Research Article

IMPACT OF SYSTEMATIC MAINTENANCE OF BIVOLTINE PARENTAL BREEDS ON THE EXPRESSION OF HYBRID VIGOUR

Dayananda[1*], V. Sivaprasad[2], V. Nishita Naik[1], S.M. Hukkeri[3] and R.S. Teotia[3]
[1]P4 Basic Seed Farm, Hassan-573 217, Karnataka, INDIA
[2]Central Sericultural Research and Training Institute, Berhampore-742 101, West Bengal, INDIA
[3]Central Sericultural Research and Training Institute, Mysuru- 570 008, Karnataka, INDIA
**Corresponding author's E-mail: dayanandacsrti@gmail.com*

KEYWORDS:
Bivoltine breed,
Bombyx mori,
Crossing pattern,
Hybrid vigour

ARTICLE INFO
Received on:
22.02.2019
Revised on:
21.05.2019
Accepted on:
25.05.2019

ABSTRACT

Realizing the need of bivoltine silk, as a substitute for the import, that suit to power looms and export oriented units in the country, the Government of India promoting bivoltine sericulture by implementing a number of programmes. Introduction of productive bivoltine single and double hybrids revolutionised the sericulture industry during 12th plan (2012-13 to 2016-17). Towards this, systematic breed maintenance is the primary requisite to maintain the genetic compositions of the parents and combine well to express full potentiality in their hybrids. Thus, In the present study, hybrid vigour in terms of heterosis for different crossing pattern involving four oval (CSR2, CSR17, CSR27 and S8) and four dumb-bell (CSR4, CSR6, CSR16 and CSR26) type cocoons of bivoltine parental breeds was investigated considering important economic traits. All the parental breeds and their hybrids of different crossing pattern (single cross, foundation cross and double cross) were reared employing one way system of breed maintenance and standard rearing technique of bivoltine rearing, respectively at P4 Basic Seed Farm, Hassan. The analysed data indicates that the parental breeds were not only confirming the original breed characteristics but also expressed relative heterosis positively in their crosses for all the nine economic traits studied. Thus, we suppose that breed maintenance is mandatory not only to maintain the purity and stability of breeds but also to express their hybrid vigour in their crosses, which facilitate to exploit full potentiality of the hybrids in the field.

INTRODUCTION

Bivoltine raw silk of international grade is required for power looms, mechanized handlooms and export oriented units (Manufactures export quality apparels) in the Country. There is a gap between the domestic demand and production of quality raw silk, which is being met through import from China. The Govt. of India is emphasized popularization of bivoltine sericulture through implementation of Cluster Promotion Programme (CPP), Catalytic Development Programme (CDP) and etc. Besides, Automatic Reeling Machines (ARMs) have proved to produce international grade raw silk. The productive bivoltine single hybrid CSR2 × CSR4 and double hybrid (CSR2×CSR27) × (CSR6×CSR26) revolutionised the Indian Sericulture industry during 12th five years plan (2012-13 to 2016-17) with the bivoltine raw silk production of 5,266 MT per annum at the end of the plan period (2016-17) as against the target of 5,260 MT (Anonymous, 2017). Bivoltine raw silk production has showed a tremendous increase of 14.20% during 2016-17 over 2015-16 (4,613 MT). With this, India is poised to produce bivoltine raw silk in a big way (8,500 MT by 2020) and to become self sufficiency of quality raw silk by 2022-23 (12,850 MT).

To achieve this task, need is potential silkworm breeds with high vigour. The genetic composition of parents utilized in the hybrid combinations combines well to express all their potentiality in their hybrids. Thus, parental breeds need to be maintained systematically so that the genotypic expression of quantitative traits in the hybrids should not declaim even after many years. However, it is well documented that inbreeding of parental breeds over many generations exhibit negative effects, such as increased homozygosity that leads to increased chances of expression of lethal recessive genes, inbreeding depression and reduction of genetic variance, which intern declined quantitative traits in the silkworm, *Bombyx mori* (Falconer, 1960). In addition, occurrence of inbreeding leads to loss of genetic diversity, inherent cause of reduced germinability of lays, loss of viability, vigour and fecundity of progenies (Lande *et al.*, 1985; Charlesworth *et al.*, 1987) leading to an inbreeding depression. Inbreeding depression and mutation accumulation may be an important source of extinction of small populations (Hedrick *et al.*, 2000). Further, such parents lose their ability to combine well and resulting in the reduced heterosis for most of the quantitative traits. Knowing the importance of conservation of genetic value of the parental breeds, one way system of silkworm breed maintenance and multiplication was introduced to maintain the bivoltine breeds of commercial importance and supply their seeds for downstream multiplication. In one way maintenance system, at P4, the basic parental stock has to replace once in a year from the breeders stock and multiply the same for another three cycles. While at P3 and P2 centres, the stock has to be replaced every time from P4 and P3 centres respectively. This system of maintenance has reduced inbreeding depression as the stock is being replaced every time at P3 and P2 level; wherein they have been multiplied to a larger extent. Thus, the parental breeds need to be maintained systematically to maintain genotypic expression of quantitative traits in the hybrids, which should not be declined even after many years. Keeping this significance, the methodology followed in conserving the genetic worth of the bivoltine breeds of the silkworm, *Bombyx mori* at P4 level is presented here.

MATERIALS AND METHODS

Maintenance of pure breeds: The bivoltine breeds of commercially important viz., CSR2, CSR17, CSR27 and S8 for Oval type, and CSR4, CSR6, CSR16 and CSR26 for Dumb-bell type were collected from CSRTI, Mysuru (breeders stock) and subsequently continued for three complete cycles. A minimum of 15 - 20 cellular beds were brushed from 5-10 sources per breed. Stringent selection pressure for egg lying pattern, fecundity, hatching and healthiness of the newly born larvae were applied at every cycle. After 3rd moult 250 larvae per cellular bed were retained for all the breeds so that budgeting of quantity of leaf and space to all the beds shall be ensured uniformly. The rearing was conducted following all the standard rearing technologies prescribed for P4 level breed maintenance procedure (Basavaraja *et al.*, 2004). The rearing performance of all the breeds such as cocoon yield per 10000 larvae (ERR) by number and weight, single cocoon weight, single shell weight and shell percentage were recorded. The rearing data were statistically analysed for mean, standard deviation and co-efficient of variation percent to assess the purity and stability of the parental breeds.

Evaluation of Heterosis: To work out the hybrid vigour in terms of heterosis, the hybrid layings of different crossing pattern such as single cross, foundation cross and double cross were prepared by utilizing the above pure breeds and conducted rearing along with their respective parents. Composite layings prepared from 10 dfls each of all the breeds and hybrids were brushed together. After 3rd moult 250 larvae with three replications each were retained and rearing was conducted following the standard rearing method (Datta, 1992). In addition to the rearing performance, a sample of 60 cocoons from each replication were reeled on multi-end reeling machine at Post Cocoon Evaluation Unit, CSRTI, Mysuru for assessing the important reeling parameters that influence silk quality. The data recorded on rearing and reeling performance of all the breeds and hybrids were analyzed statistically by two-way ANOVA (Singh and Chaudhary, 1977).

Hybrid vigour in terms of heterosis of single hybrid, foundation crosses (FCs) and double hybrids (DHs) were calculated as below and analysed statistically:

$$\text{Heterosis for single and FCs (\%)} = \frac{\text{F1 value} - \text{Mid parent value}}{\text{Mid parent value}} \times 100$$

$$\text{Heterosis for DHs (\%)} = \frac{\text{Double Hybrid value} - \text{Mid FCs value}}{\text{Mid FCs value}} \times 100$$

Evaluation of cocoon uniformity: To assess the cocoon size variability, one hundred cocoons were taken at random from each breed and hybrid. The individual cocoon length and width were measured using *Vernier calipers*. Cocoon length and breadth uniformity index was calculated by using the formula (Mano, 1994).

$$\text{Cocoon uniformity Index (\%)} = \frac{\text{Length of cocoon (cm)}}{\text{Width of cocoons (cm)}} \times 100$$

The cocoon indices were analyzed statistically to know the Standard Deviation (SD) and Co-efficient of Variation (CV). Variability in cocoon size was determined on the basis of SD and CV percent. The batch of cocoons possessing less SD and CV were considered uniform in cocoon shape and size.

RESULTS AND DISCUSSION

The morphological features of the parental breeds utilized for the study are given in Table 1. In general, the larvae of Chinese breeds are plain bluish white body colour and spins white oval cocoons with fine to medium grains. Whereas the larvae of Japanese breeds are marked reddish tinge body colour and spins white dumbbell cocoons with medium grains except CSR4 which is plain bluish white in body colour.

Table 1. Larval and cocoon characteristics of different bivoltine parental breeds of *Bombyx mori.*

Sl. No	Breed	Origin	Parentage	Developed at	Larval Characters	Cocoon characters
Oval Breeds						
1	CSR2	Chinese	Shunrei x Shogetsu	CSRTI, Mysuru, India	Plain, bluish white	White oval with fine to medium grains
2	CSR17	Chinese	(SN137×C146) × A24	CSRTI, Mysuru, India	Plain, bluish white	White oval with fine to medium grains
3	CSR27	Chinese	Thaihei × Choan	CSRTI, Mysuru, India	Plain, bluish white	White oval with medium grains
4	S8	Chinese	CSR204×CSR27	CSRTI, Mysuru, India	Plain, bluish tinge white	White oval with medium grains
Dumbbell breeds						
5	CSR4	Japanese	(BN18×BCS25) × NB4D2	CSRTI, Mysuru, India	Plain, bluish white	White dumbbell with medium grains
6	CSR6	Japanese	Shunrei × Shogetsu	CSRTI, Mysuru, India	Marked, reddish tinge	White dumbbell with medium grains
7	CSR16	Japanese	(C135 × N134) × J14	CSRTI, Mysuru, India	Marked, reddish tinge	White dumbbell with medium grains
8	CSR26	Japanese	C135 × N134	CSRTI, Mysuru, India	Marked, reddish tinge	White dumbbell with medium grains

Table 2. Mean Rearing Performance of bivoltine breeds of *Bombyx mori.*

Breeds	Effective rate of rearing by		Cocoon weight (g)	Cocoon shell weight (g)	Shell percent
	Number	Weight (kg)			
Oval breeds					
CSR2	9618±259 (2.69)	16.356±1.120 (6.85)	1.680±0.100 (5.66)	0.387±0.020 (6.92)	23.02±0.72 (3.14)
CSR17	9703±218 (2.24)	16.840±1.100 (6.51)	1.719±0.100 (5.74)	0.370±0.020 (6.17)	21.55±0.75 (3.47)
CSR27	9606±226 (2.35)	15.622±1.420 (9.09)	1.585±0.100 (6.61)	0.370±0.020 (8.11)	23.30±0.78 (3.35)
S8	9696±260 (2.68)	16.466±1.140 (6.92)	1.660±0.100 (6.01)	0.374±0.030 (9.12)	22.51±0.82 (3.65)
Mean	**9656±241 (2.50)**	**16.321±1.195 (7.33)**	**1.661±0.100 (6.02)**	**0.375±0.02 (6.00)**	**22.60±0.77 (3.41)**
Dumbbell breeds					
CSR4	9604±248 (2.59)	15.913±1.070 (9.27)	1.600±0.080 (4.75)	0.354±0.030 (7.42)	22.07±0.72 (3.27)
CSR6	9689±187 (1.93)	15.703±1.020 (9.74)	1.561±0.110 (7.42)	0.330±0.020 (6.06)	21.09±0.79 (3.74)
CSR16	9617±280 (2.91)	15.777±1.120 (9.63)	1.587±0.100 (6.49)	0.338±0.020 (5.91)	22.26±0.78 (3.50)
CSR26	9617±262 (2.73)	15.739±1.140 (9.15)	1.570±0.110 (7.84)	0.332±0.020 (6.02)	21.09±0.74 (3.51)
Mean	**9632±244 (2.54)**	**15.783±1.083 (6.86)**	**1.580±0.10 (6.34)**	**0.339±0.02 (5.90)**	**21.63±0.76 (3.51)**

Pure breeds: Mean performance of three rearing crops of eight bivoltine breeds for five cocoon traits are presented in Table 2. The data clearly indicates a marginal variation in the expression of economic traits (CV < 10%) of all the breeds. The co-efficient of variation among the traits considered was ranging from 2.69 to 6.92 in CSR2, 2.24 to 6.17 in CSR17, 2.35 to 9.09 in CSR27, 2.68 to 9.12 in S8, 2.59 to 9.27 in CSR4, 1.93 to 9.74 in CSR6, 2.91 to 9.63 in

CSR16 and 2.73 to 9.15 in CSR26. On mean performance, oval breeds were recorded the cocoon yield of 16.321 kg per 10000 larvae, 96.56% pupation, 1.616 g of average cocoon weight, 0.375 g of cocoon shell weight and 22.60 % of cocoon shell was recorded for oval breeds, while it was 15.783 kg, 96.32%, 1.580 g, 0.339 g and 21.63% was recorded for dumbbell breeds, respectively. Irrespective of the breeds, maximum co-efficient of variation was observed for the trait cocoon yield by weight (6.51 – 9.74%) and was minimum in cocoon yield by number (1.93 – 2.91%). The data indicates the insignificant co-efficient of variation in the survival among the seasons and the variation noticed in cocoon yield by weight, cocoon weight and shell weight might be partially attributed to the influence of environmental factors and the interaction of alleles responsible for the expression of the trait. The present findings are in conformity with the earlier findings of Kalpana *et al.* (2013).

Hybrid vigor: The different crossing pattern of bivoltine breeds is presented in Table 3. The mean rearing and reeling performance of parental breeds including foundation crosses were presented in Table 4. As depicted in Table 4, pupation in the different parental breeds was ranging from 94.64 % (S8) to 98.88 % (CSR4). Highest cocoon yield of 19.529 kg per 10,000 larvae was recorded in FC-2 (CSR2 × CSR27) while lowest of 15.492 kg per 10,000 larvae was recorded in CSR26. The cocoon weight varied from 1.603 (CSR4) to 2.007 g (FC-2). The shell weight was ranging from 0.342 (CSR26) to 0.450 g (FC-2). The maximum shell percentage of 22.62 was recorded in CSR2, which is lowest in CSR17 (21.35%). The reelability was ranging from 82.31 (CSR6) to 88.63 % (FC-2). Highest filament length of 988 m was recorded in CSR2 and it was lowest in CSR6 (740 m). The raw silk was ranging from 15.19 (CSR16) to 17.79 % (CSR27). The neatness of the silk filament ranged from 94 to 95 points. Though there was no significant difference in pupation, reelability and neatness among the parental breeds including FCs, significant difference ($p<0.05$) was noticed for cocoon yield, cocoon weight, shell weight, shell percent, filament length and raw silk. The maximum values for the quantitative traits viz., cocoon yield and cocoon weight in the foundation cross among the parental breeds indicates the expression of vigor to certain level even in the crosses of similar type of breeds. The results are in conformity with the findings of Mal Reddy *et al.* (2012).

Table 3. Preparation of different crossing pattern for bivoltine breeds of *Bombyx mori.*

Crossing Pattern	Direct cross	Reciprocal cross
Single hybrid	CSR2 × CSR4	CSR4 × CSR2
	CSR17 × CSR16	CSR16 × CSR17
	S8 × CSR16	CSR16 × S8
FC-1 (Dumbbell)	CSR6 × CSR26	CSR26 × CSR6
FC-2 (Oval)	CSR2 × CSR27	CSR27 × CSR2
Double hybrid	FC2 × FC1	FC1 × FC2

Table 4. Performance of parental breeds of *Bombyx mori* for hybrid vigour

Breed	ERR by		Cocoon weight (g)	Shell weight (g)	Shell percent	Reelability (%)	Filament length (m)	Raw silk (%)	Neatness (p)
	Number	Weight (kg)							
Oval breeds									
CSR2	9756	18.228	1.848	0.418	22.62	86.81	988	15.99	94
CSR17	9824	18.762	1.888	0.403	21.35	87.24	963	17.13	94
CSR27	9880	16.694	1.747	0.384	21.98	86.80	864	17.79	94
S8	9464	18.072	1.722	0.389	22.59	87.67	874	16.97	95
Mean	**9731**	**17.939**	**1.776**	**0.399**	**22.47**	**87.13**	**922**	**16.97**	**94**
Dumbbell breeds									
CSR4	9888	15.929	1.603	0.354	22.08	83.32	845	16.00	95
CSR6	9800	18.352	1.707	0.372	21.79	82.31	740	15.80	94
CSR16	9792	17.065	1.681	0.360	21.42	86.04	807	15.19	95
CSR26	9880	15.492	1.630	0.342	20.98	88.31	839	16.66	94
Mean	**9840**	**16.71**	**1.655**	**0.357**	**21.57**	**85.00**	**809**	**15.91**	**95**
Foundation cross									
FC1	9854	18.709	1.818	0.391	21.51	87.64	811	17.31	94
FC2	9832	19.529	2.007	0.450	22.42	88.63	887	17.19	95
Mean	**9843**	**19.119**	**1.913**	**0.421**	**22.01**	**88.14**	**849**	**17.25**	**95**
CD@5%	NS	0.90	0.10	0.06	0.90	NS	60	1.20	NS

ERR: Effective rate of rearing;
FC1: CSR6 × CSR26; FC2: CSR2 × CSR27

The data on the performance of hybrids of different crosses and their related Heterosis are presented in the Tables 5 and 6 respectively. As depicted in Table 5, the performance of different crosses indicated significant ($p<0.05$) variation in most of the traits studied except for the trait reelability and neatness. On overall mean performance, the maximum pupation of 98.41% was recorded in FC-1 followed by FC-2 (98.18%), single cross (97.73%) and double crosses (97.48%). Maximum cocoon yield of 21.478 kg per 10000 larvae was recorded for single cross followed by double cross (20.978 kg), FC-2 (19.671 kg) and minimum in FC-1 (18.730 kg). The maximum cocoon weight (2.118 g), shell weight (0.488 g) and shell percent (23.04%) were recorded for double crosses and the minimum in FC-1 with 1.776 g, 0.385 g and 21.68 respectively. The reelability was ranges from 88.72 (FC-1) to 87.89 % (single cross), filament length was ranging from 990 (FC-2) to 828 m (FC-1) and raw silk from 18.11 (single cross) to 17.15 % (FC-2). Statistical analysis indicated that, the double crosses have shown better cocoon traits over other crosses, which might be due to presence of genetic material from four parental strains (Nirmal Kumar *et al.*, 1998).

Table 5. Performance of different crosses of *Bombyx mori* for the hybrid vigour

Crosses	ERR by		Cocoon weight (g)	Shell weight (g)	Shell percent	Reelability (%)	Filament length (m)	Raw silk (%)	Neatness (p)
	Number	Weight (kg)							
Single cross									
CSR2 × CSR4	9836	20.969	2.135	0.490	22.95	87.05	922	16.93	95
CSR4 × CSR2	9840	21.560	2.091	0.494	23.63	88.69	988	19.35	95
CSR17 × CSR16	9826	21.932	2.181	0.480	22.00	90.34	1041	20.03	95
CSR16 × CSR17	9832	22.049	2.141	0.471	22.00	86.66	946	16.61	95
S8 × CSR16	9650	21.349	2.078	0.468	22.52	87.56	990	18.24	95
CSR16 × S8	9652	21.011	2.049	0.462	22.55	87.06	960	17.52	95
Mean	**9773**	**21.478**	**2.113**	**0.478**	**22.62**	**87.89**	**975**	**18.11**	**95**
Foundation Cross-1 (Dumbbell)									
CSR6 × CSR26	9854	18.709	1.818	0.391	21.51	87.64	811	17.31	94
CSR26 × CSR6	9828	18.751	1.734	0.379	21.86	89.79	845	18.17	95
Mean	**9841**	**18.730**	**1.776**	**0.385**	**21.68**	**88.72**	**828**	**17.74**	**95**
Foundation Cross-2 (Oval)									
CSR2 × CSR27	9832	19.529	2.007	0.450	22.42	88.63	987	17.19	95
CSR27 × CSR2	9804	19.813	2.008	0.454	22.61	88.15	992	17.10	94
Mean	**9818**	**19.671**	**2.008**	**0.452**	**21.93**	**88.39**	**990**	**17.15**	**95**
Double Cross									
FC2 × FC1	9744	20.664	2.120	0.487	22.97	88.58	951	18.40	95
FC1 × FC2	9752	21.291	2.115	0.489	23.12	88.50	948	17.72	95
Mean	**9748**	**20.978**	**2.118**	**0.488**	**23.04**	**88.54**	**950**	**18.06**	**95**
CD @5%	22	1.05	0.12	0.08	1.02	NS	80	1.20	NS

NS: Non-significant

As indicated in Table 6, the present study indicated significant ($p<0.01$) positive relative heterosis in all the crosses for the traits cocoon yield by weight, cocoon weight, cocoon shell weight, filament length and raw silk percent while characters such as pupation, shell percent, reelability and neatness did not show much heterosis. On mean of different crosses, the highest heterosis was registered for the trait shell weight by single cross (25.42%) followed by double cross (16.05%), FC-2 (12.72%) and the lowest in FC1 (7.84%). Low heterosis was registered for the majority of the traits for FC1. The heterosis recorded for other economic traits was almost similar to that of cocoon shell weight. The higher degree of heterosis exhibited by the crosses can be attributed to the influence of additive genes (Harada, 1961; Kobayashi *et al.*, 1968; Bhargav *et al.*, 1996).

Cocoon size uniformity: Cocoon size variability in the different parental breeds is presented in Table 7. It is evident from the data that SD and CV (%) on cocoon indices relatively less in dumbbell breeds (5.85 and 3.75) followed by Oval breeds (6.91and 4.33) and they were comparatively high in FCs (7.22 and 4.55). All the parents studied have exhibited standard deviation of less than 8 and their CV % ranged from 3.69 to 5.14. The less cocoon size variability observed is due to more uniformity of cocoons shape and size.

Table 6. Heterosis for nine economic traits in different crosses of *Bombyx mori*

Cross	ERR by		Cocoon weight (g)	Shell weight (g)	Shell percent	Reelability (%)	Filament length (m)	Raw silk (%)	Neatness (p)
	Number	Weight (kg)							
Single cross									
CSR2 × CSR4	0.14	22.78**	23.73**	26.94**	2.60*	2.33	0.60	5.85*	0.53
CSR4 × CSR2	0.18	26.24**	21.18**	27.98**	5.73*	4.26*	7.80*	20.98**	0.53
CSR17 × CSR16	0.18	22.43**	22.22**	25.82**	2.88*	4.27*	17.63**	23.95**	0.53
CSR16 × CSR17	0.24	23.09**	19.98**	23.46**	2.88*	0.02	6.89*	2.78	0.53
S8 × CSR16	0.23	21.52**	22.13**	24.97**	2.34*	0.81	17.79**	13.43**	0.00
CSR16 × S8	0.25	19.59**	20.42**	23.36**	2.48*	0.24	14.22**	8.96*	0.00
Mean	**0.20**	**22.61**	**21.61**	**25.42**	**3.15**	**1.99**	**10.82**	**12.66**	**0.35**
Foundation Cross-1 (Dumbbell)									
CSR6 × CSR26	0.14	10.56*	8.96	9.52*	0.58	2.73	2.72	6.65	0.00
CSR26 × CSR6	0.10	10.81*	3.93	6.16*	2.22	5.25*	7.03*	11.95*	1.06
Mean	**0.12**	**10.69**	**6.45**	**7.84**	**1.40**	**3.99**	**4.88**	**9.30**	**0.53**
Foundation Cross-2 (Oval)									
CSR2 × CSR27	0.14	11.84*	11.66*	12.22*	0.54	2.10	6.59*	1.78	1.06
CSR27 × CSR2	0.27	13.47*	14.91*	13.22*	1.39	1.55	7.13	1.24	0.00
Mean	**0.21**	**12.66**	**13.29**	**12.72**	**0.97**	**1.83**	**6.86**	**1.51**	**0.53**
Double Cross									
FC2 × FC1	0.12	11.06*	10.85*	15.81**	4.60**	0.50	12.01**	9.85*	0.53
FC1 × FC2	0.21	14.43*	10.59*	16.29**	5.28**	0.41	11.66**	5.79*	0.53
Mean	**0.17**	**12.75**	**10.72**	**16.05**	**4.94**	**0.46**	**11.84**	**7.82**	**0.53**

*Significant at 5%, **Significant at 1%

Table 7. Cocoon size variability in different parental breeds of *Bombyx mori*

Cross	Cocoon length (cm)	Cocoon width (cm)	Cocoon Index (L/W*100)	CV (%)
Oval Breeds				
CSR2	3.36±0.18	2.15±0.12	156.27±6.90	4.40
CSR17	3.34±0.13	2.17±0.11	153.91±6.80	4.41
CSR27	3.36±0.12	2.10±0.08	159.90±6.65	4.15
S8	3.39±0.09	2.12±0.07	159.90±6.30	3.94
Mean	**3.36±0.13**	**2.11±0.10**	**159.44±6.91**	**4.33**
Dumbbell breeds				
CSR4	3.36±0.08	2.16±0.06	155.96±6.75	4.32
CSR6	3.38±0.12	2.15±0.10	156.69±6.50	4.15
CSR16	3.39±0.09	2.16±0.07	156.93±6.24	3.98
CSR26	3.36±0.11	2.10±0.07	160.00±5.91	3.69
Mean	**3.35±0.10**	**2.15±0.08**	**155.80±5.85**	**3.75**
Foundation crosses				
FC1	3.28±0.12	2.09±0.10	156.69±7.50	4.78
FC2	3.29±0.09	2.06±0.07	160.13±8.24	5.14
Mean	**3.28±0.12**	**2.07±0.08**	**158.50±7.22**	**4.55**

FC1: CSR6 × CSR26; FC2: CSR2 × CSR27;

Data are the mean ± SD of 100 cocoons and measurement of cocoon width was taken in the central region.

Cocoon size variability in the different crosses is presented in Table 8. It is evident from the data that minimum SD and CV (%) on cocoon indices recorded for single crosses (7.71 and 4.56) followed by FC2 (8.25 and 5.12), FC1 (6.38 and 10.75) and maximum for double cross (11.42 and 7.06). All the crosses under the study were exhibited CV % ranged from 4.56 to 7.06. Standard deviation and CV % on cocoon index relatively less in single hybrids. The cocoons are thus more uniform in size in single hybrids than FCs and double hybrids. To obtain uniform filament size especially in auto and semi-automatic reeling machine cocoon size uniformity is very important (Mano *et al.*, 1993; Nirupama *et al.*, 2008). The results are in agreement with that of Ravindra Singh *et al.* (1998).

Table 8. Cocoon size variability in different crosses of *Bombyx mori*

Cross	Cocoon length (cm)	Cocoon width (cm)	Cocoon Index (L/W*100)	CV (%)
Single cross				
CSR2 × CSR4	3.46±0.20	2.07±0.13	166.95±06.56	3.93
CSR4 × CSR2	3.33±0.16	2.01±0.17	166.01±08.09	4.87
CSR16 × CSR17	3.52±0.15	2.07±0.10	170.18±08.00	4.71
CSR17 × CSR16	3.46±0.18	2.06±0.10	168.11±07.06	4.85
S8 × CSR16	3.49±0.13	2.04±0.10	171.41±07.88	4.60
CSR16 × S8	3.26±0.19	1.98±0.13	164.91±09.05	5.49
Mean	**3.65±0.18**	**2.16±0.12**	**168.98±7.71**	**4.56**
Foundation Cross-1 (Dumbbell)				
CSR6 × CSR26	3.28±0.19	1.94±0.14	169.82±10.86	6.40
CSR26 × CSR6	3.27±0.18	1.96±0.14	167.02±10.65	6.38
Mean	**3.28±0.19**	**1.95±0.14**	**168.42±10.75**	**6.38**
Foundation Cross-2 (Oval)				
CSR2 × CSR27	3.31±0.15	2.01±0.13	165.23±08.36	5.06
CSR27 × CSR2	3.32±0.17	2.10±0.12	158.09±08.15	5.15
Mean	**3.32±0.16**	**2.06±0.13**	**160.92±08.25**	**5.12**
Double Cross				
FC1 × FC2	3.44±0.15	2.05±0.17	168.88±11.98	7.10
FC2 × FC1	3.28±0.19	1.94±0.14	169.82±10.86	6.40
Mean	**3.36±0.17**	**2.08±0.15**	**161.54±11.42**	**7.06**

Data are the mean ± SD of 100 cocoons and measurement of cocoon width was taken in the central region

The result of the study shows that the parental breeds exhibits their purity, stability and conforming to the original breed characteristics. Oval foundation and double crosses are on par with single cross hybrids in terms of quantitative traits. The single cross hybrids are superior to other crosses with respect to expression of higher magnitude of hybrid vigor. More cocoon variability was observed in double crosses followed by FCs. The dumbbell FCs was inferior to all other crossing pattern. Systematic silkworm breed maintenance and multiplication following one way system of breed maintenance with interbred crossing at P4 level, breed characters conforming true to the breed and maximum expression of hybrid vigour in their crosses can be maintained without any deterioration. Thus, breed maintenance is mandatory not only to maintain the purity and stability of breeds but also expression of hybrid vigour in terms of heterosis in their crosses, which helps to exploit the full potentiality of the hybrids for commercial cocoon production in the field.

REFERENCES

Anonymous. 2017. Annual report 2016-17 of Central Silk Board, Ministry of Textiles: Government of India, Bengaluru, India, p.83.

Basavaraja, H.K., S.B. Dandin., M. Baig., K.V. Benchamin., A. Yamaguchi and H. Yanagava. 2004. Guidelines for bivoltine silkworm race maintenance and multiplication at BSF/GSF. JICA-CSB pub., India, **pp**. 01-37.

Bhargav, S.K., V. Thigarajan and E. Rajalakshmi. 1996. Hetorotic expression in silk productivity in different crosses of silkworm *Bombyx mori*. *Indian Veterinary Journal,* **73:** 176-180.

Charlesworth, O and B. Charlesworth. 1987. Inbreeding depression and its evolutionary consequences. *Ann. Rev. Ecol. Syst.*, **18**: 237-268.

Datta, R.K. 1992. Guidelines for bivoltine silkworm rearing. Central Silk Board pub., Bengaluru, India.

Falconer, D.S. 1960. Introduction to Qualitative Genetics. Oliver and Boyd Eds., Edinburgh.

Harada, C. 1961. Heterosis of quantitative characters in the silkworm. *Bulletin of Sericulture. Experimental Station,* **17**:1-52.

Hedrick, P.W and S.T. Kalinowski. 2000. Inbreeding depression in conservation biology, *Ann. Rev. Ecol. Syst.*, **31**:139-162.

Kalpana, G.V., K.B. Chandra Shekar and B.B. Bindroo. 2013. Impact of systematic bivoltine silkworm breed maintenance on the consistency in the expression of breed characters over generations at P4 level. *Biospectra,* **8** (2): 67-72.

Kobayashi, E., T. Gamo and Y. Otsuka. 1968. Analysis of Heterosis by means of diallel cross between different regional varieties of the silkworm. Data of a pilot Experiment. *Journal of Sericulture Science, Japan,* **37**:144-150.

Lande, R. and D.W. Schemske. 1985. The evolution of self fertilization and inbreeding depression in plants. *Genetic models, Evolution,* **39**: 24-40.

Mal Reddy, N., A. Naseema Begum., K.B. Chandra Shekar., S. Nirmal Kumar and S.M.H. Qadri. 2012. Expression of Hybrid Vigour in different crossing pattern involving the bivoltine silkworm (*Bombyx mori*) parents. *Indian Journal of Sericulture,* **51** (1): 26-31.

Mano, Y. 1994. Comprehensive report on silkworm breeding. Central Silk Board pub., Bengaluru, India, p.180.

Mano, Y., S. Nirmal Kumar., H.K. Basavaraja., N. Mal Reddy and R.K. Datta. 1993. A new method to select promising silkworm breeds/combinations. *Indian Silk,* **31** (10): p.53.

Nirmal Kumar, S., M. Ramesh Babu., H.K. Basavaraja., N. Mal Reddy and R.K. Datta. 1998. Double hybrids for improve silk production in silkworm *Bombyx mori* In: Silkworm Breeding , (Eds.) G. Srirama Reddy, *Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, Calcutta, India,* pp. 209-217.

Nirupama, R., Ravindra Singh and C.K. Kamble. 2008. Identification of silkworm breeds and hybrids through evaluation indices and cocoon size variability. *Indian Journal of Sericulture,* **47** (2): 183-187.

Ravindra Singh, G.V. Kalpana., P.S. Rao and M. Ahsan. 1998. Studies on cocoon shapes in different crosses of the mulberry silkworm, *Bombyx mori. Indian Journal of Sericulture,* **37** (1): 85-88.

Singh, R.K. and B.D. Chaudhury. 1977. Biometrical methods in quantitative genetic analysis. Kalyani Pub., New Delhi, India.

How to cite this article?

Dayananda, V. Sivaprasad, V. Nishita Naik, S.M. Hukkeri and R.S. Teotia. 2019. Impact of systematic maintenance of bivoltine parental breeds on the expression of hybrid vigour. *Innovative Farming*, 4(2): 83-90.