Journal of Entomology and Zoology Studies
Available online at www.entomoljournal.com

ISSN 2320-7078
JEZS 2013; 1 (6): 39-43

Received 10-10-2013
Accepted: 01-11-2013

Veeranna Gowda
Central Sericultural Germplasm Resources Centre, Hosur-635 109, Tamil Nadu.

Kalpana GV
P4 Basic Seed Farm, CSR&TI, Hassan- 573 217, Karnataka.
Email: v_gowda62@yahoo.com

Ashwath SK
Central Sericultural Research & Training Institute, Mysore-570 008, Karnataka

Correspondence:
Dr. Veeranna Gowda
Central Sericultural Germplasm Resources Centre (CSGRC), Hosur-635 109, Tamil Nadu.
Email: v_gowda62@yahoo.com

Evaluation and Identification of Potential Bivoltine Silkworm Hybrids of *Bombyx Mori* L.

Veeranna Gowda, Kalpana GV, Ashwath SK

ABSTRACT
With the objective of identifying potential hybrids, bivoltine three-way cross hybrids involving inbred dumbbell foundation cross hybrids (FCs) and oval breeds, as parents, were evaluated. Overall performance, multiple trait evaluation indices and heterosis estimates were analyzed for the quantitative traits in a total of twenty one hybrids. The consequential data reveals that the hybrids studied performed significantly different indicating the existence of wide variation in phenotypic traits. It is inferred that, six promising three-way cross (DxD)xO hybrids *viz.,* [(D13 x S9) x CSR17], [(S9 x CSR26) x JPN8], [(D13 x CSR26) x CSR27], [(CSR16 x CSR26) x CSR17], [(S9 x CSR16) x CSR27] and [(D13 x CSR26) x CSR17] were identified as promising ones based on performance, E. I. values and heterosis for majority of the traits in three different seasons and preserve commercial exploitation.

Keywords: Three-way cross hybrids, inbred foundation cross hybrids, genetic potential, phenotypic, heterosis, economic trait.

1. Introduction

The manifestation of heterosis, described in terms of superiority, through F1 hybrids performance over the parental performance is practical in biological kingdom. Fusion of new-gene combinations by genetic manipulation is one of the powerful tools in exploiting the commercial qualities of plants and animals. As per available literature, manifestation of heterosis in silkworm has been demonstrated by many breeders [1, 2]. The F1 hybrids are more productive and robust, which can be reared easily by adopting appropriate rearing technology [3]. Heterosis, expressed as the improvement in a character shown by the hybrid over their parental values is a vital measure of the genetic progress made in plant, animal and silkworm selection.

In silkworm *Bombyx mori* L. the importance of increased hybrid vigour in order to understand the phenotypic expression of the hybrids was studied and realized earlier in Japan. Whereas, India is dependent upon tropical climate withstanding multi bivoltine hybrid commercial exploitation up to 90% output of the total silk production, such studies in respect of bivoltine F1 hybrids is found scanty. Studies on heterosis effect on economic traits report a result of overdominance and linked favorable dominant gene contribution to heterosis[4]. The degree of considerable variation with maximum heterosis for different parameters[5] was carried out for a series of out-breed crosses to select a suitable F1 hybrid for better silk production. In other study, the hybrid combinations manifested positive heterosis value for the cocoon traits studied[6] and observations of all these studies is that the heterotic effects were significant for most of the quantitative characters.

Silkworm breeding programs are based on the development and selection of outstanding hybrids from the inbred lines and the performance of hybrids depends largely on yield trials and genetic divergence of the populations from which the parental lines are extracted. As per findings [7], the level of genetic diversity between the two parents used for crossing has been projected as a feasible predictor of hybrid performance and prediction of hybrid performance is of primary interest to all breeding programs and attracts for massive effort.

Hence, a concise study has been undertaken to measure the level of overall performance among the bivoltine three-way cross (DxD)xO hybrids which will be useful to assess their ability to encounter challenges in raising commercial crops, multiple trait evaluation index and exploring the extent of hybrid vigour of F1 hybrids besides selecting suitable parents, population for an effective silkworm breeding program and utilization in future crop improvement programs.

2. Materials and methods

In the present study, selected 12 bivoltine breeds viz., BBE226, CSR17, CSR27, JPN8, JPN7, S5 (oval) and BBE267, BBE247, D13, S9, CSR16, CSR26 (dumbbell) drawn from the Germplasm bank of CSR&TI, Mysore and CSGRC, Hosur were utilized. Six dumbbell breeds were crossed in selective method, 15 dumbbell foundation crosses (FCs) were prepared and reared along with oval breeds. These 15 dumbbell inbred FCs were used as female parents and crossed with oval breeds by employing partial diallel cross technique and obtained 21 (DxD)xO three-way cross hybrids. Composite layings of all the hybrids were reared en-mass in three replications each during three seasons (Summer, Rainy and Winter) of the year under standard rearing conditions [8] to assess their rearing performance and reeling parameters were analyzed by following standard procedures [9].

Results on important economic traits covering pre-cocoon, cocoon and post-cocoon spheres such as fecundity, total larval duration, 5th age larval duration, yield/10000 larvae (No.), yield/10000 larvae (Wt.), cocoon weight, cocoon shell weight, shell ratio, filament length, filament size, raw silk content, renditta, neatness and boil-off loss were considered for evaluating the overall performance of the hybrids, assessment of multiple trait E. I. values and hybrid vigour estimation. Evaluation Index (E. I.) was calculated for all the traits (except total and 5thage larval duration) using the formula,

E. I. = A – B / C x 10 + 50

where, A = Value of the particular hybrid,

B = Mean value of all the hybrids,

C = Standard deviation of all the hybrids,

10 = Standard unit,

50 = Fixed value.

The hybrid vigour (H%) was estimated for all the traits (except total and 5thage larval duration) resultant data by using the formula of [10], which is as under.

$$H\% = \frac{\overline{F} - (0.50\overline{A} + 0.25\overline{B} + 0.25\overline{C})}{(0.50\overline{A} + 0.25\overline{B} + 0.25\overline{C})} \times 100$$

Where, H% = Value of heterosis ratio,

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

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

3. Results

The rearing and reeling performance of new three-way cross (DxD)xO hybrids along with single cross and double cross hybrids, as control, were studied. All the hybrids including control hybrids have recorded less variation in larval duration and mean values remained almost same during different seasons. The mean values of the trait fecundity ranged from 499 [(S9xCSR26)xCSR27] to 559 [(D13xCSR26)xCSR27]. Yield/10000 (No.) larvae varied from 8,121 [(CSR16xCSR26)xJPN8] to 9,534 [(D13xS9)xCSR17] and yield/10000 larvae (Wt.) ranged from 16.78kg [(CSR16xCSR26)xJPN8] to 18.83 kg [(S9xCSR26)xJPN9]. The cocoon weight mean values ranged from 1.72g [(CSR16xCSR26)xJPN8] to 1.98g [(D13xS9)xCSR17], shell weight from 0.36g [(CSR16xCSR26)xBBE226] to 0.44g [(D13xCSR26)xCSR27], cocoon shell ratio from 19.97% [(CSR16xCSR26)xBBE226] to 23.45% [(S9xCSR16)xCSR27], filament length from 780m [(S9xCSR26)xJPN7] to 1123m [(S9xCSR26)xJPN8], filament size 2.61d [(S9xCSR16)xJPN8] to 3.02d [(D13xS9)xJPN7], raw silk from 16.12% [(CSR16xCSR26)xJPN7] to 19.58% [(D13xS9)xCSR17], renditta from 5.55 [(D13xS9)xCSR17] to 6.44 [(CSR16xCSR26)xBBE226], neatness from 90.78p [(CSR16xCSR26)xJPN8] to 92.11p [(CSR16xCSR26)x17] and boil-off loss from 23.50% [(S9xCSR16)xCSR17] to 24.78% [(CSR16xCSR26)xJPN8] in three different seasons (Table 1).

Multiple trait evaluation indices (E. I.) assessment is the multiple performance of a population for selection / short-listing of the hybrids by taking into consideration all the economic traits. Based on the performance of the 21 (D x D) x O hybrids, individual indices were calculated for each of the 12 traits. Evaluation index values were calculated for each of the hybrid in all the 12 parameters (Table 2). The indices obtained from all the traits in each hybrid were combined and the average E. I. values was assessed. The criteria for selection of the hybrid were based on the average E. I. value >50. The hybrids which scored above the limit of 50 in many of the traits were considered to possess greater economic value. Out of 21 (DxD)xO hybrids, six hybrids scored average E. I. values ranging from 53.46 [(D13xCSR26)xCSR17] to 58.37 [(D13xS9)xCSR17]. However, out of selected six hybrids, four hybrids expressed the individual E. I. value more than 50 for 10 traits (except renditta and boil-off loss) out of 12 parameters. Similarly, in the other two selected hybrids (S9xCSR16)xCSR27 and (D13xCSR26)xCSR17 the individual E.I. value was >50 in nine traits (except filament size, renditta and boil-off loss) but the average E. I. value was 53.48 and 53.46, respectively.

The results of hybrid vigour estimation in (DxD)xO hybrids during different seasons studied are presented in Table 3. All the 21 (DxD)xO three-way cross hybrids have shown positive heteosis in many of the parameters. The maximum positive hybrid vigour (3.39%) for fecundity trait was recorded in [(D13xS9)xCSR17] and minimum of -8.31% was noticed in [(S9xCSR26)xCSR27]. Maximum hybrid vigour for yield / 10000 larvae by number, by weight, single cocoon weight, single shell weight, cocoon shell percentage, filament length, raw silk percentage, neatness and negative heterosis for filament size, renditta and boil-off loss were recorded in most of the hybrids during different seasons. Based on the results, six promising (DxD)xO hybrids viz., [(D13 x S9) x CSR17], [(S9 x CSR26) x JPN8], [(D13 x CSR26) x CSR27], [(CSR16 x CSR26) x CSR17], [(S9 x CSR16) x CSR27] and [(D13 x CSR26) x CSR17] exhibited hybrid vigour for 10 and 9 traits respectively. Further, the overall performance, assessment of E. I. and estimation of hybrid vigour of the selected (DxD)xO hybrids scored positive and significant mean values in respect of 9 and 10 out of 12 traits.

Table 1: Rearing and Reeling performance of Three-way cross (DxD)xO Hybrids during different seasons

(Mean values of 3 Seasons)

#	Three-way cross (DxD)xO hybrids	Fecun-dity	Larval duration		Yield/10000 larvae		Cocoon	Shell	Cocoon	Filament		Raw	Rend -itta	Neat-	Boil-off
			Larval (H)	Vage (H)	No.	Wt. (kg)	Wt. (g)	Wt. (g)	Shell ratio	length (m)	size (d)	Silk (%)		ness (p)	loss (%)
1	**(CSR16xCSR26)xBBE226**	**518 ±14.92**	**546 ±19.40**	**149 ±8.31**	**8618 ±397.36**	**16.72 ±1.43**	**1.76 ±0.14**	**0.36 ±0.03**	**19.97 ±0.18**	**841 ±11.80**	**2.99 ±0.16**	**16.54 ±0.80**	**6.44 ±0.05**	**90.83 ±0.00**	**24.50 ±0.00**
2	**(CSR16xCSR26)xS5**	**517 ±14.17**	**546 ±19.40**	**149 ±8.31**	**8452 ±220.49**	**16.95 ±1.49**	**1.76 ±0.17**	**0.37 ±0.03**	**20.03 ±0.32**	**903 ±55.93**	**2.65 ±0.15**	**16.87 ±0.58**	**5.86 ±0.29**	**91.22 ±0.38**	**24.17 ±0.29**
3	**(CSR16xCSR26)xJPN8**	**507 ±22.39**	**546 ±19.40**	**149 ±8.31**	**8121 ±140.71**	**16.78 ±1.46**	**1.72 ±0.11**	**0.36 ±0.02**	**20.15 ±0.46**	**880 ±48.37**	**2.88 ±0.13**	**16.61 ±0.98**	**5.79 ±0.20**	**90.78 ±0.38**	**24.78 ±0.48**
4	**(CSR16xCSR26)xCSR27**	**538 ±6.34**	**546 ±19.40**	**149 ±8.31**	**8843 ±291.53**	**17.77 ±0.81**	**1.85 ±0.04**	**0.39 ±0.01**	**21.50 ±1.14**	**902 ±76.96**	**2.95 ±0.27**	**17.22 ±1.13**	**5.71 ±0.18**	**91.33 ±0.58**	**24.31 ±0.34**
5	**(CSR16xCSR26)xCSR17**	**545 ±26.40**	**546 ±19.40**	**149 ±8.31**	**9393 ±391.65**	**18.70 ±0.86**	**1.92 ±0.11**	**0.43 ±0.04**	**23.20 ±0.94**	**1041 ±87.35**	**2.96 ±0.14**	**18.89 ±0.88**	**5.61 ±0.14**	**92.11 ±0.35**	**23.72 ±0.41**
6	**(CSR16xCSR26)xJPN7**	**510 ±30.63**	**546 ±19.40**	**149 ±8.31**	**8674 ±282.52**	**17.27 ±0.72**	**1.85 ±0.08**	**0.38 ±0.01**	**20.57 ±0.43**	**841 ±39.20**	**2.73 ±0.25**	**16.12 ±1.52**	**5.87 ±0.10**	**90.94 ±0.10**	**24.17 ±0.58**
7	**(S9xCSR16)xS5**	**508 ±11.53**	**546 ±19.40**	**149 ±8.31**	**8701 ±242.72**	**17.57 ±0.88**	**1.89 ±0.06**	**0.39 ±0.01**	**20.43 ±0.73**	**882 ±33.56**	**2.80 ±0.10**	**16.66 ±1.12**	**5.90 ±0.18**	**91.00 ±0.00**	**24.50 ±0.00**
8	**(S9xCSR16)xJPN8**	**506 ±11.10**	**546 ±19.40**	**149 ±8.31**	**8505 ±121.27**	**17.03 ±0.77**	**1.86 ±0.03**	**0.39 ±0.00**	**20.71 ±0.18**	**893 ±46.62**	**2.61 ±0.36**	**17.95 ±0.33**	**5.83 ±0.03**	**91.44 ±0.38**	**24.25 ±0.00**
9	**(S9xCSR16)xCSR27**	**552 ±26.93**	**546 ±19.40**	**149 ±8.31**	**9398 ±314.89**	**18.51 ±1.01**	**1.89 ±0.08**	**0.44 ±0.04**	**23.45 ±0.96**	**1056 ±92.86**	**2.69 ±0.24**	**19.18 ±1.03**	**5.58 ±0.14**	**92.06 ±0.42**	**23.50 ±0.00**
10	**(S9xCSR16)xCSR17**	**507 ±7.17**	**546 ±19.40**	**149 ±8.31**	**8671 ±208.54**	**17.03 ±0.98**	**1.87 ±0.01**	**0.39 ±0.01**	**20.78 ±0.32**	**936 ±5.56**	**2.86 ±0.28**	**17.52 ±0.21**	**5.74 ±0.07**	**91.00 ±0.00**	**24.25 ±0.00**
11	**(S9xCSR16)xJPN7**	**514 ±21.75**	**546 ±19.40**	**149 ±8.31**	**8571 ±138.15**	**17.70 ±1.06**	**1.87 ±0.04**	**0.38 ±0.01**	**20.57 ±0.23**	**882 ±15.84**	**2.65 ±0.35**	**17.10 ±0.68**	**5.86 ±0.06**	**91.00 ±0.00**	**24.25 ±0.00**
12	**(S9xCSR26)xJPN8**	**547 ±22.56**	**546 ±19.40**	**149 ±8.31**	**9480 ±266.94**	**18.83 ±0.35**	**1.95 ±0.11**	**0.42 ±0.04**	**22.60 ±0.10**	**1123 ±66.05**	**2.94 ±0.20**	**19.05 ±0.77**	**5.59 ±0.10**	**91.87 ±0.23**	**23.64 ±0.24**
13	**(S9xCSR26)xCSR27**	**499 ±13.51**	**546 ±19.40**	**149 ±8.31**	**8578 ±148.26**	**17.13 ±0.60**	**1.86 ±0.03**	**0.38 ±0.00**	**20.33 ±0.16**	**872 ±61.79**	**2.93 ±0.13**	**16.62 ±0.71**	**5.98 ±0.07**	**91.00 ±0.00**	**24.50 ±0.00**
14	**(S9xCSR26)xCSR17**	**515 ±32.41**	**546 ±19.40**	**149 ±8.31**	**8637 ±204.28**	**17.22 ±0.68**	**1.82 ±0.07**	**0.38 ±0.00**	**20.72 ±0.92**	**873 ±86.24**	**2.95 ±0.12**	**16.94 ±0.66**	**5.83 ±0.21**	**91.00 ±0.00**	**24.50 ±0.00**
15	**(S9xCSR26)xJPN7**	**526 ±28.62**	**546 ±19.40**	**149 ±8.31**	**8593 ±75.20**	**17.26 ±0.68**	**1.89 ±0.04**	**0.38 ±0.00**	**20.31 ±0.42**	**780 ±12.48**	**2.70 ±0.24**	**16.46 ±2.13**	**5.93 ±0.10**	**91.00 ±0.00**	**24.50 ±0.00**
16	**(D13xCSR26)xCSR27**	**559 ±31.58**	**546 ±19.40**	**149 ±8.31**	**9515 ±362.45**	**18.36 ±0.99**	**1.97 ±0.09**	**0.44 ±0.04**	**23.36 ±1.15**	**1066 ±126.74**	**2.87 ±0.11**	**19.30 ±0.88**	**5.66 ±0.14**	**92.06 ±0.42**	**23.86 ±0.24**
17	**(D13xCSR26)xCSR17**	**550 ±21.07**	**546 ±19.40**	**149 ±8.31**	**9530 ±163.29**	**18.59 ±0.65**	**1.93 ±0.07**	**0.44 ±0.02**	**22.93 ±0.41**	**1033 ±78.13**	**2.75 ±0.18**	**19.23 ±0.50**	**5.64 ±0.10**	**91.98 ±0.47**	**23.81 ±0.51**
18	**(D13xCSR26)xJPN7**	**510 ±12.51**	**546 ±19.40**	**149 ±8.31**	**9057 ±129.77**	**17.57 ±0.64**	**1.86 ±0.03**	**0.39 ±0.01**	**20.95 ±0.34**	**846 ±30.97**	**2.71 ±0.20**	**17.57 ±0.53**	**5.78 ±0.09**	**91.56 ±0.19**	**24.17 ±0.58**
19	**(D13xS9)xCSR17**	**532 ±45.83**	**546 ±19.40**	**149 ±8.31**	**9534 ±213.49**	**18.51 ±1.43**	**1.98 ±0.09**	**0.43 ±0.04**	**22.72 ±0.62**	**1032 ±102.33**	**2.98 ±0.13**	**19.58 ±0.63**	**5.55 ±0.06**	**91.89 ±0.19**	**23.97 0.50**
20	**(D13xS9)xJPN7**	**512 ±11.72**	**546 ±19.40**	**149 ±8.31**	**8854 ±22.70**	**17.60 ±0.28**	**1.84 ±0.02**	**0.39 ±0.01**	**21.08 ±0.22**	**780 ±22.50**	**3.02 ±0.06**	**17.23 ±0.58**	**5.75 ±0.05**	**91.44 ±0.38**	**24.50 ±0.00**
21	**(D13xCSR16)xJPN7**	**506 ±9.51**	**546 ±19.40**	**149 ±8.31**	**8825 ±252.64**	**16.89 ±1.03**	**1.83 ±0.07**	**0.38 ±0.00**	**20.97 ±0.88**	**882 ±36.73**	**2.94 ±0.13**	**17.41 ±0.42**	**5.80 ±0.24**	**91.33 ±0.33**	**24.31 ±0.76**
22	**CSR2 x CSR4 (Control)**	**537 ±56.12**	**546 ±19.40**	**149 ±8.31**	**9065 ±184.28**	**17.77 ±2.07**	**1.86 ±0.22**	**0.40 ±0.06**	**21.29 ±2.99**	**943 ±129.82**	**2.57 ±2.19**	**18.23 ±0.11**	**5.69 ±0.63**	**92.00 ±0.39**	**23.89 ±2.51**
23	**(CSR2xCSR27)x(CSR6xCSR26) (Control)**	**545 ±30.37**	**546 ±19.40**	**149 ±8.31**	**9155 ±64.77**	**18.82 ±0.30**	**2.04 ±0.01**	**0.41 ±0.01**	**20.20 ±0.61**	**994 ±36.72**	**2.63 ±0.02**	**18.91 ±0.14**	**4.66 ±0.56**	**91.33 ±0.33**	**24.00 ±0.00**

Table 2: Evaluation Index (E. I.) values in Three-way Cross (DxD)xO hybrids performance during different seasons

(Mean values of 3 Seasons)

#	Three-way cross (DxD)xO hybrids	Evaluation Index (E. I.)													
		Fecu-ndity	Yield/10000 larvae		Cocoon	Shell	Shell	F'ment	Raw	Neat-	F'ment	Rend-itta	Boil-off	Total	**Avg.**
			No.	Wt.	Wt.	Wt.	ratio	Length	silk	ness	Size		loss		**E. I.**
1	(CSR16xCSR26)xBBE226	47.19	43.96	40.81	37.66	41.92	39.04	43.35	42.05	43.26	52.92	58.28	54.27	544.72	45.39
2	(CSR16xCSR26)xS5	47.29	40.27	43.63	37.49	47.39	39.47	50.67	44.13	47.95	42.48	61.07	49.21	551.05	45.92
3	(CSR16xCSR26)xJPN8	42.32	32.85	41.50	34.05	40.78	40.74	48.00	42.28	42.74	52.30	59.41	60.36	537.32	44.78
4	(CSR16xCSR26)xCSR27	51.55	49.36	49.88	48.91	52.19	50.06	51.29	49.21	49.26	51.90	45.45	50.28	599.33	49.94
5	**(CSR16xCSR26)xCSR17**	**58.37**	**60.16**	**62.26**	**55.12**	**56.46**	**59.72**	**59.86**	**56.39**	**59.36**	**54.11**	**40.26**	**41.35**	**663.42**	**55.29**
6	(CSR16xCSR26)xJPN7	48.70	48.22	47.01	49.06	47.55	46.90	46.40	43.30	46.90	49.62	53.02	54.00	580.68	48.39
7	(S9xCSR16)xS5	43.34	45.91	49.68	53.77	46.82	43.53	48.61	43.57	45.34	48.78	56.51	55.61	581.47	48.46
8	(S9xCSR16)xJPN8	42.64	41.55	42.98	50.11	47.81	46.87	48.37	52.59	51.06	42.48	52.77	50.98	570.21	47.52
9	**(S9xCSR16)xCSR27**	**61.41**	**61.62**	**60.30**	**52.46**	**54.65**	**61.38**	**54.71**	**56.04**	**58.48**	**44.75**	**38.80**	**37.11**	**641.72**	**53.48**
10	(S9xCSR16)xCSR17	43.11	45.26	43.67	50.26	48.75	47.45	54.75	49.70	45.34	50.14	52.15	50.98	581.57	48.46
11	(S9xCSR16)xJPN7	45.34	43.03	51.50	51.01	47.45	45.16	48.22	47.33	45.34	43.94	54.57	50.98	573.87	47.82
12	**(S9xCSR26)xJPN8**	**59.48**	**63.51**	**63.08**	**61.03**	**56.03**	**66.43**	**61.58**	**60.86**	**56.15**	**52.70**	**34.19**	**39.48**	**674.50**	**56.21**
13	(S9xCSR26)xCSR27	39.28	43.17	44.10	48.91	44.67	43.03	47.37	42.61	45.34	52.98	56.99	55.61	564.06	47.00
14	(S9xCSR26)xCSR17	45.62	44.47	45.32	46.27	44.69	46.01	48.65	45.53	45.34	54.69	53.97	55.61	576.19	48.02
15	(S9xCSR26)xJPN7	50.92	43.56	45.59	52.08	46.65	43.11	35.18	41.68	45.34	43.02	56.91	55.61	559.64	46.64
16	**(D13xCSR26)xCSR27**	**61.54**	**60.93**	**56.69**	**58.18**	**60.29**	**56.49**	**59.64**	**58.61**	**54.00**	**50.46**	**44.58**	**46.76**	**668.18**	**55.68**
17	**(D13xCSR26)xCSR17**	**55.97**	**59.81**	**54.91**	**53.81**	**55.86**	**54.16**	**56.82**	**57.40**	**53.05**	**49.20**	**45.56**	**44.95**	**641.51**	**53.46**
18	(D13xCSR26)xJPN7	42.40	50.37	49.43	46.86	49.03	50.82	44.50	49.64	52.59	48.17	48.93	54.00	586.74	48.89
19	**(D13xS9)xCSR17**	**65.77**	**64.76**	**60.67**	**63.48**	**61.14**	**63.97**	**60.16**	**65.42**	**56.53**	**56.60**	**36.35**	**45.68**	**700.54**	**58.38**
20	(D13xS9)xJPN7	44.84	49.48	48.90	47.90	49.99	50.82	34.93	46.48	51.06	56.80	48.73	55.61	585.53	48.79
21	(D13xCSR16)xJPN7	42.87	50.04	42.04	44.80	47.61	50.34	48.04	48.60	49.36	53.26	49.60	51.07	577.63	48.14
22	CSR2xCSR4 **(Control)**	45.89	36.84	43.81	37.38	44.75	57.28	52.52	53.58	52.27	46.87	59.41	45.11	575.72	47.98
23	(CSR2xCSR27)x(CSR6xCSR26) **(Control)**	50.74	46.84	50.39	44.50	46.81	50.24	46.61	47.79	52.02	56.06	50.07	51.58	593.64	49.47

Table 3: Estimation of Heterosis in Three-way cross (DxD)xO hybrids during different seasons

(Mean values of 3 Seasons)

#	Three-way cross (DxD)xO hybrids	Fecundity	Yield / 10000 larvae		Cocoon	Shell	Shell	Filament		Raw	Renditta	Neat-	Boil off
			No.	Wt.	Wt.	Wt.	ratio	Length	Size	Silk		ness	Ratio
1	(CSR16xCSR26)xBBE226	-2.31	-6.72	3.55	-0.06	-9.32	-12.02	-8.06	1.87	-7.62	5.92	3.31	4.25
2	(CSR16xCSR26) x S5	-2.77	-10.70	-0.53	-6.03	-13.15	-12.08	-12.90	-3.28	-9.35	-0.09	-1.09	5.09
3	(CSR16xCSR26)xJPN8	-5.19	-14.02	-1.46	-5.08	-11.76	-10.57	-18.84	17.07	-11.13	-1.28	-1.09	11.37
4	(CSR16xCSR26)xCSR27	0.05	-6.43	8.13	-0.80	-10.96	-8.66	-9.60	5.17	-7.57	-1.81	-1.09	5.70
5	**(CSR16xCSR26)xCSR17**	**1.25**	**0.12**	**9.70**	**2.02**	**0.12**	**0.93**	**1.46**	**5.53**	**0.56**	**-3.69**	**0.00**	**3.13**
6	(CSR16xCSR26)xJPN7	-5.25	-8.36	1.32	-1.67	-11.42	-10.01	-14.42	7.69	-13.50	-0.25	-1.09	8.63
7	(S9xCSR16)xS5	-4.69	-8.07	2.95	1.10	-9.67	-11.65	-17.82	3.80	-11.55	0.90	-1.36	7.69
8	(S9xCSR16)xJPN8	-5.60	-9.96	-0.15	2.85	-5.74	-9.46	-20.32	7.96	-5.10	-0.30	-1.36	10.23
9	**(S9xCSR16)xCSR27**	**2.41**	**0.56**	**12.45**	**1.53**	**1.41**	**1.34**	**1.76**	**-2.62**	**0.34**	**-3.75**	**0.27**	**3.30**
10	(S9xCSR16)xCSR17	-6.02	-8.29	-0.26	-0.45	-10.40	-10.35	-10.49	3.53	-7.40	-1.16	-1.36	6.59
11	(S9xCSR16)xJPN7	-4.73	-9.45	3.68	-0.43	-12.59	-11.34	-13.47	6.32	-9.33	-0.13	-1.36	10.23
12	**(S9xCSR26)xJPN8**	**1.06**	**0.45**	**10.70**	**7.79**	**1.76**	**0.25**	**0.27**	**-1.34**	**0.45**	**-4.24**	**0.00**	**7.45**
13	(S9xCSR26)xCSR27	-8.31	-9.16	4.35	-0.11	-14.17	-14.66	-15.71	5.49	-12.09	3.33	-1.36	7.69
14	(S9xCSR26)xCSR17	-5.46	-8.58	1.12	-3.14	-12.49	-10.39	-16.54	6.21	-10.70	0.56	-1.36	7.69
15	(S9xCSR26)xJPN7	-3.44	-9.15	1.37	0.61	-12.39	-12.24	-23.49	7.68	-12.96	1.24	-1.36	11.36
16	**(D13xCSR26)xCSR27**	**2.38**	**0.95**	**11.25**	**5.72**	**0.35**	**0.13**	**0.50**	**-3.14**	**4.47**	**-2.25**	**0.00**	**3.74**
17	**(D13xCSR26)xCSR17**	**0.64**	**1.06**	**8.60**	**2.63**	**1.18**	**0.31**	**0.45**	**-1.17**	**3.72**	**-2.76**	**0.00**	**3.52**
18	(D13xCSR26)xJPN7	-6.68	-4.06	2.66	-1.06	-8.13	-7.51	-13.59	7.86	-4.92	-1.37	0.00	8.63
19	**(D13xS9)xCSR17**	**3.39**	**1.10**	**8.13**	**5.29**	**1.18**	**0.88**	**0.35**	**-0.09**	**5.61**	**-4.31**	**0.00**	**0.74**
20	(D13xS9)xJPN7	-6.53	-6.21	2.67	-1.95	-9.36	-8.32	-23.19	22.27	-7.89	-1.58	-1.36	11.36
21	(D13xCSR16)xJPN7	-6.51	-6.60	-1.58	-2.63	-10.69	-7.65	-9.89	17.72	-5.53	-1.19	-1.09	9.26
22	CSR2xCSR4 **(Control)**	0.58	-4.85	8.12	2.53	13.11	6.50	12.36	-6.16	4.92	-4.55	1.56	-2.04
23	(CSR2xCSR27)x(CSR6xCSR26) **(Control)**	5.29	-1.14	7.58	4.20	4.70	-8.50	1.67	2.08	2.09	9.32	0.35	4.75

4. Discussion

The final outcome in silkworm breeding is judged by the best desirable characters of the parental strains that appear in F1 hybrids. Realizing the need for high cocoon shell and raw silk percentage as thrust areas many single and double cross hybrids were identified and authorized for commercial utilization [11]. Of late, much emphasis was given for bivoltine silkworm rearing to boost up quality silk production matching to International standards. Attempt was also made to assess evaluation index values, useful to opt for potential hybrids, of all the traits by fixing 50 or >50 as E. I. value for selection. The hybrid which scored above the limit is considered to possess greater economic values. Improved hybrids with higher silk have been developed by crossing different productive bivoltine breeds [12]. However, information on utilization of bivoltine three-way cross hybrids for commercial utilization is scanty.

Though, the phenomenon of hybrid vigour was exploited in plants much earlier to that of silkworm, the extent of utilization in silkworm is unparallel to any of the commercial crops. Attempts have been made in various systems like diallel cross techniques, line x tester analysis, three-way and four-way crosses to study the gene action, evaluating the combining ability of different strains and utilize the hybrid vigour to adjudicate the superior hybrids for commercial purpose [13-15]. Among the 21 (DxD)xO hybrids reared, six hybrids performed better during different seasons and confirm the works of [16-17] who demonstrated the superiority of single, three-way and four-way cross hybrids over their parental breeds / hybrids.

However, heterosis and over dominance with regard to each hybrid derived from the parents is an important aspect which enables to understand the manifestation of hybrid vigour in respect of each of the traits independently and in conjugation with other. Moreover, the skillful utilization of hybrid vigour is utmost important in sericulture as well as in other agriculture crops to obtain maximum desirable economic benefits [18-19]. The results of the present study indicate that the 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 many three-way cross hybrids have shown desirable manifestation of hybrid vigour in most of the traits. This is in agreement with the observations of [20-21] who opined that manifestation of heterosis differ widely and such differences suggests that parental materials involved differ in their genetic makeup and the high degree of hybrid vigour in any specific cross can be due to additive gene effects [22].

Results of the present study conclude that, based on the overall rearing performance, evaluation index values and the magnitude of heterosis, six (DxD)xO hybrids *viz*., [(D13 x S9) x CSR17], [(S9 x CSR26) x JPN8], [(D13 x CSR26) x CSR27], [(CSR16 x CSR26) x CSR17], [(S9 x CSR16) x CSR27] and [(D13 x CSR26) x CSR17] are the potential hybrids. Amongst the identified six (DxD)xO hybrids, [(D13xS9)xCSR17] scored first position followed by [(S9xCSR26)xJPN8] and [(D13xCSR26)xCSR27] in second and third position, respectively, securing top ranking in improved cumulative performance, higher E.I. scores and hybrid vigour in many of the quantitative economic traits studied expressing superiority under pre-cocoon, cocoon and post-cocoon spheres and have been selected as potential bivoltine three-way cross hybrids for commercial utilization for silk yarn quality.

5. Acknowledgement

The authors wish to thank CSR&TI, Mysore for its support in this research work.

6. Reference

1. Talebi E, Subramanya G. Diallel analysis of bivoltine and multivoltine races for six quantitative traits. J Applied Sci 2009, 2:331-339.
2. Nirmal KS, Murthy P, Moorthy SM. Heterosis studies in selected quantitative traits in silkworm *Bombyx mori* L. African J Basic & Appl Sci 2010, 83:409-414.

3. Datta RK, Raghavendra Rao D, Jayaswal KP, Premalatha V, Ravindra Singh, Kariappa BK. Heterosis in relation to combining ability in multi x bi strain of silkworm, *Bombyx mori* L. Indian J Seric 2001; 40:1-6.
4. Doddaswamy MS, Subramanya G, Talebi E. Studies on some economic traits and biological characters of regular and reciprocal cross between a multivoltine and bivoltine race of silkworm *Bombyx mori*. J Entomol Nematol 2009; 1:50-55.
5. Das SK, Patnaik S, Ghosh B, Singh T, Nair BB, Sen KK, Subba RG. Heterosis analysis in some three-way crosses of *Bombyx mori* L. Sericologia 1994; 34(1):51-61.
6. Farooq M, Malik MA, Malik GN, Kukiloo FA. Combining ability analysis of some bivoltine silkworm (*Bombyx mori* L.) genotypes. Applied Biological Research 2006; 8(1&2):10-18.
7. Moll RH, Sulhana WS, Robinson HF. Heterosis and genetic diversity in variety crosses of maize. Crop Sci 1962; 2:197-208.
8. Datta RK, Basavaraja HK, Mano Y. Manual on Bivoltine rearing, Race maintenance & multiplication. C.S.R. & T.I, Mysore, India, 1996, 1-25.
9. Sonwalkar TN. Silk Reeling and processing in India. Lead paper. Proceedings of International Congress on Tropical Sericulture Practices, 1987, 5:1-12.
10. Xiang Li, Yubo Zhang, Zhonglin Tang, Mei Yu, Bang Liu, Bin F *et al.* Comparative estimation on Three-way heterosis in reveals genetic bias of widely used empherical formula. J Animal & Veterinary Advances 2009: 8(6):1212-1218.
11. Basavaraja HK, Nirmal KS, Suresh KN, Reddy MN, Kshama G, Ashan MM, Datta RK. New productive bivoltine hybrids. Indian Silk 1995; 34:5-9.
12. Datta RK. Improvement of silkworm races (*Bombyx mori* L.) in India. Sericologia 1984; 24(1):393-415.
13. Datta RK, Pershad GD. Combining ability among multivoltine x bivoltine silkworm (*Bombyx mori*) hybrids. Sericologia 1988; 28(1):21-29.
14. Ravindra S, Kalpana GV, Sudhakar RP, Ahsan MM, Datta RK, Rekha M. Studies on combining ability and heterosis in the silkworm *Bombyx mori* L. Indian J Seric 2000; 39(1):43-48.
15. Kalpana GV, Sudhakar RP, Kshama G, Ahsan MM, Datta RK. Identification of promising bivoltine hybrids by Maize Selection Tool (MST) – A software package. Uttar Pradesh J Zool 1999; 19(1):25-29.
16. Harada C. On the heterosis of quantitative characters in the silkworm. Bull Seric Expt Stn 1961; 17(1):50-52.
17. Pennegpet P, Jaroonchai J. Survey on the practical characters of double cross hybrids of bivoltine silkworm races. Bull Thai Seri Res Train Cen, Thailand 1975; 5:85-86.
18. Sheshagiri SV, Ramesh C, Rao CGP. Genetic manifestation of hybrid vigour in cross breeds of mulberry silkworm, *Bombyx mori* L. Int J Zoological Res 2009; 5:150-160.
19. Ramesh C, Sheshagiri SV, Rao CGP. Evaluation and identification of superior polyvoltine crossbreeds of mulberry silkworm, *Bombyx mori* L. Journal of Entomology 2009; 6:188-197.
20. Tayade DS. Heterosis effect in economic traits of new hybrids of silkworm, *Bombyx mori* L. under Marathwada conditions. Sericologia 1987; 27:301-307.
21. Sathenahalli SB, Govindan R, Goud JV. Analysis of heterosis for some quantitative traits in silkworm, *Bombyx mori* L. Mysore J Agric Sci 1989; 24:214-221.
22. Rao PRT, Ghosh SM, Moorthy SK, Das GC, Roy AK, Sengupta, 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.