International Journal of Advanced Science and Research
ISSN: 2455-4227, Impact Factor: RJIF 5.12
www.newresearchjournal.com/science
Volume 1; Issue 3; March 2016; Page No. 15-20

Comparative performance and differential expression of economic parameters in the parents of bivoltine silkworm, *Bombyx mori* L. and their hybrids

[1] Veeranna Gowda, [2] Kalpana GV, [3]Ashok Kumar K
[1, 3] Central Sericultural Germplasm Resources Centre, Hosur, Tamil Nadu, India
[2] P4 Basic Seed Farm, Hassan, Karnataka, India

Abstract

Comparative performance of selected parental and different crossing pattern hybrids is an important yard stick to understand the potentiality of a breed / hybrid for evaluating the differential expression of quantitative traits. The parental breeds, foundation crosses and different cross hybrids were reared in three replications during three different seasons of the year to evaluate their performance for pre- and post-cocoon traits. Hybrid vigor in terms of heterosis for different crossing pattern hybrids was studied for important economic traits. The results of the study reveals that, out of different crossing pattern hybrids studied, two each of single, three-way and four-way cross hybrids exhibited better performance with desirable positive heterosis for most of the economic traits, which may be attributed to better inherent advancement and prophecy for field testing based on the overall performance and heterosis for each of the quantitative trait studied.

Keywords: - Quantitative traits, bivoltine silkworm, crossing pattern, estimation, hybrid vigour.

Introduction

The bivoltine silkworm breeds / hybrids that are currently being exploited in the field are developed through suitable breeding approach by utilizing Japanese hybrids has resulted in development of many productive bivoltine breeds (Datta *et al.*, 2000; Basavaraja *et al.*, 1995). For assessing the productivity and their suitability to confined environment, the breeds / hybrids are to be subjected to favorable and unfavorable conditions. Genotype and environmental interactions is of major importance in breeding to develop new breeds as it is well established that the phenotypic expression of the genotype for different traits are not consistent in all the environmental conditions. Further, the diverse environmental factors prevailing in the tropics, management practices and quality of leaf plays a significant role in the expression of quantitative traits.

Hybrid vigour in silkworm has received a considerable attention because of the marked effect of the important economic parameters including the yield components. As per the literature, it is documented that the single cross hybrids are superior to their parents in many qualitative as well as quantitative characters. The superiority of the hybrids is adjudicated by their cocoon yield and yield attributes as compared to their parents. In India, utilization of hybrid vigor came rather belatedly and maximum utilization was undoubtedly contributed by the crosses of multivoltine with bivoltine inbred lines. Since last two decades, relatively good number of potential bivoltine breeds / hybrids were identified (Basavaraja *et al.*, 1995; Nirmal Kumar *et al.*, 1998; Mal Reddy *et al.*, 2005) and the quantitative traits of some of these identified breeds / hybrids were documented (Datta *et al.*, 2000). However, information on hybrid vigor in different crossing pattern of these bivoltine breeds is scanty.

Hence, an attempt has been made to analyze the comparative performance of bivoltine parental as well as foundation crosses (FC) and single, three-way and four-way crosses in three replications during different seasons of the year. Also, analyzed evaluation of differential expression of heterosis in different crossing pattern *viz.*, foundation, single, three-way and four-way cross hybrids involving identified promising bivoltine parental breeds.

Materials and Methods

Twelve bivoltine breeds *viz*., BBE226, CSR27, CSR17, JPN8, JPN7, S5 (oval) and BBE267, D13, S9, BBE247, CSR16, CSR26 (dumb-bell) were utilized for preparation of oval and dumb-bell foundation crosses (FC). Selected oval FCs were utilized as female parents with dumb-bell breeds (in three-way cross) and oval and dumb-bell FCs as lines x testers in (OxO)x(DxD) four-way crosses preparation by employing partial diallel cross method. The parental breeds, foundation cross, single-cross, three-way cross and four-way cross hybrids were brushed together. After third moult, 250 larvae with three replications each were retained and reared by following the standard rearing method (Datta, 1992) during different seasons of the year *viz*., summer, rainy and winter. To evaluate the pre-cocoon, cocoon and post-cocoon performance, 13 important economic traits that govern quality and quantity of silk output *viz.*, fecundity, larval duration (total and 5th age), yield / 10,000 larvae by number, Yield/10,000 larvae by weight, cocoon weight, shell weight, cocoon shell percentage, filament length, filament size (denier), raw silk percentage, neatness, renditta and boil-off loss were evaluated.

Hybrid vigour in respect of both foundation cross (FCs) and single-cross hybrids was estimated for all the traits (except total and 5th age larval duration) by following the formula as detailed below.

$$H\% = \frac{F1 - MPV}{MPV} \times 100$$

H% = Heterosis percentage,
F1 = Mean value of the F1 hybrid,
MPV = Mean of the mid parent value (P1+P2 / 2),

The Hybrid vigour in respect of three-way cross hybrids was calculated for all the traits (except total and 5th age larval duration) by adopting the formula of Xiang Li., *et al.*, 2009.

$$H\% = \frac{\overline{F} - (0.5\overline{A} + 0.25\overline{B} + 0.25\overline{C})}{0.5\overline{A} + 0.25\overline{B} + 0.25\overline{C}} \times 100$$

Where,

$H\%$ = Heterosis percentage,

$\overline{F}$ = Phenotypic mean values of three-way cross hybrid,

$\overline{A}$, $\overline{B}$ and $\overline{C}$ = Phenotypic mean values of parental lines.

Similarly, the magnitude of heterosis (%) in four-way cross hybrids for all the metric traits (except total and 5th age larval duration) were estimated by using the formula (Maria, 2001) as detailed hereunder.

$$H\% = \frac{F1 - (A + B) + (C + D) / 4}{(A + B) + (C + D) / 4} \times 100$$

H%= Heterosis percentage,

F1 = Phenotypic mean value of four-way crosses,

(A+B),(C+D) = Phenotypic mean values of parents (4 parents).

Results

The mean performance of bivoltine parents, oval foundation crosses, dumb-bell foundation crosses and also single-cross, three-way cross and four-way crosses are presented in Tables 1, 2 and 3, respectively. Estimation of the hybrid vigour for the quantitative traits studied in oval FCs, dumb-bell FCs and other hybrids of different crossing pattern is as presented in Table 4.

Fecundity in FCs and different hybrids ranged from 517 (CSR17xBBE247) to 636 in (CSR27xCSR17) x(D13xCSR26). Larval duration in FCs and other cross hybrids showed mean larval duration of 545h, 542h, 549h, 546h and 553h, respectively. In the different crossing pattern, the hybrids exhibited uniform mean value of 5th age larval duration (Table 2 and 3). Cocoon yield / 10000 larvae by number is found to be highest (9775) in FC hybrid (CSR16xCSR26) while the lowest of 8356 in the control (CSR2xCSR27). Highest cocoon yield / 10000 larvae by weight was 21.140kg in four-way cross hybrid, (CSR27xCSR17)x(D13xCSR26) while lowest of 16.570kg was recorded in single-cross hybrid, (CSR17xBBE247) (Table 2 and 3). Cocoon weight varied from 1.741g in (CSR6xCSR26) to 2.180g [(JPN8xCSR27)x (D13xCSR26)]. Shell weight varied from 0.407g in oval FC (JPN8xJPN7) to 0.494g [(JPN8xCSR27) x (D13xCSR26)]. Shell ratio ranged from 21.36% [(CSR27xCSR17) x CSR26] to 24.19% (CSR27xCSR17). The filament length ranged from a minimum of 843m (CSR17xBBE247) to maximum of 1198m [(JPN8xCSR27)x(D13xCSR26)]. The overall mean of filament size recorded thickness of 3.03d in [(CSR27xCSR17)x (D13xCSR26) and thin size of 2.37d in [(JPN8xCSR17)xD13]. Mean values revealed maximum raw silk percentage of 19.45% [(JPN8xCSR27)x(S9xCSR26)] and minimum of 17.18% (CSR17xBBE247). The overall mean values of renditta revealed maximum (7.62) in (D13xCSR16) and (CSR27xD13) recorded 6.18. The traits neatness ranging from 90.89 to 93.50p and boil-off loss from 23.00 to 24.67% didn't show much variation (Tables 2 and 3).

The foundation cross and different crossing pattern hybrids showed significant heterosis for all the quantitative traits estimated (except total and 5th age larval duration). Highest heterosis of 18.42% for the trait fecundity was registered by [(JPN8xCSR27)x(S9xCSR26)]. In respect of yield/10000 larvae by number, single-cross hybrid (JPN8xBBE267) scored top heterosis of 3.67%. Highest heterosis of 25.76% for the trait yield/10000 larvae by weight was recorded by [(CSR27xCSR17)x(D13xCSR26)]. The maximum heterosis for other economic traits such as, cocoon weight [(JPN8xCSR27)x (D13xCSR26)], shell weight (JPN8xBBE267), shell ratio (S5xBBE267), filament length [(CSR27xCSR17)x (D13xCSR26)], denier (S5xJPN8), raw silk percentage [(CSR27xCSR17)x(D13xCSR26)], renditta (S5xBBE267), neatness (S5xJPN8) and boil-off loss (S5xJPN8) was observed in the different crossing pattern hybrids shown within the bracket ((Table 4).

Table 1: Performance of bivoltine parental breeds in different seasons

(Mean values of three seasons)

Breed	Fecundity	Larval duration		Yield/10000 larvae		Cocoon weight (g)	Shell weight (g)	Cocoon shell (%)	Filament		Raw silk (%)	Renditta	Neatness (p)	Boil-off loss (%)
		Larval (h)	V age (h)	No.	Wt. (kg)				length (m)	size (d)				
Oval breeds														
CSR17	537 ±31.88	537 ±24.04	149 ±8.31	9172 ±123.52	16.04 ±0.86	1.855 ±0.12	0.438 ±0.02	23.61 ±0.22	1053 ±80.28	2.81 ±0.24	18.37 ±0.87	6.76 ±0.04	92.50 ±0.51	23.00 ±1.00
CSR27	536 ±40.30	537 ±24.04	149 ±8.31	9163 ±83.43	16.70 ±0.73	1.821 ±0.02	0.455 ±0.02	25.01 ±0.79	1030 ±44.76	2.80 ±0.10	18.40 ±0.30	6.70 ±0.10	92.80 ±0.19	23.00 ±1.00
JPN8	530 ±23.06	533 ±18.42	149 ±8.31	9153 ±82.71	16.00 ±0.34	1.715 ±0.02	0.395 ±0.01	23.01 ±0.38	1203 ±35.50	2.11 ±0.09	18.26 ±1.41	6.68 ±0.03	92.85 ±0.69	21.50 ±0.50
JPN7	537 ±37.17	534 ±19.54	149 ±8.30	9193 ±76.95	16.03 ±0.60	1.854 ±0.12	0.437 ±0.03	23.65 ±1.56	1000 ±20.41	2.26 ±0.14	18.15 ±0.79	6.77 ±0.08	92.01 ±0.38	21.50 ±0.50
S5	524 ±18.83	534 ±19.54	149 ±8.31	9192 ±47.44	16.02 ±0.56	1.837 ±0.06	0.432 ±0.03	23.50 ±2.01	1108 ±30.50	2.67 ±0.15	18.30 ±0.26	6.85 ±0.22	92.50 ±0.69	23.00 ±0.58
BBE226	521 ±19.98	539 ±22.74	149 ±8.31	8740 ±109.55	14.24 ±0.76	1.643 ±0.06	0.376 ±0.02	23.33 ±0.93	864 ±11.65	3.06 ±0.26	17.09 ±0.60	7.26 ±0.08	90.10 ±0.06	25.00 ±0.58
Dumb-bell breeds														
CSR16	529 ±25.27	533 ±31.48	149 ±8.31	9754 ±86.33	18.15 ±0.69	1.908 ±0.14	0.423 ±0.03	22.18 ±0.37	965 ±100.16	2.78 ±0.35	18.12 ±0.935	6.75 ±0.05	92.50 ±0.58	23.00 ±1.00
CSR26	550 ±35.22	533 ±31.48	149 ±8.31	9723 ±159.94	17.97 ±1.50	1.910 ±0.16	0.419 ±0.03	21.95 ±0.14	966 ±66.12	2.84 ±0.18	18.32 ±1.33	6.72 ±0.03	92.85 ±0.51	23.00 ±1.15
S9	555 ±41.85	533 ±31.48	149 ±8.31	9723 ±234.26	18.08 ±1.52	1.896 ±0.10	0.412 ±0.02	21.72 ±0.42	991 ±83.45	2.67 ±0.17	19.22 ±0.58	6.70 ±0.05	93.50 ±0.00	22.00 ±0.58
D13	562 ±31.29	533 ±31.48	149 ±8.31	9653 ±42.27	18.43 ±0.56	1.902 ±0.20	0.406 ±0.02	21.35 ±1.16	950 ±121.11	2.69 ±0.18	17.80 ±1.31	6.77 ±0.30	92.88 ±0.58	23.00 ±1.00
BBE247	516 ±30.00	533 ±31.48	149 ±8.31	9370 ±451.57	16.90 ±1.47	1.748 ±0.13	0.385 ±0.03	22.04 ±0.37	896 ±85.50	3.08 ±0.23	16.35 ±1.01	7.55 ±0.06	90.50 ±0.58	25.00 ±0.58
BBE267	537 ±25.92	524 ±18.33	149 ±8.31	9382 ±266.47	16.831 ±1.51	1.781 ±0.22	0.323 ±0.01	18.15 ±1.95	915 ±30.83	3.16 ±0.15	16.30 ±0.42	7.45 ±0.12	90.50 ±0.58	25.00 ±0.58

Table 2: Performance of bivoltine foundation cross (FCs) hybrids during different seasons

(Mean values of three seasons)

FCs	Fecundity	Larval duration		Yield/10000 larvae		Cocoon wt. (g)	Shell wt. (g)	Cocoon shell %	Filament		Raw silk (%)	Renditta	Neatness (p)	Boil-off loss (%)
		Larval (h)	V age (h)	No.	wt. (kg)				length (m)	size (d)				
Oval FCs														
S5xJPN8	546 ± 15.87	545 ± 23.64	144 ± 0.00	9170 ± 112.86	17.640 ± 1.40	1.810 ± 0.08	0.421 ± 0.01	23.30 ± 0.83	1091 ± 94.89	2.89 ± 0.16	19.26 ± 0.69	6.55 ± 0.18	93.50 ± 0.25	24.50 ± 0.87
JPN8xCSR27	545 ± 8.19	545 ± 23.64	144 ± 0.00	9217 ± 224.04	17.410 ± 0.88	1.850 ± 0.04	0.426 ± 0.00	23.06 ± 0.34	1125 ± 60.55	2.73 ± 0.45	19.32 ± 1.56	6.54 ± 0.07	92.50 ± 0.44	24.33 ± 1.26
JPN8xCSR17	545 ± 7.88	545 ± 23.64	144 ± 0.00	9160 ± 117.55	17.740 ± 1.13	1.850 ± 0.08	0.423 ± 0.01	22.85 ± 0.54	1148 ± 44.22	2.62 ± 0.38	19.23 ± 0.92	6.62 ± 0.13	92.80 ± 0.25	24.56 ± 1.36
JPN8xJPN7	542 ± 12.33	545 ± 23.64	144 ± 0.00	9093 ± 88.38	18.190 ± 0.45	1.851 ± 0.06	0.407 ± 0.01	22.08 ± 0.43	1004 ± 48.19	2.41 ± 0.14	18.79 ± 0.95	6.63 ± 0.12	92.00 ± 0.51	23.50 ± 0.50
CSR27xCSR17	548 ± 18.99	545 ± 23.64	144 ± 0.00	9193 ± 69.12	17.910 ± 1.08	1.860 ± 0.07	0.450 ± 0.00	24.26 ± 0.66	1108 ± 99.12	2.73 ± 0.29	19.55 ± 1.19	6.61 ± 0.10	92.75 ± 0.58	23.83 ± 0.76
CSR2xCSR27 **(C)**	525 ±13.33	545 ± 23.64	144 ± 0.00	8356 ± 120.77	17.150 ± 1.14	1.780 ± 0.16	0.393 ± 0.01	22.10 ± 0.61	1050 ± 40.19	2.65 ± 0.21	18.01 ± 0.57	6.75 ± 0.09	92.50 ± 0.25	25.00 ± 0.28
Dumb-bell FCs														
CSR16xCSR26	547 ± 15.84	542 ± 17.09	144 ± 0.00	9775 ±148.75	18.730 ±0.71	1.940 ± 0.12	0.430 ± 0.02	22.57 ± 0.00	1013 ± 84.17	2.55 ± 0.27	18.55 ± 1.02	6.42 ± 0.00	92.00 ± 0.29	23.50 ± 0.50
D13xCSR16	548 ± 25.51	542 ± 17.09	144 ± 0.00	9763 ±178.32	18.550 ±1.03	1.931 ± 0.10	0.420 ± 0.02	21.61 ± 0.18	978 ± 88.55	2.65 ± 0.24	18.27 ± 0.92	6.66 ± 0.04	92.50 ± 0.93	24.14 ± 0.80
D13xCSR26	556 ± 21.59	542 ± 17.09	144 ± 0.00	9731 ±214.73	18.600 ±1.06	1.930 ± 0.12	0.430 ± 0.01	22.22 ± 0.68	999 ± 61.15	2.52 ± 0.02	18.35 ± 0.84	6.62 ± 0.14	92.50 ± 0.82	22.64 ± 0.48
S9xCSR16	549 ± 31.86	542 ± 17.09	144 ± 0.00	9751 ±516.96	18.360 ±1.35	1.940 ± 0.09	0.439 ± 0.01	22.76 ± 0.47	1064 ± 89.08	2.76 ± 0.35	18.78 ± 0.52	6.58 ± 0.09	92.50 ± 0.67	23.50 ± 0.50
S9xCSR26	562 ± 16.05	542 ± 17.09	144 ± 0.00	9738 ±521.89	18.320 ±1.03	1.930 ± 0.05	0.440 ± 0.02	22.66 ± 0.25	1056 ± 105.52	2.32 ± 0.01	18.88 ± 0.36	6.57 ± 0.06	92.50 ± 0.67	23.50 ± 0.50
CSR6xCSR26 **(C)**	534 ± 10.74	542 ± 17.09	144 ± 0.00	9257 ±303.06	17.460 ±0.47	1.741 ± 0.05	0.380 ± 0.01	21.62 ± 0.17	1015 ± 82.14	2.70 ± 0.29	17.80 ± 0.66	6.95 ± 0.12	91.50 ± 0.62	23.50 ± 0.51

Table 3: Performance of bivoltine hybrids of different crosses during different seasons

(Mean values of 3 Seasons)

Different cross hybrids	**Fecu-ndity**	**Larval duration**		**Yield/10000 larvae**		**Cocoon Wt. (g)**	**Shell Wt. (g)**	**Cocoon shell (%)**	**Filament length (m)**	**Raw Silk (%)**	**Filament size (d)**	**Rend-Itta**	**Neat-ness (p)**	**Boil-off loss**
		Larval (h)	**V age (h)**	**No.**	**Wt.**									
Single-cross														
CSR27xS9	543 ± 15.28	549 ± 29.14	144 ± 0.00	9608 ± 333.82	17.89 ± 0.34	2.080 ± 0.31	0.493 ± 0.08	23.56 ± 0.20	1075 ±118.28	18.75 ± 0.40	2.76 ± 2.80	6.24 ± 0.02	92.75 ± 0.63	24.03 ± 1.05
CSR27xD13	526 ± 19.5	549 ± 29.14	144 ± 0.00	9505 ± 582.39	17.38 ± 2.55	1.930 ± 0.28	0.446 ± 0.09	23.12 ± 0.78	932 ± 249.08	18.39 ± 0.30	2.67 ± 2.55	6.18 ± 0.34	92.03 ± 2.62	23.83 ± 1.76
CSR17xBBE247	517 ± 19.01	549 ± 29.14	144 ± 0.00	9048 ± 377.44	16.57 ± 0.93	1.901 ± 0.30	0.453 ± 0.11	22.82 ±2.31	843 ±239.82	17.18 ± 0.04	2.87 ± 2.40	6.24 ± 0.48	90.89 ± 0.75	24.89 ± 0.67
S5xBBE267	533 ± 17.36	549 ± 29.14	144 ± 0.00	9356 ± 660.60	17.40 ± 2.33	1.810 ± 0.18	0.427 ± 0.02	23.59 ± 3.32	945 ± 77.32	17.47 ± 0.10	2.83 ± 2.04	6.27 ± 0.57	92.06 ± 1.50	24.67 ± 0.29
JPN8xBBE267	536 ± 8.50	549 ± 29.14	144 ± 0.00	9517 ± 236.29	17.68 ± 1.13	1.860 ± 0.22	0.428 ± 0.09	23.02 ± 1.77	898 ±166.58	17.79 ± 0.22	3.01 ± 2.33	6.19 ± 0.35	90.94 ± 0.95	24.50 ± 1.32
Three-way cross														
(CSR27xCSR17)xS9	547 ±11.05	546 ±19.40	144 ±8.31	9015 ±191.85	18.578 ±0.74	1.950 ±0.10	0.416 ±0.02	21.36 ±0.30	1044 ±109.06	18.36 ±0.52	2.70 ±0.32	6.68 ±0.07	92.50 ±0.67	23.34 ±0.14
(CSR27xCSR17)xCSR26	545 ±9.67	546 ±19.40	144 ±8.31	9183 ±321.75	18.629 ±0.67	1.971 ±0.06	0.421 ±0.01	21.36 ±0.32	1021 ±94.81	18.54 ±0.53	2.48 ±0.07	6.49 ±0.07	92.50 ±0.10	23.89 ±0.54
(JPN8xCSR27)xS9	557 ±15.04	546 ±19.40	144 ±8.31	9201 ±344.05	18.666 ±0.70	1.948 ±0.09	0.424 ±0.01	21.78 ±0.56	1018 ±102.40	18.59 ±1.08	2.76 ±0.30	6.60 ±0.12	92.25 ±0.79	24.08 ±0.72
(JPN8xCSR17)xD13	548 ±15.82	546 ±19.40	144 ±8.31	9124 ±154.48	18.567 ±0.58	1.942 ±0.09	0.419 ±0.01	21.58 ±0.35	1029 ±87.54	18.24 ±0.67	2.37 ±0.11	6.64 ±0.07	92.33 ±0.10	23.83 ±0.58
(S5xJPN8)xCSR26	550 ±12.02	546 ±19.40	144 ±8.31	9031 ±221.64	19.677 ±0.82	1.966 ±0.04	0.421 ±0.00	21.41 ±0.32	990 ±64.72	18.53 ±0.35	2.67 ±0.05	6.86 ±0.07	92.80 ±0.00	24.19 ±0.53
Four-way cross														
(CSR27xCSR17) x (D13xCSR26)	636 ±17.30	553 ±11.87	153 ±7.57	9324 ±74.17	21.140 ±0.33	2.143 ±26.50	0.471 ±0.02	22.01 ±0.01	1112 ±40.43	19.34 ±0.29	3.03 ±0.53	6.64 ±0.00	92.44 ±0.19	23.50 ±0.00
(JPN8xCSR27) x (S9xCSR26)	634 ±17.00	553 ±11.87	153 ±7.57	9581 ±49.60	19.990 ±0.31	2.143 ±20.36	0.486 ±0.01	22.70 ±0.06	1092 ±75.07	19.45 ±0.05	2.39 ±0.55	6.60 ±0.01	92.33 ±0.00	23.50 ±0.00
(S5xJPN8) x (D13xCSR16)	610 ±12.34	553 ±11.87	153 ±7.57	9256 ±27.09	19.010 ±0.34	2.179 ±20.03	0.493 ±0.02	22.60 ±0.28	1022 ±54.03	18.87 ±0.16	3.00 ±0.35	6.70 ±0.07	91.67 ±0.00	23.50 ±0.12
(JPN8xCSR27) x (D13xCSR26)	632 ±18.68	553 ±11.87	153 ±7.57	9331 ±108.72	20.150 ±0.58	2.180 ±20.11	0.494 ±0.03	22.62 ±0.24	1118 ±49.56	19.18 ±0.08	2.55 ±0.75	6.61 ±0.03	92.33 ±0.00	23.50 ±0.00
(JPN8xCSR17) x (D13xCSR26)	635 ±18.90	553 ±11.87	153 ±7.57	9447 ±167.74	20.440 ±0.36	2.144 ±20.16	0.493 ±0.02	22.99 ±0.24	1108 ±86.82	19.28 ±0.09	2.56 ±0.76	6.63 ±0.05	92.44 ±0.19	23.50 ±0.00
CSR2 x CSR4 **(Control)**	503 ±51.92	546 ±19.42	144 ±8.31	8632 ±143.69	16.939 ±1.80	1.771 ±0.19	0.389 ±0.05	20.91 ±3.26	965 ±92.51	17.47 ±2.02	2.46 ±0.28	6.36 ±0.63	92.10 ±10.20	23.22 ±2.51
(CSR2xCSR27)x(CSR6xCSR26) **(Control)**	595 ±30.37	553 ±11.87	153 ±7.57	9155 ±64.77	18.820 ±0.30	2.043 ±0.01	0.462 ±0.01	22.60 ±0.61	994 ±36.72	18.91 ±0.02	2.63 ±0.56	6.66 ±0.14	91.33 ±0.33	24.00 ±0.10

Table 4: Estimation of heterosis for economic parameters in different crosses during different seasons

(Mean values of 3 Seasons)

Different crosses	Fecu-ndity	Yield/10000 larvae		Cocoon Wt.	Shell Wt.	Shell %	Filament		Raw Silk	Rendita	Neat-ness	Boil-off loss
		No.	Wt.				length	size				
Oval FC												
S5xJPN8	5.98	0.03	10.20	1.75	1.94	0.22	3.07	20.92	5.67	-3.25	1.09	10.11
JPN8xCSR27	2.25	0.64	13.05	4.64	0.24	3.96	0.72	10.98	5.40	-2.24	0.00	9.35
JPN8xCSR17	2.16	0.03	10.72	3.64	1.68	1.97	1.77	6.50	4.68	-1.49	0.00	10.38
CSR27xCSR17	2.14	0.28	16.09	0.92	0.67	0.21	6.33	-2.50	6.31	-1.78	0.00	3.61
CSR2xCSR27	1.02	-0.08	9.67	4.11	-2.19	-5.17	0.70	2.17	5.11	-2.97	1.08	4.44
Dumb-bell FC												
D13xCSR16	1.92	0.61	1.44	1.31	1.45	0.73	0.78	-3.11	1.73	-1.48	0.00	4.96
D13xCSR26	0.00	0.44	2.21	1.26	4.37	2.68	4.28	-8.86	1.61	-1.93	0.00	2.78
S9xCSR16	1.29	0.13	1.38	2.01	1.73	3.69	2.46	1.28	0.60	-2.23	0.54	4.44
S9xCSR26	1.72	0.15	1.66	1.42	1.15	3.78	1.64	-15.79	0.59	-2.09	0.54	4.44
CSR6xCSR26	-0.78	-5.19	-4.66	-0.46	-0.51	0.77	4.56	-13.97	0.61	-3.52	0.05	2.16
Single-cross												
CSR27xS9	0.25	2.31	8.60	11.30	9.23	2.09	0.16	-1.50	2.18	-1.09	0.84	6.67
CSR27xD13	2.39	3.24	3.77	4.37	6.31	1.41	10.19	-0.36	4.13	-2.10	0.85	5.13
CSR17xBBE247	-0.23	-1.16	3.60	13.19	16.50	2.93	-1.83	-10.91	-0.08	-2.33	0.12	4.73
S5xBBE267	1.77	0.78	5.89	1.01	13.69	12.20	-4.88	-12.00	0.46	-10.63	0.97	2.17
JPN8xBBE267	2.11	3.67	8.15	7.70	20.50	10.85	-15.70	0.72	0.35	-10.45	-0.43	6.51
Three-way cross												
(CSR27xCSR17)xS9	3.38	-1.41	6.99	3.63	-2.55	-8.43	-0.29	3.69	-2.71	-0.61	-0.45	5.50
(CSR27xCSR17)xCSR26	3.31	0.77	13.69	7.54	2.03	-2.92	8.23	-13.66	1.90	-3.42	0.61	4.10
(JPN8xCSR27)xS9	4.24	0.38	11.78	6.07	0.53	0.47	0.07	11.92	1.06	-1.49	0.78	6.64
(JPN8xCSR17)xCSR26	2.67	0.78	11.17	4.86	0.77	0.28	0.35	4.51	0.49	-1.19	0.58	7.79
(S5xJPN8)xCSR26	3.35	1.45	15.95	6.82	2.67	5.07	0.30	-0.99	1.68	-1.15	0.61	7.47
Four-way cross												
(CSR27xCSR17)x(D13XCSR26)	16.37	1.11	25.76	14.44	6.98	4.22	11.23	-8.25	4.48	-1.48	0.78	2.17
(JPN8xCSR27)x(S9xCSR26)	18.42	1.49	19.63	16.30	9.30	-0.96	1.34	-8.08	2.69	-2.69	0.39	5.36
(S5xJPN8)x(D13XCSR16)	13.74	-1.93	10.85	18.40	4.88	0.40	-3.28	7.19	2.17	-0.91	-0.42	3.84
(JPN8xCSR27)x(D13XCSR26)	16.39	1.20	19.94	18.48	11.90	-0.921	7.79	-1.92	3.62	-1.64	0.57	3.84
(JPN8xCSR17)x(D13XCSR26)	16.53	0.23	19.46	15.68	14.63	2.27	6.21	-1.92	3.99	-1.49	0.63	3.84
CSR2 x CSR4 **(C)**	1.96	-1.59	-3.05	-5.34	0.46	0.88	-2.22	-4.26	1.07	-3.93	0.42	1.42
(CSR2xCSR27)x(CSR6xCSR26) **(C)**	15.29	-1.14	15.78	14.20	4.70	-2.58	1.67	2.08	2.19	9.32	-2.39	4.75

Discussion

The success of silkworm rearing depends upon several factors including biotic and abiotic environmental factors as the major ones. The performance of a breed is largely dependent on the combined action of heredity of its population and environment to which it is exposed during its lifetime. Studies on implication of genotype x environment interaction with respect to seasonal variations has been reported by several investigators (Kalpana and Reddy, 1998; Rao *et al.*, 2003).The parental breeds were found to exhibit a high degree of phenotypic manifestation with regard to various economic traits indicating their genetic constitution and response to the prevailing environmental conditions in the tropical climate. The different crossing pattern hybrids are more stable than their parental and foundation crosses in unfavorable environments because of their flexibility in the gene constitution (Watanabe, 2002).

Though, the phenomenon of heterosis was exploited in plants much earlier to that of silkworm, the extent of exploitation in silkworm are unparallel to any of the commercial crops. Outcome of silkworm breeding is judged by the best desirable traits of the parental characters that appear in F1 hybrids. In India, diallel, lines x tester, three-way and four-way crosses were utilized in hybrid vigor manifestation (Sengupta *et al.*, 1974). Also, utilization of diallel cross technique evaluation of the combining ability of different strains, determining superiority of a breed / hybrid for a particular trait has lead adjudicating the potential hybrids for commercial purpose (Kalpana *et al.*, 1999). Many of the earlier studies (Harada 1961; Pannegpet and Jaroonchai 1975; Udupa and Gowda 1988; Ashoka and Govindan 1994; Mukarjee 1994; Nagaraju *et al.*,1996) demonstrated the superiority of single, three way and double hybrids over their parental races and confirms the present findings where maximum hybrid vigor was expressed in (CSR27xS9), [(S5xJPN8)xCSR26] and (CSR27xCSR17) x (D13 x CSR26) for yield / weight, cocoon weight, shell weight, cocoon shell ratio, filament length, raw silk percentage, neatness and boil off ratio among the selected 5 each of different crossing pattern hybrids. However, heterosis with regard to each hybrid derived from the parents is an important aspect, which enables to understand the manifestation of hybrid vigor in respect of each of the characters independently and in conjugation with other and in the present study single-cross (CSR27xS9), three-way cross [(S5xJPN8)xCSR26] and (JPN8xCSR27)x(S9xCSR26) expressed positive hybrid vigor for majority (10 out of 12) of the quantitative traits and negative desirable hybrid vigor for denier and renditta.

Moreover, skillful utilization of hybrid vigor is of utmost importance in sericulture or any other agricultural crops to obtain maximum desirable economic benefits (Ramesha *et al.*, 2009; Seshagiri *et al.*, 2009). Realizing the essentiality of high cocoon shell percentage and raw silk percentage, as thrust areas, many viable single crosses were evolved and authorized for commercial exploitation (Basavaraja *et al.*, 1995; Datta *et al.*, 2002). However, manifestation of heterosis may be differing on the extent of genetic advancement and the distance achieved in new genetic materials in a breeding study, as it is seen that many foundation crosses, single-cross, three-way cross and four-way crosses have shown desirable manifestation of heterosis for many traits. This is in agreement with the earlier findings of Sathenahalli *et al*., 1989 who reported that manifestation of heterosis differ widely and such differences suggests that parental materials involved differ in their genetic makeup and the high degree of heterosis in any specific cross can be due to additive gene effects as per report of Rao *et al*., 1998.

The results of the present study clearly show that the performance of foundation cross, three-way and four-way cross hybrids are on par with the single-cross hybrids in terms of quantitative traits. The single-cross hybrids are superior to all other crossing pattern with respect to expression of higher magnitude of hybrid vigor. Based on the results, two combinations each of single-crosses CSR27xS9, CSR27xD13; three-way crosses [(JPN8xCSR27)xS9], [(JPN8xCSR17)xCSR26] and four-way crosses (CSR27xCSR17)x(D13xCSR26), JPN8xCSR27)x(S9xCSR26) were identified to have better potentiality as evidenced from the study by scoring higher and positive hybrid vigor for most of the quantitative traits of pre-cocoon, cocoon and post-cocoon parameters. Considering the above facts, the information generated in the present study clearly show utilization of identified potential single, three-way and four-way cross hybrids and their parents (both foundation crosses and parents) for field evaluation in tropical conditions for enhancement of total raw silk production.

References

1. Ashoka J, Govindan R. Performances of some bivoltine silkworm breeds and their single and double cross hybrids for yield and cocoon traits. *Kar. J. Agri.* (1994), 7(1):28-31.
2. Basavaraja HK, Nirmal Kumar S, Suresh Kumar N, Mal Reddy N, Kshama Giridhar, Ashan MM, Datta RK. New productive bivoltine hybrids. *Indian Silk,* (1995), 34: 5-9.
3. Datta RK, Basavaraja HK, Mal Reddy N, Nirmal Kumar S, Ashan MM, Suresh Kumar N, Ramesh Babu S. Evolution of new bivoltine hybrids, CSR2xCSR4 and CSR2xCSR5. *Sericologia,* 2000, 40:151-167.
4. Datta RK, Basavaraja HK, Mal Reddy N, Nirmal Kumar S, Suresh Kumar N, Ramesh Babu M, Ahsan MM. Jayaswal KP. Breeding of new productive bivoltine hybrid, CSR12xCSR6 of silkworm *Bombyx mori* L. *Int. J. Indust. Entomol.* 2002, 3: 127-133.
5. Harada C. Heterosis of quantitative characters in silkworm. *Bull. Sric. Expl. Stan.,* 1961, 17: 1-52
6. Kalpana GV, Sreerama Reddy G. Seasonal studies on the performance of the new multivoltine breed MU953 in the tropics. *Sericologia,* 1998, 41:451-458.
7. Kalpana GV, Sudhakar Rao P, Kshama Giridhar, Ahsan MM, Datta RK. Identification of promising bivoltine hybrids by maize Selection Tool (MST) – A software package. *Uttarpradesh J. Zool.,* 1999, 19(1):25-29.
8. Mal Reddy N, Basavaraja HK, Suresh Kumar N, Nirmal Kumar S, Kalpana GV. Breeding of bivoltine double hybrid (CSR6xCSR26) x (CSR2xCSR27) of silkworm, *Bomby mori* L. for commercial exploitation. *Advances in Tropical Sericulture*, (Eds.) Dandin S.B., Mishra R. K., Gupta V. P. and Reddy Y. S., 2005, 58-62.
9. Maria Elisa AGP. Use of heterosis in maize breeding: History, methods and perspective – a review. *Crop breeding and Applied Biotechnology,* 2001, 1(2):159-178.
10. Mukherjee P. Hybrid vigour in different crossing systems in silkworm *Bombyx mori*. In: *Silkworm Breeding,* G. Srinivasa Reddy (Ed.) Oxford and IBH Pub. Co. Ltd., New Delhi. 1994, 73-74.
11. Nagaraju J, Raje Urs S, Datta RK. Cross breeding and heterosis in the silkworm, *Bombyx mori*, a review. *Sericologia,* 1996, 36: 1-20.
12. Nagaraju J, Goldsmith MR. Silkworm genomics–Prospects and progress. C*urrent Sci.,* 2002a, 83: 1-20.
13. Nagaraju J, Goldsmith MR. Application of genetic principles for improving silk production. *Current Sci.*, 2002b, 83: 409-414.
14. Nirmal Kumar S, Ramesh Babu M, Basavaraja HK, Mal Reddy N, Datta RK. Double hybrids for improvement in silk production in silkworm, *Bombyx mori L. Silkworm Breeding*. Oxford and IBH publishing Co. Pvt. Ltd., New Delhi, India, 1998, 209-211.
15. Pannegpet P, Jaroonchai J. Survey on the practical characters of double cross hybrids of bivoltine silkworm races. *Bull. Thai Sericultural Research and Training Centre,* Thailand. 5: 85-86.
16. Rao PRT, Ghosh SM, Moorthy SK, Das GC, Roy AK, Sen AK. Combining ability, Gene action and heterosis through introgressive hybridization in *Bombyx mori* L. *Proceedings of Perspectives in Cytology and Genetics*, 1998, 9: 461-470.
17. Rao PS, Ravindra Singh, Nishitha Naik, V, Basavaraja HK, Rekha M. Datta RK. Seasonal performance of newly evolved bivoltine hybrids of silkworm, *Bombyx mori* L in the tropics. *Bull. Ind. Acad. Seri.*, 2003, 7(2):21-27.
18. Ramesha C, Seshagiri SV, Rao CGP. Evaluation and identification of superior polyvoltine crossbreeds of mulberry silkworm, *Bombyx mori* L. *J. Entomol.,* 2009, 6: 188-197.
19. Sathenahalli SB, Govindan R, Gous JV. Analysis of heterosis for some quantitative traits in silkworm, *Bombyx mori* L. *Mysore J. Agric. Sci*., 1989, 24: 214-221.
20. Sengupta K., Yusuf M R. and Grover S. P. (1974) Hybrid vigour and genetic analysis of quantitative traits in silkworm. *Indian J. Genet.,* 34: 249-256.
21. Seshagiri S. V., Ramesha C. and Rao C. G. P. (2009) Genetic manipestation of hybrid vigour in cross breeds of mulberry silkworm, *Bombyx mori* L. *Int. J. Zool. Res*., *5*: 150-160.
22. Sripada S Udupa and Vishweshwara Gowda B L. (1988) Heterosis in single, three-way and double cross hybrids of silkworm, *Bombyx mori* L. *Insect Sci. Applic.,* 9(4):519-525.
23. Watanabe H. Genetic resistance of the silkworm, *Bombyx mori* L. to viral disease. *Curr. Sci.*, 2002, 83(4): 439-449.
24. Xiang Li, Yubo Zhang, Zhonglin Tang, Mei Yu, Bang Liu and Bin F. Comparative estimation of three-way heterosis in reveal genetic bias of widely used empherical formula. *J. Animal & Vet. Advances,* 2009, 8(6):1212-1218.