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ANALYSIS OF HETEROSIS OVER ENVIRONMENTS IN SILKWORM (*Bombyx mori* L.)

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ABSTRACT

The magnitude of heterosis over mid-parent and better parent were calculated in fifty bivoltine hybrids derived from five oval type and five dumbbell type bivoltine genotypes of silkworm, *Bombyx mori* L. for eight important traits under varying environmental conditions. The expression of both relative heterosis and heterobeltiosis was higher in summer (8.97 and 6.71%), followed by rainy (5.87 and 3.42%) and winter (2.13 and 0.03%). In summer, pupation rate, cocoon weight, shell weight and filament length exhibited higher heterosis for both relative heterosis and heterobeltiosis and total larval period in winter. Negative heterosis was observed for neatness. Among the characters, pupation exhibited higher heterosis (14.56%), followed by shell weight (11.74%), filament length (8.91%) and cocoon weight (6.49). Many hybrids displayed conspicuous heterosis for most of the characters. There was differential behaviour of various hybrids in different environments for the expression of heterosis. Estimates of heterosis computed revealed significant reciprocal effect for most of the traits but no consistent pattern was found across hybrids. All straight and reciprocal crosses exhibited significant positive heterosis and heterobeltiosis for pupation rate in all three environments. Other characters did not show such uniform trend. The crosses which involved CSR4, CSR17, CSR18, CSR19, KA and NB4D2 as one of the parents exhibited favourable heterosis and crosses (Straight and reciprocals) viz., CSR17 x CSR4, CSR18 x CSR19, CSR4 x KA and CSR17 x 19 showed desirable heterosis for most of the characters. The study showed the potential of commercial exploitation of heterosis as well as the potential of isolating pure lines among the progenies of heterotic F_1s for improvement of yield potential in silkworm.

Keywords: *Bombyx mori* L., heterosis, hybrid vigor, heterobeltiosis.

INTRODUCTION

Suitable silkworm hybrids play a vital role in increasing the productivity and quality of silk which are important for sustainable sericulture industry. In spite of continuous efforts for the development of sericulture through various conventional breeding programmes, still there is a demand for productive superior hybrids to fulfill the needs of sericulture industry. In consideration of crop stability and adaptability to fluctuating environmental conditions, development of productivity and qualitatively superior silkworm hybrids are necessary.

Heterosis breeding has been recognized as the most suitable breeding methodology for augmenting yield and quality parameters in silkworm and selection of suitable parents and assessment of degree of heterosis in the resulting crosses forms an important step (Ridey *et al*., 2003). The term ''heterosis'' describes the superiority of heterozygous genotypes in one or more characteristics in comparison with the corresponding parental homozygotes (Shull 1908). The increased productivity of the heterozygotes, and resistance to biotic and abiotic stresses (Dobzhansky 1950), is exploited through the development of hybrid varieties in several crop and animal species (Falconer 1981; Stuber 1994) and historically it represented one of the most revolutionary advancements in silkworm improvement (Ohkuma 1971; Tayade 1987 Nagaraju *et al*., 1990; Datta *et al*., 2001). Information on the magnitude of heterosis in different cross combination is a basic requisite for identifying crosses that exhibit high amount of exploitable heterosis and also important in deciding the directions of future breeding programmes. Hence, the present study was undertaken with an objective of studying the extent of heterosis across different environments in straight and reciprocal crosses of bivoltine and to identify the best combinations and their utilization in future crop improvement programmes.

MATERIALS AND METHODS

Ten bivoltine breeds drawn from Germplasm bank of C.S.R. and T.I. Mysore viz., CSR2, CSR3, CSR17, CSR18, KA (Spin oval shaped cocoons), CSR4, CSR5, CSR16, CSR19, NB4D2 (Spin dumbbell shaped cocoons) were selected for the study. Five oval and dumbell parents were crossed in all possible combinations and obtained fifty F_1s including reciprocals. The ten parents and fifty F_1s were reared with three replications under three environments i.e., March-April (summer), July/September (rainy) and November - January (winter). The data pertaining to eight traits *viz*., pupation percentage, fifth instar larval duration, total larval duration, cocoon weight, cocoon shell weight, cocoon shell percentage, filament length and neatness were recorded. The heterosis was estimated in terms of two parameters, (1) heterosis (expressed over mid-parental value) and (2) over-dominance (expressed over better parental value). They were measured as the proportion of deviation from the value of mid parent and better parent, respectively which are as follows:

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

$$OD\% = \frac{F1 - BPV}{BPV} \times 100$$

Where,

H% = Heterosis percentage
OD% = Overdominance percentage
F1 = Mean of the F1 hybrid
MPV = Mean of the mid parent = P1 + P2/2
BPV = Mean of the better parent
To establish the significance level between the hybrids for the traits C.D. was computed. CD = SE x F-value at 5% level for error degree of freedom.

RESULTS

Heterosis (%) in straight and reciprocal crosses

The range of heterosis varied greatly between seasons and different combinations depicting variability among the hybrids. The range of heterosis for different characters and seasons for straight and reciprocal crosses are shown in Table-1.

Pupation rate (%)

In straight crosses, the magnitude of heterosis ranged from 8.0 (CSR2 x CSR5) to 26.86 (KA x CSR4) in summer, from 5.31 (CSR2 x CSR5) to 31.87 (CSR18 x CSR19) in rainy and from 7.8 (CSR3 x CSR5) to 14.86 (KA x CSR19) in winter. In reciprocals, the minimum and maximum heterosis value in summer, rainy and winter are 7.09 (CSR5 x CSR12) and 27.93 (CSR4 x KA), 4.25 (CSR5 x CSR2) and 32.24 (CSR19 x CSR18), 7.57 (CSR5 x CSR3) and 14.50 (CSR19 x KA), respectively (Table-1).

Fifth age larval duration

The range of heterosis value obtained in straight crosses during summer are from 9.42 (CSR3 x CSR19) to -5.03 (CSR18 x CSR4), in rainy from 8.16 (KA x CSR19) to -6.55 (CSR2 x CSR4) and in winter from -2.47 (CSR18 x CSR19) to -10.0 (CSR2 x CSR5). In reciprocals, the minimum and maximum heterosis value obtained in summer are 9.42 (CSR19 x CSR2) and -4.40 (CSR4 x CSR18), in rainy 8.84 (NB4D2 x CSR18) and -5.36 (CSR4 x KA) and in winter 0.002 (NB4D2 x KA) and -8.33 (CSR4 x KA), respectively (Table-1).

Total larval duration

The magnitude of heterosis ranged in straight crosses in summer are from - 6.63 (KA x CSR4) to -1.73 (CSR18 x CSR19), in rainy from -12.41 (KA x CSR4) to -0.96 (CSR18 x CSR16) and in winter from -16.60 (KA x CSR5) to -14.96 (CSR17 x CSR16 and CSR3 x CSR16), respectively. The lower and higher heterotic values observed for reciprocal crosses in summer are -11.84 (CSR5 x CSR12) and -6.04 (CSR4 x CSR17), in rainy -11.84 (CSR5 x CSR2) and -1.16 (CSR19 x CSR18) and in winter -16.18 (CSR19 x CSR18 and CSR19 x CSR3) and -14.80 (CSR16 x CSR17 and CSR17 x KA), respectively (Table-1).

Cocoon weight

Among straight crosses, the heterosis ranged from 6.26 (CSR2 x CSR5) to 26.57(CSR18 x CSR19) in summer, from 0.69 (CSR2 x CSR5) to 16.63 (KA x CSR19) in rainy and from -10.65 (KA x CSR5) to 11.48 (CSR2x CSR4) in winter. In reciprocals it was ranged between 3.35 (NB4D2 x CSR2) and 28.52 (CSR19 x CSR18) in summer, 0.17 (CSR5 x CSR3) and 18.58 (CSR19 x KA) in rainy and -7.14 (CSR5 x KA) and 11.07 (CSR4 x CSR2) in winter (Table-1).

Shell weight

The magnitude of heterosis in straight crosses ranged from -4.42 (KA x CSR5) to 33.94 (CSR18 x CSR19) in summer, from -18.95 (KA x CSR16) to 28.42 (CSR18 x NB4D2) in rainy and from -19.39 (KA x CSR5) to 20.11 (CSR3 x NB4D2) in winter.

Among reciprocals, in summer the heterosis ranged between -16.32 (CSR19 x KA) and 39.13 (CSR4 x KA), in rainy and winter between 16.36,-20.23 (NB4D2 x CSR3) and 38.36, 19.13 (CSR19 x CSR18), respectively (Table-1).

Shell%

Among straight crosses, twenty, nineteen and twenty crosses had shown significant and positive heterosis for this character in summer, rainy and winter, respectively. The magnitude of heterosis in straight crosses ranged from -18.95 (KA x CSR6) to 9.89 (CSR3 x CSR4) in summer, from -15.59 (KA x CSR5) to 16.04 (CSR3 x NB4D2) in rainy and from -10.83 (KA x CSR4) to 16.88 (CSR3 x NB4D2) in winter. Among reciprocals, in summer the heterosis ranged between -21.42 (NB4D2 x CSR17) and 11.07(CSR4 x KA), in rainy -19.80 (CSR19 x KA) and 16.07 (CSR16 x CSR18) and in winter -17.9 (NB4D2 x CSR3) and 16.40 (CSR5 x CSR18) (Table-1).

Filament length

The heterosis ranged from 3.39 (CSR2 x CSR16) to 29.97 (CSR17 x CSR5) in summer, from -1.48 (KA x CSR4) to 22.79 (CSR17 x CSR5) in rainy and from -3.17 (CSR2 x CSR4) to 21.71 (CSR17 x NB4D2) in winter in straight crosses. Among reciprocals, the heterosis was ranged between 0.80 (NB4D2 x CSR2) and 34.42 (CSR5 x KA) in summer, -1.30 (CSR19 x KA) and 23.78 (CSR16 x CSR3) in rainy and -1.30 (CSR19 x KA) and 22.05 (CSR5 x CSR18) in winter (Table-1).

Neatness

The magnitude of heterosis of ranged in straight crosses in summer are from -9.78 (CSR17 x CSR5) to -2.22 (CSR18 x CSR19), in rainy from -7.95 (KA x CSR19) to 1.68 (CSR17 x NB4D2) and in winter from -7.34 (KA x NB4D2) to 3.33 (CSR18 x CSR4). The lower and higher heterosis values observed for reciprocal crosses in summer are -2.22 (CSR19 x CSR17) and -9.09 (NB4D2

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x CSR3), in rainy -0.37 (CSR16 x CSR3) and 2.79 (CSR4 x CSR2) and in winter -1.60 (CSR5 x KA) and 4.4 (CSR4 x CSR3) (Table-1).

Heterobeltiosis (%) **in straight and reciprocal crosses**

The range of heterobeltiosis for different characters and seasons for straight crosses and reciprocals are shown in Table-2.

Pupation rate (%)

In straight crosses, the magnitude of heterobeltiosis ranged from 1.98 (CSR2 x CSR16) to 25.53 (KA x CSR4) in summer, from 3.34 (CSR2 x NB4D2) to 27.85 (CSR18 x CSR19) in rainy and from 6.7(CSR3 x NB4D2) to 12.18 (KA x CSR16) in winter. The minimum and maximum heterobeltiotic values obtained for reciprocals in summer, rainy and winter are 0.68 (NB4D2 x CSR2) and 26.58 (CSR4 x KA), 2.79 (NB4D2 x CSR2) and 28.21 (CSR19 x CSR18), 6.58 (NB4D2 x CSR3) and 11.47 (CSR19 x CSR18), respectively (Table-2).

Fifth age larval duration

The range of heterosis value obtained in straight crosses during summer are from -3.21 (CSR18x CSR4) to 19.84 (CSR3 x CSR19 and KA x CSR19), in rainy from -3.09 (CSR2 x CSR4) to 8.33 (CSR3 x CSR19 and CSR17 x CSR19) and in winter from -0.62(CSR18 x CSR5) to -6.94 (CSR2 x NB4D2). The magnitude of heterobeltiosis ranged between in summer are -2.56 (CSR4 x CSR8) and 20.63 (CSR19 x KA and CSR19 x CSR17), in rainy -1.85 (CSR4 x KA) and 11.11 (NB4D2 x CSR18) and in winter -6.94 (NB4D2 x CSR2) and 4.32 (CSR5 x CSR18), respectively (Table-2).

Total larval duration

The magnitude of heterosis of ranged in straight crosses in summer were from -0.58 (CSR18 x CSR5) to 6.23 (CSR17 x CSR4), in rainy from -0.39 (CSR18 x CSR6) to -9.30 (CSR2 x CSR5 and CSR3 x NB4D2) and in winter from -14.54 (CSR17 x CSR16) to -16.83 (KA x CSR19). The lower and higher heterosis values observed for reciprocal crosses in summer were -6.04 (CSR4 x CSR17) and 0.19 (CSR5 x CSR18), in rainy -1.72 (CSR19 x CSR18) and -14.87 (CSR5 x CSR2 and CSR5 x CSR3) and in winter -15.21 (CSR16 x CSR17 and CSR16 x KA) and -16.35 (NB4D2 x CSR2 and NB4D2 x CSR3), respectively (Table-2).

Cocoon weight

In straight crosses, the heterosis ranged from -1.57 (CSR2 x NB4D2) to 24.03 (CSR18 x CSR16) in summer, from -2.46 (CSR3 x NB4D2) to 15.72 (KA x CSR19) in rainy and from -10.55 (KA x NB4D2) to 9.37 (CSR2x CSR4) in winter. The magnitude of heterobeltiosis in reciprocals ranged between -6.24 (NB4D2 x CSR2) and 20.87 (CSR16 x CSR18) in summer, -5.05 (NB4D2 x CSR3) and 7.26 (CSR16 x CSR18) in rainy and -10.79 (NB4D2 x KA) and 8.98 (CSR4 x CSR2) in winter (Table-2).

Shell weight

The magnitude of heterosis in straight crosses were ranged from -10.09 (KA x CSR5) to 30.61 (CSR18 x CSR19) in summer, from -25.92 (KA x CSR5) to 22.40 (CSR18 x CSR19) in rainy and from -24.57 (KA x CSR5) to 13.91(CSR3 x CSR4) in winter.

In summer the heterosis ranged between -22.82 (NB4D2 x CSR2) and 38.67 (CSR4 x KA), in rainy -27.94 (CSR19 x KA) and 26.27 (CSR19 x CSR18) and in winter between -28.72 (NB4D2 x CSR17) and 17.20 (CSR19 x KA) among reciprocals (Table-2).

Shell%

The magnitude of heterobeltiosis in straight crosses ranged from -22.83 (KA x CSR16) to 9.31 (CSR2 x CSR3) in summer, from -25.58 (KA x CSR5) to 8.89 (CSR18 x CSR4) in rainy and from -16.9 (KA x CSR4) to 9.60 (CSR3 x CSR16) in winter. Among reciprocals in summer the heterosis ranged between -23.5 (NB4D2 x CSR17) and 9.58 (CSR5 x CSR3), in rainy -27.38 (CSR19 x KA) and 9.04 (CSR4 x CSR2) and in winter between -23.89 (NB4D2 x CSR17) and 13.60 (CSR19 x KA) (Table-2).

Filament length

Among straight crosses, the heterosis ranged from in summer were from -3.95 (KA x CSR16) to 28.05 (CSR17 x CSR5), from -8.19 (CSR2 x NB4D2) to 21.61 (CSR17 x CSR5) in rainy and from -0.01 (CSR3 x CSR19) to 12.80 (CSR17 x CSR16) in winter. The heterobeltiosis in reciprocals was ranged between -12.66 (NB4D2 x CSR2) and 32.27 (CSR5 x KA) in summer, -15.86 (CSR19 x KA) and 22.34 (CSR5 x CSR3) in rainy and -16.04 (NB4D2 x CSR2) and 17.46 (NB4D2 x KA) in winter (Table-2).

Neatness

No cross has shown positive heterobeltiosis for straight crosses during summer. The magnitude of heterosis was ranged in straight crosses are in summer from -10.87 (KA x CSR5 and CSR17 x NB4D2) to -2.22 (CSR18 x CSR4), in rainy from -8.55 (KA x CSR5) to 1.11 (CSR17 x NB4D2) and in winter from -7.87 (KA x NB4D2) to 2.22 (CSR3 x CSR4 and CSR17 x CSR4). No significant values were observed in rainy season for reciprocals and three hybrids each in rainy and winter did not show any heterosis. The lower and higher heterosis values observed for reciprocal crosses in summer were -3.33 (CSR4 x CSR18) and -10.87 (NB4D2 x CSR17), in rainy -7.78 (CSR19 x KA) and 2.22 (CSR4 x CSR3) and in winter -7.61 (NB4D2 x CSR2) and 4.4 (CSR4 x CSR17) (Table-2).

Heterosis over environment

The analysis of heterosis over seasons and over characters were depicted in Table-4. The expression of

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relative heterosis (mean of all characters) over environment indicated expression was higher in summer (8.97%) followed by rainy (5.87%) and winter (2.14%). The expression of heterobeltiosis was also followed the same trend, summer being highest (6.71%) followed by rainy (3.42%) and winter (0.03%). However expression of heterosis between straight and reciprocal crosses indicated higher heterotic expression in reciprocal than straight crosses. The expression of relative heterosis in reciprocal crosses are 10.08%, 5.69% and 3.91% in summer, rainy and winter respectively as compared to 8.54%, 5.56% and 2.05% in straight crosses. Similarly in heterobeltiotic expression, reciprocal showed 7.54%, 3.43% and 0.18% as compared to 6.44%, 2.88% and -0.08% in straight crosses in summer, rainy and winter seasons, respectively.

The character wise heterosis expression is depicted in Table-5. The higher expression of both heterosis and heterobeltiosis observed in pupation rate (16.01 and 13.11) followed by shell weight (14.49 and 11.74), filament length (12.20 and 5.62) cocoon weight (8.44 and 4.55). Negative heterosis observed for neatness.

Table-1. Range of heterosis and number of crosses showing significant heterosis in straight and reciprocal crosses of silkworm, *Bombyx mori* L.

Traits	**Heterosis (%) over mid parent**											
	Straight crosses						**Reciprocals**					
	Seasons											
	Summer		**Rainy**		**Winter**		**Summer**		**Rainy**		**Winter**	
	Range of heterosis	No. of desirable combinations	Range of heterosis	No. of desirable combinations	Range of heterosis	No. of desirable combinations	Range of heterosis	No. of desirable combinations	Range of heterosis	No. of desirable combinations	Range of heterosis	No. of desirable combinations
Pupation rate (%)	8.0 to 26.86	25	5.31 to 31.87	25	7.8 to 14.86	25	7.09 to 27.93	25	4.25 to 32.24	25	7.57 to 14.50	25
Fifth age larval period (hrs)	-5.03 to 9.42	15	-6.5 to 8.16	-	-10.0 to -2.47	25	-4.40 to 9.42	12	-5.36 to 8.84	-	-8.33 to 0.002	-
Total larval period (D:H)	-6.63 to -1.73	-	-12.41 to -0.96	-	-16.60 to -14.96	25	-1.93 to -6.04	25	-1.16 to -11.84	-	-14.80 to -16.18	-
Cocoon weight (g)	6.2 to 26.57	25	0.69 to 16.63	25	-10.65 to 11.48	13	3.35 to 28.52	25	0.17 to 15.58	25	-7.14 to 11.07	14
Shell weight (g)	-4.42 to 33.94	21	-10.51 to 28.42	22	-19.39 to 20.11	20	-12.75 to 39.13	23	-16.36 to 38.36	-	-20.25 to 19.43	.
Shell%	-18.95 to 9.89	20	-15.59 to 16.04	19	-10.83 to 16.88	20	-21.42 to 11.07	19	-19.80 to 16.07	-	-17.9 to 16.40	-
Filament length (m)	3.39 to 29.97	25	-1.48 to 22.79	23	-3.17 to 21.71	22	0.80 to 34.42	25	-3.09 to 23.78	-	-1.30 to 22.05	-
Neatness (p)	-9.78 to -2.2	-	-7.95 to 0.00	-	-7.34 to 3.33	13	-2.22 to -9.09	-	-6.82 to 2.79	-	-6.15 to 4.44	-

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Table-2. Range of heterobeltiosis and number of crosses showing significant heterosis in straight and reciprocal crosses of silkworm, *Bombyx mori* L.

Traits	Heterosis (%) over better parent											
	Straight crosses						Reciprocals					
	Seasons											
	Summer		Rainy		Winter		Summer		Rainy		Winter	
	Range of heterobeltiosis	No. of desirable combinations	Range of heterobeltiosis	No. of desirable combinations	Range of heterobeltiosis	No. of desirable combinations	Range of heterobeltiosis	No. of desirable combinations	Range of heterobeltiosis	No. of desirable combinations	Range of heterobeltiosis	No. of desirable combinations
Pupation rate (%)	1.98 to 25.53	25	3.44 to 27.85	25	6.70 to 12.18	25	0.68 to 26.58	-	2.79 to 28.21	25	6.58 to 11.47	25
Fifth age larval period (hrs)	-3.21 to 19.84	6	-3.09 to 10.42	-	-0.62 to -6.94	25	-2.56 to 20.63	6	-1.85 to 11.11	-	-6.94 to 4.32	20
Total larval period (D:H)	-0.58 to -6.23	-	-0.58 to -9.30	-	-14.54 to -16.83	25	-6.04 to 0.19	24	-1.72 to -14.87	-	-15.21 to - 16.38	-
Cocoon weight(g)	-1.57 to 24.28	20	-2.45 to 15.72	19	-10.55 to 7.83	14	-6.24 to 25.54	21	-5.05 to 17.65	20	-10.79 to 8.98	10
Shell weight (g)	-10.09 to 30.61	20	-25.92 to 22.40	20	-24.57 to 13.91	20	-22.82 to 38.67	21	-27.94 to 26.57	-	-28.72 to 17.20	-
Shell%	-22.88 to 9.31	20	-25.58 to 8.89	13	-16.90 to 9.60	20	-23.50 to 9.58	20	-27.38 to 9.04	-	-23.89 to 13.60 13.6013 .6019	19
Filament length (m)	-3.95 to 28.05	19	-8.9 to 21.61	18	-13.30 to 12.80	9	-12.66 to 32.37	19	-15.86 to 22.34	-	-16.04 to 17.46	13
Neatness (p)	-2.22 to --10.87	-	-1.11 to -8.88	-	-7.87 to 2.22	7	-3.33 to -10.87	-	-7.78 to 2.22	-	-7.61 to 4.44	10

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Table-3. Top five desirable crosses showing higher heterosis for different characters.

Traits	Heterosis over mid parent				Heterosis over better parent			
	Straight crosses	**Range**	**Reciprocals**	**Range**	**Straight crosses**	**Range**	**Reciprocals**	**Range**
Pupation rate (%)	KA x CSR19 KA x CSR4 CSR18 x CSR19 KA x CSR16 CSR17 x CSR4	21.23 to 20.29	CSR4 x KA CSR19 x KA CSR19 x SR18 CSR4 x CSR17 CSR16 x KA	21.57 to 19.68	CSR18 x CSR19 KA x CSR19 KA x CSR16 KA x CSR4 CSR17 x CSR4	18.94 to 17.18	CSR19 x KA CSR19 x CSR18 CSR4 x CSR17 CSR4 x KA CSR19 x CSR17	20.2 to 18.20
Fifth age larval period (Hrs)	CSR2 x CSR4 CSR18 x CSR4 CSR17 x CSR4 KA x CSR4 CSR3 x CSR4	-4.76 to -3.05	CSR4 x KA CSR5 x CSR2 CSR16 x KA CSR4 x CSR2 CSR4 x CSR17	-5.61 to -1.96	CSR2 x CSR4 KA x NB4D2 CSR2 x NB4D2 CSR17 x NB4D2 CSR17 x CSR4	-2.39 to -1.48	CSR4 x KA CSR4 x CSR17 CSR4 x CSR2 NB4D2 x KA CSR5 x CSR2	1.84 to -0.05
Total larval period (D:H)	KA x CSR4 CSR17 x CSR4 KA x CSR5 CSR3 x NB4D2 CSR18 x NB4D2	-11.20 to -10.32	NB4D2 x CSR3 CSR5 x KA CSR16 x CSR3 CSR19 x KA CSR4 x CSR17	-6.84 to -6.30	CSR17 x CSR4 KA x CSR4 KA x CSR5 CSR17 x CSR5 CSR3 x NB4D2	-7.59 to -6.62	CSR4 x CSR17 CSR5x KA CSR16 x CSR3 NB4D2 x CSR3 CSR5 xCSR17;	-6.71 to -6.01
Cocoon weight (g)	CSR18 x CSR19 KA x CSR19 CSR17 x CSR19 CSR17 xCSR4 CSR18 x NB4D2	15.78 to 11.91	CSR19 x CSR18 CSR19 x KA CSR19 x CSR17 CSR4xCSR17 CSR19 xCSR3	16.44 to 11.20	CSR18 x CSR19 CSR18 xNB4D2 CSR18 x CSR16 CSR17 x CSR4 KA x CSR19	13.36 to 7.72	CSR19 x CSR18 CSR19 x KA NB4D2 x KA CSR16 x CSR18 NB4D2 x CSR18	13.78 to -7.82
Shell weight (g)	CSR18 x CSR19 CSR18 x NB4D2 CSR3 x NB4D2 CSR3 x CSR19 CSR17 x CSR4	25.19 to 21.03	CSR19 x CSR18 CSR16 x KA CSR4 x CSR17 CSR16 x CSR18 CSR19XCSR17	31.20 to 22.23	CSR18 x CSR19 CSR3 x CSR4 CSR18 x NB4D2 CSR18 x CSR16 CSR18x CSR4	21.09 to 14.07	CSR19 x CSR18 CSR4 x KA CSR16 x CSR18 CSR4 x CSR17 CSR16 x KA	22.80 to 16.0
Shell%	CSR3 x NB4D2 CSR18 x NB4D2 CSR17 x NB4D2 CSR2 x NB4D2 CSR3 x CSR19	13.44 to 9.31	CSR19 x CSR18 CSR19 x CSR2 CSR4 x CSR18 CSR5 x CSR18 CSR16 x CSR18	13.51 to 9.72	CSR3 x NB4D2 CSR3 x CSR16 CSR3 x CSR4 CSR3 x CSR19 CSR17 x CSR4	9.24 to 6.74	CSR19 x KA CSR4 x CSR3 CSR4 x CSR2 CSR19 x CSR3 CSR16 x CSR3	8.72 to 6.03
Filament length (m)	CSR17 xNB4D2 CSR17 xCSR4 CSR17 x CSR19 CSR17 x CSR16 CSR3 x NB4D2	24.40 to 17.14	CSR5 x CSR3 CSR5 x CSR18 CSR16 x CSR3 CSR19 x CSR3 CSR5 x CSR17	22.28 to 19.13	CSR17 x NB4D2 CSR17 x CSR4 CSR17xCSR19 CSR17xCSR16 CSR3xCSR5	20.53 to 9.51	CSR4 x CSR17 CSR5 x CSR3 CSR19 x CSR17 CSR16 xCSR17 NB4D2 x KA	17.24 to 12.33
Neatness (p)	CSR17 x CSR4 CSR18 x CSR19 CSR3 x CSR4 CSR2 x CSR4 CSR18 x CSR16	0.0 to 1.48	CSR4 x CSR3 CSR4 x CSR17 CSR19 x CSR3 CSR4 x CSR2 CSR19 xCSR17	1.29 to 0.0	CSR18 xCSR4 CSR3 xCSR4 CSR18 x CSR19 CSR3 x CSR19 CSR18 x CSR16	0.0 to -1.85	CSR4xCSR17 CSR4 x CSR3 CSR19 x CSR17 CSR4 x CSR18 CSR19 x CSR3	0.76 to -0.04

Table-4. Mean heterosis over environment.

Type of heterosis	Combination	Season		
		Summer	**Rainy**	**Winter**
Relative Heterosis	Straight crosses	8.54	5.56	2.05
	Reciprocal crosses	10.08	5.69	3.91
Hetero beltiosis	Straight crosses	6.44	2.88	-0.08
	Reciprocal crosses	7.54	3.43	0.18
Relative Heterosis	Mean of both crosses	8.97	5.87	2.14
Hetero beltiosis	Mean of both crosses	6.71	3.42	0.03

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Table-5. Character wise expression of heterosis.

Heterosis	Pupation %	Fifth age larval duration (hrs)	Total larval duration (D;H)	Cocoon weight (g)	Shell weight (g)	Shell %	Filament length (m)	Neatness (p)
Relative heterosis	16.01	-0.72	-7.11	8.44	14.49	4.97	12.20	-2.68
Hetero beltiosis	13.11	2.20	-4.35	4.55	8.99	1.99	5.62	-3.38
Mean	14.56	0.74	-5.73	6.49	11.74	3.48	8.91	-3.03

DISCUSSIONS

Utilization of heterosis has become a major strategy for increasing productivity of plants and animals. Heterosis is a genetic expression of the beneficial effects of hybridization. Investigations about the degree of heterosis are important in deciding the directions of future breeding programmes. In the present investigation, both heterosis and heterobeltiosis were determined in the fifty-bivoltine crosses of silkworm, *Bombyx mori* L. The study revealed that expression of heterosis was varying with characters. It was highest in pupation% followed by shell weight, filament length and cocoon weight. Harada (1961) reported highest heterosis in cocoon shell weight (27.8%) followed by cocoon weight (25.9%), survival rate (23%) and filament length (19%). Further Subba Rao and Sahai (1989) reported the highest significant level of heterosis for cocoon yield (14.25) followed by cocoon weight (3.89). Such wide differences in the manifestation of heterosis suggest that the parental strains involved in the hybrids differ in their genetic make up (Gamo and Hirabayshi, 1983; Tayade 1987; Sathenhalli *et al*., 1989). Many hybrids in this study are displayed conspicuous heterosis for most of the characters. The partial or complete dominance is the main cause for heterosis of this crosses (Paterniani 2001), The higher heterosis for better parent can be due to the accumulated action of favourable dominant or semi-dominant genes dispersed among two parents, i.e., dominance; or by the complementary interaction of additive dominant or recessive genes at different loci, i.e., non-allelic interaction or epistasis (Mackey 1976). Further the higher degree of heterosis might be due to the smaller the degree of genetic resemblance between parental populations, also the magnitude of heterosis is then expected to be proportional to the degree of heterozygosity of crosses (Sheridan 1981). The direction and magnitude of heterosis also varied from cross to cross. This indicates that the mechanism of expression of heterosis was different in the various crosses under different environments and confirming the hypothesis that heterosis can be affected by the environments (Betran *et al*., 2003), which have a differential effect in parental inbreds and hybrids. The expression of highly varied heterosis for the traits under study in the hybrids and its reciprocal crosses can be due to non-allelic interaction which also can decrease heterosis. It may be the reason for negative heterosis in neatness. Further negative values for heterosis and heterobeltiosis for nearness may be due to the higher values for the character in the parents involved.

Overall, the expression of heterosis was found higher in summer followed by rainy and winter for yield contributing characters, since population maintained in a varying environment can be expected to have greater genetic variance and higher fitness than population from a constant environment. This suggests that heterozygote superiority is to a greatest degree in a fluctuating environment. Generally in good environment (If optimum temperature and Humidity, High nutritive value of mulberry leaf etc., provided), the parental breeds perform better; the heterosis (MPV) values are closer to parents. On the other hand MPV exhibit higher value in poor environment. According to Lerner (1958), the degree of heterosis shown by a particular cross can be influenced by the environment, since crossbred animals are expected to be both more uniform and less influenced by environmental factors than their purebred parental lines.” This implies that heterozygotes are expected to be less susceptible to external changes than homozygotes. Barlow (1981), in a comprehensive review on the matter, reported that heterosis for most traits appears to be greater in stressful rather than in favorable conditions, and the nature of interactions depends on the species and trait considered in the analysis. On the whole, Heterosis x Environment interaction has to be evaluated in relation to the specific conditions in which animals perform, so that it would be possible to better understand where crossbred animals can positively interact with the environment.

The range of heterosis and heterobeltiosis under individual environments as well as over all the three environments indicates wide variability among hybrids. All straight crosses and reciprocals exhibited significant positive heterosis and heterobeltiosis for pupation rate in all three environments. Other characters did not show such consistent trend. The positive heterotic gain among the parents in F1 hybrid and reciprocal crosses can be due to epistasis effect (Falconer 1985, Aruga 1994). Though wide range of heterosis in three environment and pronounced desired heterosis was expressed in all the three environments, but more so in the summer. This further indicates the influence of environment on the expression of heterosis. Studies show that the heterotic patterns of inbred lines and populations can change

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depending on the test environment under which the evaluation is made (Barlow 1981; Betran, *et al*., 2003). Thus, using only the environmental mean will not be sufficient for proper selection of superior hybrids and the breeder has to consider season specific hybrids. The pronounced heterosis in different seasons provides a better chance for selection of desirable season specific highly heterotic crosses for exploitation. For example out of twenty five straight crosses, twenty one crosses has shown positive significant heterosis in all environments for shell weight, shell% and filament length, but twenty four reciprocals showed positive significant heterosis only in summer, no significant results observed in rainy and winter. The positive heterotic gain among the selected parents in F1 hybrid and reciprocal crosses can be due to epistasis effect (Falconer 1985, Aruga 1994), while the positive heterosis in shell weight and filament length can be due to dominant and overdominance gene expression for this character (Verma *et al*., 2005; Reddy *et al*., 2008).

Results of this study indicated environment dependent differential expression of heterosis between straight crosses and reciprocals for different characters. The reciprocal hybrids have shown better heterosis compared to straight crosses in some of the traits and seasons. The larval span of the females to be shorter than that of the males in the reciprocal cross hybrids. The fact that the females of the hybrids grow too quickly has an adverse effect on the cocoon shell weight (Morohoshi 1949). Nagatomo (1942) proposed that maturity genes linked to the Z chromosome in silkworm, play an important role in reciprocal hybrid differences since the larval maturity gene has a close correlation with body size, cocoon weight, cocoon shell weight and body weight. Nevertheless, the strong maternal influence, and a general lack of paternal contribution is indicative of strong non-nuclear (maternal) effects (Betran *et al*., 2003). Hirobe (1957) also analyzed the heterosis from the genetic as well as cytoplasmic point of view and opined that the degree of heterosis varies according to the character and when the improvement of particular character is high in the parental strains, the degree of heterosis declines in the hybrids.

The parents viz., CSR3, CSR17, CSR18, KA (Oval type) and CSR4, CSR19, NB4D2 (Dumbbell) are involved the crosses including reciprocals exhibited higher heterosis and heterobeltiosis than other crosses for most of the characters. According to Arunachalam *et al. (*1984*)* optimum level of genetic divergence between parents is required to obtain heterosis in F1 generation and thus indicating divergence in these breeds, since heterosis is a function of dominance effect and genetic distance between parents. When two genetically diverse homozygous parents are crossed, maximum heterozygosity can be achieved and this in turn leads to significant heterosis (Falconer and Mackay 1996)

Among the fifty crosses, four crosses (including their reciprocals) namely CSR17 x CSR4 (CSR18 x CSR19, CSR4 x KA and CSR17 x 19 has exhibited desired heterosis and heterobeltiosis for more than three characters. Of which, CSR17 x CSR4 exhibited higher heterosis and heterobeltiosis for six characters, CSR18 x CSR19 for 5 and 4, CSR4 x KA for 3 and 4 and CSR17 x CSR19 for 4 and 3 characters respectively out of eight characters. This study was carried out in three environments and it was remarkable that four hybrids maintained their consistently superior performance under all the environments. So, these hybrids can be exploited for possible use over wide areas. Specially CS17 x CSR16 can be used for commercial exploitation. Further, the superiority of these hybrids, particularly over the better parent, is useful in determining the feasibility of the commercial exploitation of heterosis as well as in identifying the parental combinations capable of producing the highest level of transgressive segregants.

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REFERENCES

Aruga H. 1994. Principles of Sericulture. Oxford and IBH Publishing Company Private Ltd. New Delhi, Bombay and Calcutta, India. pp. 99-111.

Arunachalam V, Bandyopadhyay A, Nigam S N and Gibbons R W. 1984. Heterosis in relation to genetic divergence and specific combining ability in ground nut (*Arachis hypogaea* L.). Euphytica. 33: 33-39.

Barlow R. 1981. Experimental evidence for interaction between heterosis and environment in animals. Animal Breed. Abst. 49: 715-739.

Betran J, Ribaut M, Beck D and Gonzalez de Leo´ n, D. 2003. Genetic diversity, specific combining ability and heterosis in tropical maize under stress and nonstress environments. Crop Sci. 43: 797-806.

Datta R K, Rao D P, Jayaswal K P, Premlatha V, Singh R and Kariappa B K. 2001. Heterosis in relation to combining ability in multi x bi strain of silkworm, *Bombyx mori* L. Indian J. Seric. 40: 1-6.

Dobzhansky T. 1950. Genetics of natural populations. XIX. Origin of heterosis through natural selection in populations of Drosophila pseudoobscura. Genetics. 35: 288-302.

Falconer D S and Mackey F C. 1996. Introduction to quantitative genetics. 4th Edition, Longman, New York.

Falconer D S.1981. Introduction to Quantitative Genetics, 2nd Ed. Longman, London/ New York.

Falconer D S.1985. Introduction to quantitative Genetics. English language book society, Longman. London. pp. 224-238.

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Gamo T and Hirabayashi T. 1983. Genetic analysis of growth rate, pupation rate and some quantitative characters by diallel cross in silkworm, *Bombyx mori* L. Japan J. Breed. 33: 178 -190.

Harada C. 1961. On the heterosis of quantitative characters in the silkworm. Bulletin Seric. Expt. Stn. 17: 50-52.

Hirobe T. 1957. Advancement in the improvement of silkworm Varieties. Heredity. 21: 18-24.

Larner. 1958. The genetic basis of selection. John Wiley sons. Inc NewYork. p. 298.

Mackey I .1976. Genetics and evolutionary principles of heterosis. Procedings of the 8th Cong. of Eucarpia on Heterosis of Plant Breeding. Janossy, A., Lupton, F.G.H (Ed.), Elsevier Scientific Pub. Co., Amsterdom, Netherlands. pp. 17-33.

Morohoshi S. 1949. Developmental mechanism in *Bombyx mori* L. Meibundo, Tokyo. Japan. pp. 111-120.

Nagaraju J, Raje Urs S and Datta R K.1996. Cross breeding and heterosis in silkworm, *Bombyx mori* L.A review. Sericologia. 36: 1-20.

Nagatomo T. 1942. On the sex linked inheritance of quantitative characters in the silkworm, *Bombyx mori* L. J Agric. Sci. 281: 155-173.

Ohkuma T. 1971. Studies on the mechanism of hybrid vigour by means of artificial parthenogenesis in the silkworm, *Bombyx mori* L. J Seric. Sci. Jpn. 40: 422-430.

Paterniani M A G Z. 2001. Use of Heterosis in Maize Breeding: History, Methods and Perspectives - A Review. Crop Breed. Appl. Biotech. 2: 159-178.

Reddy R M, Suryanarayana N and Vijaya Prakash N B. 2008. Heterosis potential in selective parental F1 hybrids of divergent geographic ecoraces of tropical tasar Silkworm, Antheraea mylitta D (Lepidoptera: Saturniidae). Academy J. Ento. 1: 32-35.

Riday H, Brummer E C, Cambell T A and Luth D. 2003. Comparison of genetic and morphological distance with heterosis between Medicago sativa and subsp. falcata. Euphytica. 131: 37-45.

Satenahalli S B, Govindan R and Goud J V. 1989. Genetic analysis of some quantitative traits by diallel crosses in silkworm, *Bombyx mori* L. Sericologia. 29: 333 - 342.

Sheridan A K. 1981. Crosses breeding and heterosis. Animal Breed. Abst. 49: 131-144.

Shull G H. 1908. The composition of a field of maize. Annals Breeders Assoc. Rep. 4: 296-301.

Stuber C W. 1994. Heterosis in plant breeding. Plant Breed. Rev. 12: 227-251.

Subba Rao G and Sahai V. 1989. Combining ability and heterosis studies in bivoltine strains of silkworms *Bombyx mori* L. Uttar P. J. Zool. 9: 150-164.

Tayade D S. 1987. Heterosis effect on economic traits of new hybrids of silkworm, *Bombyx mori* L. under Marathwada conditions. Sericologia. 27: 301 - 307.

Verma A K, Chattopadhyay G K, Sengupta M, Das S K and Sarkar A. 2005. Heterobeltiotic genetic interaction between congenic and syngenic breeds of silkworm breeds of *Bombyx mori* L. International J. Indus. Entomol. 11: 119-124.