73	13.57*	-8.17	-2.89	-5.91**	-1.12
BNR5 x BNR8	-14.28**	-8.06*	-9.83	-8.06**	8.83	-18.94**	-25.52**	-11.91*	-10.94	-6.91*	-2.40**	-1.26
BNR5 x BNR10	-6.00	-10.63**	-7.43	-13.62**	4.53	-6.33	-10.21*	-7.46	-0.81	-9.51**	0.29	-0.37
BNR7 x BNR2	5.76	1.25	19.80**	1.76	15.07**	22.68**	6.00	12.86*	23.26**	-5.49	-6.42**	-1.75
BNR7 x BNR4	-7.82*	-7.70*	-10.25	-12.54**	2.03	2.06	-0.003	-9.46	-26.39**	-11.00**	-4.88**	-2.70**
BNR7 x BNR6	3.21	1.07	24.75**	1.99	25.11**	25.45**	8.20	20.78**	-10.19*	0.08	-1.81*	2.41**
BNR7 x BNR8	-13.42**	-13.83**	-17.21**	-18.39**	8.33	-1.47	-8.73*	-9.55	-24.40**	-19.92**	-4.60**	-3.43**
BNR7 x BNR10	-2.4	-16.89**	-0.81	-24.64**	18.07**	13.79**	-2.27	-8.87	-20.17**	-9.42**	-6.10**	-3.72**
BNR9 x BNR2	0.12	-7.5	-0.72	-11.99**	2.88	-1.19	-5.78	0.18	20.39**	-9.71**	0.13	-3.64**
BNR9 x BNR4	5.33	3.41	16.22**	4.09	15.76**	13.80**	-5.13	10.1	19.74**	-8.14**	-1.13	-2.91**
BNR9 x BNR6	-6.55	-7.83*	-1.39	-11.20**	4.82	-13.97**	-16.58**	-10.03	-16.02**	-10.14**	-3.46**	-2.25*
BNR9 x BNR8	-11.60**	0.07	2.84	1.31	15.10**	2.59	-10.87**	10.78	33.30**	-13.40**	-3.82**	-2.91**
BNR9 x BNR10	8.75*	1.18	22.32**	4.30	17.19**	6.98	-8.63	16.57**	22.88**	-4.31	-3.96**	-2.47**

NBFL= Non-breakable filament length; * Significant ($p < 0.05$); ** Significant ($p < 0.01$)

Denier: The mean values for the trait denier in the parental lines exhibited variability to a greater extent ranging from a maximum of 2.39 (BNR5) to minimum of 2.27 (BNR2). Out of ten parental lines, seven lines *viz*., BNR5, BNR7, BNR6, BNR9, BNR1and BNR8 were found to exhibit higher mean values than the (2.34) overall mean. Highly significant ($p<0.01$) variations were observed between the treatments, parents, hybrids, parents *vs* hybrids and F_1's, while the variations were found to be significant among the replications. Similarly gca, sca and reciprocal effects for this trait were found to reveal highly significant ($p<0.01$) variations whereas nine hybrids were found to exhibit non-significant sca effect. Six hybrids were found to exhibit highly significant ($p<0.01$) heterosis values while the hybrids revealed significant values ($p<0.05$) for over dominance.

Neatness: The trait neatness showed lesser variations in the pure lines and the hybrids recorded wider variations for the trait which ranged from 88 p to 91 p is suggestive of their genetic constitution variation. The estimation of gca revealed significantly ($p<0.01$) higher values for three breeds. Four hybrids were found to exhibit highly significant ($p<0.01$) sca. With regard to the heterosis and over-dominance highly significant ($p<0.01$) values each for two hybrids were observed.

Multiple Trait Evaluation Index: Eleven combinations recorded average cumulative evaluation index value above 50. Among them, BNR9 x BNR4 that recorded highest value (61.54) was assigned first rank followed by BNR1 x BNR6 (60.08), BNR3 x BNR8 (59.78), BNR9 x BNR10 (59.41), BNR5 x BNR6 (59.04), BNR1 x BNR2 (58.89), BNR9 x BNR8 (58.72), BNR7 x BNR2 (58.54), BNR3 x BNR6 (58.36), BNR7 x BNR6 (56.60) and BNR3 x BNR2 (50.68) for which the ranks were assigned in descending order respectively (Table 3).

CONCLUSIONS

As per analysis of the data based on SCA, heterosis, over dominance and evaluation index value, ten hybrid combinations of oval x peanut (BNR9 x BNR4, BNR1 x BNR6, BNR3 x BNR8, BNR9 x BNR10, BNR5 x BNR6, BNR1 x BNR2, BNR9 x BNR8, BNR7 x BNR2, BNR3 x BNR6 and BNR7 x BNR6 were selected as promising hybrid combinations for further study.

REFERENCES

[1] Falconer, D.S. Introduction to Quantitative Genetics. *3rd Edn*, Longman, London. 1988.
[2] Griffing, B. Concepts on general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci. 1956. 9: 463-493.
[3] Sudhakara Rao, P. Studies on the evolution of adaptive bivoltine hybrids of silkworm, Bombyx mori L. for tropical climates. *Ph.D. Thesis*. University of Mysore, Mysore. 2003.
[4] Narasimhanna, M.N. Contribution to the genetics of silkworm. *Ph.D. Thesis,* University of Mysore, Mysore. 1976.
[5] Raju, P.J. Studies on the hybridization and synthesis of new breeds of silkworm, *Bombyx mori* L. *Ph.D. Thesis*, *University of Mysore*, Mysore. 1990.
[6] Yokoyama, T. On the application of heterosis in Japanese Sericulture. Proc. Int. Genet Symp, 1957. 527 – 531.
[7] Iyengar, M.N. S.; Jolly, M.S.; Datta, R.K. and Subramaniam, R.K. Relative silk productivity of different silkworm breeds and its use as breeding index. Natl. Semi. Silk Res. & Dev. 10th – 13th March. Bangalore. 1983.
[8] Tayade, D.S. Heterosis effect of economic traits of new hybrids of silkworm, *Bombyx mori* L. Marathwada conditions. Sericologia. 1987. 27(2): 301-307.
[9] Kalpana, G.V. Breeding of superior races of silkworm, *Bombyx mori* L. for tropical climates. *Ph.D. Thesis*, *University of Mysore*, Mysore. 1992
[10] Goel, A.K. 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. 2008.
[11] Nanjundaswamy, L. Studies on the combining ability in silkworm, *Bombyx mori* L. *Ph.D Thesis, University of Mysore*, Mysore, India. 1997.
[12] Guruswamy, D. Breeding of promising races of silkworm *Bombyx mori* L. and identification of suitable hybrids for rainfed area in Karnataka. *Ph.D Thesis, Bangalore University*, Bangalore, India. 2006. pp. 100-104.
[13] Bhargava, S.K.; Majumdar, M.K. and Datta, R.K.Combining ability of seven silk technological characters in the mulberry silkworm, *Bombyx mori* L. Bull. Zool. 1995. 62: 359-362.
[14] Nirmal Kumar, S. Studies on the synthesis of appropriate silkworm breeds (*Bombyx mori* L.) for tropics. *Ph.D. Thesis, University of Mysore*, Mysore. 1995.
[15] Krishnaswami, S.; Jolly, M.S. and Subba Rao, G. Diallel analysis of quantitative characters in multivoltine races of silkworm. Indian J Genet Pl Breed 1964. 34 A: 229 – 236.
[16] Sengupta, K.; Yusuf, M.R. and Grover, S.P. Hybrid vigour and Genetic analysis of quantitative traits in silkworm. Indian J. Genet. & Plan. Breed. 1974. 34 A: 249-256.
[17] Raje Urs, S. Studies on the genetics of heterosis and voltinism in silkworm, *Bombyx mori* L. *Ph.D. Thesis, University of Mysore*, Mysore. 1988.
[18] Satenahalli, S.B.; Govindan, R.; Goud, J.V. and Magadum, S.B. Genetic parameters and correlation co-efficient analysis in silkworm (Bombyx mori L.). Mysore J. Agric. Sci. 1990b. 24: 491-495.
[19] Govindan, R.; Magadum, S.B.; Satenahalli, S.B.; Yelshetty, S.; Magadum, V.B. and Narayanaswamy, T.K. Comparative variability in cocoon and pupal weights, ovariole length, ovariole egg number and fecundity in some pure breeds and F_1 hybrids of silkworm, *Bombyx mori* L. Mysore J. Agric. Sci. 1990. 24(1): 86-88.
[20] Pershad, G.D.; Datta, R.K.; Bhargava, S.K.; Vijayakumar, H.V. and Jolly, M. S. Combining ability analysis in multivoltine races of *Bombyx mori* L. Sericologia. 1986a. 26: 307-315.
[21] Chauhan, T.P.S., Lakshamanan, V. and Rajalakshmi, E. Combining ability studies in bivoltine silkworm, *Bombyx mori* L. Indian J. Seric. 2000. 39:127-130.
[22] Raghavendra Rao, D.; Premalatha, V.; Ravindra Singh; Kariappa, B.K.; Jayaswal, K.P.; Ramamohana Rao, P. and Datta, R.K. Studies on manifestation of hybrid vigour in polyvoltine x bivoltine crosses of silkworm, *Bombyx mori* L. J. Expt. Zool. 2001. 4: 219-232.

[23] Raghavendra Rao, D. Ravindra Singh, Premalatha; Kariappa, B.K.; Rekha, M and Jayaswal, K. P Manifestation of hybrid vigour and combining ability in polyvoltine x bivoltine hybrids of the silkworm, *Bombyx mori* L. Int.J.Indust.Entomol. 2002. 4:23-30.
[24] Nacheva, I. Heterosis effect on some technological qualities of cocoons and silk fibre of *Bombyx mori* L. newly evolved hybrids. Zhivatnov'D Nauki. 1980. 17: 88-94.
[25] Petkov, N. Improving the initial breeds of the regionally distributed hybrid $Hessa_1$ x $Hessa_2$ intended for spring industrial silkworm feedings. (I). Correlations between quantitative breeding characters. Genetikai Selektsiya. 1989. 22(3): 248-252.
[26] Petkov, N. and Nguyen, V.L. Breeding-genetic studies of some lines of the silkworm (*Bombyx mori* L.) reared at high temperature and humidity. (III). Heterosis performances of quantitative characters. Genetikai Selektsiya. 1988. 21(4): 336-342.
[27] Narasimhanna, M.N. and Rajashekarashetty. Line x Tester analysis of *Bombyx mori* L. Isolation of multivoltine hybrids for Karnataka state. E.S.A.P. Bangalore. 1979
[28] Gamo, T. and Hirabayashi, T. Genetic analysis of growth rate, pupation rate and some quantitative characters by diallel cross in silkworm, *Bombyx mori* L. Japan J. Breed. 1983. 33: 178-190.
[29] Chandrashekharaiah (1994). Studies on genetics of quantitative traits in a few multivoltine and bivoltine races of silkworm *Bombyx mori* L. *Ph.D Thesis.*, Univ. of Mysore, Mysore.
[30] Malik, G.N.; Masoodi, M.A.; Zargar, G.H.; Kamili, A.S. and Aijaz, M. Genotypes-Environment interactions in some bivoltine silkworm (*Bombyx mori* L.) genotypes. Appl. Bio. Res. 1999a. 1: 109-111.
[31] Ravindra Singh; Raghavendra Rao, D.; Premalatha, V.; Kariappa, B. K.; Jayaswal, K. P. and Datta, R. K. Evaluation of combining ability in hybrids between low, medium and high cocoon weight polyvoltine and bivoltine breeds of silkworm, *Bombyx mori* L. Sericologia. 2001a. 41: 57-64.
[32] Ravindra Singh, Premalatha, V.; Raghavendra Rao, D.; Kariappa, B. K.; Jayaswal, K. P. and Datta, R. K. Line x tester analysis in sex-limited strains of mulberry silkworm, *Bombyx mori* L. with coloured cocoons. Indian J. Seric. 2001b. 40, 39-43.
[33] Datta, R.K. and Pershad, C.D. Combining ability among multivoltine x bivoltine silkworm (*Bombyx mori* L.) hybrids. Sericologia. 1988. 28(1): 21-29.
[34] Subba Rao, G. and Sahai, V. Combining ability and heterosis studies in bivoltine strains of the silkworm, *Bombyx mori* L. Uttar Pradesh J. Zool. 1989. 9: 152-164.
[35] Razdan, J. L.; Siddiqui, A. A.; Bali, R.K. and Mukherjee, P. Study on the identification of region-specific heterotic crosses in *Bombyx mori* L. Sericologia. 1994a. 34(2): 249-260.
[36] Ramesh Babu, M.; Chandrashekharaiah; Lakshmi, H.; Prasad, J. and Goel, A.K. Combining ability of diallel crosses of bivoltine silkworm, *Bombyx mori* L. Int. J. Indust. Entomol. 2005b. 10(1): 61-64.
[37] Rajyalakshmi, E.; Chauhan, T.P.S.; Thiagarajan, V.; Lakshmanan, V. and Kamble, C.K. Line x tester analysis of combining ability in new genotypes of bivoltine silkworm (*Bombyx mori* L.). Indian J. Agric. Sci. 1997. 67: 287-290.
[38] Sudhakara Rao, P.; Basavaraja, H.K.; Nishitha Naik, V.; Jayaswal, K.P.; Rekha, M. and Datta, R.K. Evaluation of combining ability in hybrids between polyvoltine and bivoltine sex-limited cocoon colour breeds of silkworm, *Bombyx mori* L. Indian J. Seric. 2001a. 40(2): 163-168.
[39] Lakshmi, H.; Ramesh Babu, M.; Chandrashekharaiah; Goel, A.K.; Saha. A.K. and Bindroo, B.B. Genetic analysis of silk technological characters of bivoltine silkworm (*Bombyx mori* L.). Advances in Bioresearch, Society of Education, India. 2012. 3(4): 29-33.
[40] Mal Reddy, N.; Basavaraja, H.K.; Suresh Kumar. N.; Joge, P.G.; Kalpana, G.V.; Dandin, S.B. and Datta, R.K. Breeding of productive bivoltine hybrid, CSR16 x CSR17 of silkworm *Bombyx mori* L. Int. J. Indust. Entomol. 2003. 8: 129-133.