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Manifestation of Hybrid Vigour and Cocoon Shape Variability in F1 Hybrids of the Mulberry Silkworm, *Bombyx mori* L.

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Data from an experiment involving six polyvoltine and three bivoltine silkworm breeds have been analysed to know the level of hybrid vigour and cocoon shape variation in F1 hybrids among silkworm breeds with low, medium and high cocoon weight. Results indicated significantly positive heterosis for several quantitative characters with maximum total heterosis over mid parent value in hybrids between low and medium followed by low and low, medium and medium, low and high and high and low cocoon-weighed breeds, respectively. Study on cocoon shape measurement revealed that among F1 hybrids, cocoons of the three combinations such as GNP× CSR2, GNP× J2 and PM× NB4 D2 were comparatively uniform in their cocoon shape. Importance of this study to know the level of heterosis and cocoon shape variability in different silkworm crosses have been discussed.

Key words : *Bombyx mori*, Cocoon shape, Cocoon weight, Hybrid vigour

Introduction

Studies on hybrid vigour have been carried out in plant (Marani, 1967; Kaushik *et al.*, 1984) as well as in crosses between breeds, inbred and isolated breeds of farm and laboratory animals (Bhuvan Kumar *et al.*, 1985; Falconer, 1988; Ehiobu and Goddard, 1989). Commercial exploitation of hybrid vigour in the mulberry silkworm, *Bombyx mori*, was first advocated by Toyama in 1911 (Yokoyama, 1956). Since then, extensive studies were made on hybrid vigour in silkworm (Singh and Hirobe, 1964; Subba Rao and Sahai, 1989; Ravindra Singh *et al.*, 1990, 1994; Moon and Han, 1994; Rao *et al.*, 1997; Rajalakshmi *et al.*, 1998). In India, more than 95% silk production is attributed from polyvoltine X bivoltine F1 hybrids (Datta, 1984) and hybrid vigour for most of the economic characters was higher in polyvoltine x bivoltine hybrids as compared to bivoltine F1 hybrids (Yucheng,1964; Ravindra Singh *et al.*, 1998b).

Manifestation of hybrid vigour has been studied in single, double and three-way crosses of silkworm (Kremsky, 1983; Ashoka and Govindan, 1990; Singh and Subba Rao, 1994; Sohn and Ramirez,1999). Studies on inheritance of quantitative characters in silkworm are limited (Petkov and Jolov, 1979; Oshiki *et al.*, 1986; Grekov and Petkov, 1989; Puttaraju and Rajanna, 1997). Recently, Rajanna and Puttaraju (1998a, b) have observed that hybrid vigour was more pronounced in several quantitative characters in interline crosses involving either low male or female bivoltine component selected for pupal weight and higher pupal weight did not result in higher hybrid vigour. Ravindra Singh *et al.* (1998a) have observed less variation in cocoon shape in F1 hybrids between Chinese type polyvoltine× bivoltine silkworm breeds as compared to Japanese type hybrids. The present study was undertaken with the main objective to know the manifestation of hybrid vigour in quantitative characters as well as cocoon shape variability in polyvoltine× bivoltine F1 hybrids between low, medium and high cocoon- weighed polyvoltine and bivoltine breeds of the mulberry silkworm, *Bombyx mori* L.

Materials and Methods

The present study has been conducted in Multivoltine Breeding Laboratory at Central Sericultural Research

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Table 1. Characteristics of multivoltine and bivoltine silkworm breeds used in the present study

Race/breed	Origin	Voltinism	Cocoon colour	Cocoon shape	Cocoon weight range (g)
Pure Mysore (L)	India	Polyvoltine	Greenish yellow	Spindle	0.9 - 1.0
Nistari (L)	India	Polyvoltine	Golden yellow	Spindle	0.9 - 1.0
MY1 (M)	India	Polyvoltine	Greenish yellow	Elongated oval	1.2 - 1.3
GNP (M)	China	Polyvoltine	White	Oval	1.1 - 1.2
BL24 (H)	India	Polyvoltine	Greenish yellow	Oval	1.3 - 1.4
BL43 (H)	India	Polyvoltine	Greenish yellow	Oval	1.3 - 1.4
J2 (L)	China	Bivoltine	White	Peanut	1.4 - 1.5
NB4D2 (M)	India	Bivoltine	White	Dumb-bell	1.6 - 1.7
CSR2 (H)	India	Bivoltine	white	Oval	1.8 - 1.9

Letters in parentheses indicate L for low ; M for medium and H for high cocoon- weighed silkworm breeds.

Polyvoltine× bivoltine

LOW	LL	LM	LH
MEDIUM	ML	MM	MH
HIGH	HL	HM	HH

Fig. 1. Experimental design to show the crossing pattern between polyvoltine female and bivoltine male.

and Training Institute, Mysore. Six polyvoltine silkworm breeds viz., Pure Mysore and Nistari (low cocoon weight), MY1 and GNP (medium cocoon weight) and BL24 and BL43 (high cocoon weight) and three bivoltine silkworm breeds viz., J2 (low cocoon weight), NB4D2 (medium cocoon weight) and CSR2 (high cocoon weight) were utilised as female and male parents respectively. Characteristics of these breeds are given in Table 1. Crosses were made between females of polyvoltine breeds respectively with low, medium and high cocoon weights to each males of bivoltine silkworm breeds with low, medium and high cocoon weights, so a total of 18 crosses were made. Crossing pattern between polyvoltine and bivoltine silkworm breeds has been shown in Fig. 1. Rearing of F1 hybrids along with parents was conducted during January- February, 2000 by adopting standard rearing technique (Krishnaswami, 1978). Three replications were reared in each hybrid / parent and 300 larvae were retained after third moult. Data were recorded for fecundity, hatching %, total larval duration, effective rate of rearing both by number and weight, cocoon weight, cocoon shell weight, cocoon shell ratio and pupal weight. Level of heterosis for each hybrid were also calculated.

Heterosis over mid parent value (MPV) and better parent value (BPV) for each character was calculated by the following formulae :-

1. Heterosis over MPV = $\frac{F1 - MPV}{MPV} \times 100$

2. Heterosis over BPV = $\frac{F1 - BPV}{BPV} \times 100$

Cocoon shape measurement was carried out by randomly taking 100 cocoons from each replication using vernier callipers. Three cocoon shape variables are viz., cocoon length, cocoon width and length/width ratio. Cocoon shape variation was determined by uniformity test on the basis of standard deviation as suggested by Mano (1994). Cocoon length / width ratio was calculated for each cocoon and its standard deviation and coefficient of variation were considered for cocoon uniformity. Hybrids showing standard deviation less than 8, were considered as uniform.

Results

Comparative performance of polyvoltine and bivoltine parents along with F1 hybrids is presented in Tables 2 and 3, respectively. Heterosis over mid parent value and better parent value for quantitative characters in different crosses between polyvoltine× bivoltine F1 hybrids are presented in Table 4.

Fecundity

A great deal of variation was observed in the degree of heterosis. Maximum hybrid vigour for fecundity over mid parent value was observed in MY1× CSR2 (+9.25%) followed by BL43× J2 (+6.40%) and MY1× NB4D2 (+6.31 %).

Yield/10,000 larvae (By No.)

BL24× CSR2 exhibited maximum significant heterosis (+9.51%) for yield/10,000 larvae by number followed by Nistari× NB4D2 (+7.60%) and Pure Mysore× J2 (+7.03 %) over mid parent value.

Yield / 10,000 larvae (By Wt.)

Table 2. Average rearing performance of parental silkworm breeds

Sl. No.	Breed	Fecun -dity	Hatching (%)	Larval Span (hr)	Yield/10,000 larvae By No.	By Wt (kg)	Cocoon Wt. (g)	Pupal Wt. (g)	Shell Wt. (g)	SR (%)
A	Polyvoltines									
1	Pure Mysore	510	97.1	646	7944	8.744	1.100	0.939	0.174	15.88
2	Nistari	410	96.3	504	9142	9.763	1.067	0.912	0.160	15.04
3	MY1	502	95.3	528	8588	10.666	1.240	0.981	0.190	15.33
4	GNP	460	95.5	480	8538	9.336	1.195	0.999	0.196	16.40
5	BL24	471	96.7	504	9588	12.522	1.305	0.990	0.208	15.95
6	BL43	487	97.0	492	9522	10.432	1.305	0.910	0.193	14.83
7	J2	518	96.6	558	9599	13.377	1.393	1.187	0.300	21.74
8	NB4D2	586	98.4	534	9155	14.022	1.532	1.250	0.313	20.45
9	CSR2	571	97.2	552	9344	15.899	1.701	1.300	0.413	24.28

Table 3. Average rearing performance of polyvoltine× bivoltine F1 hybrids

Sl. No.	F1 Hybrid	Fecun -dity	Hatch -ing (%)	Larval Span (hr)	Yield/10,000 larvae By No.	By Wt (kg)	Cocoon Wt (g)	Pupal Wt (g)	Shell Wt (g)	SR (%)
1	Pure Mysore× J2	538	95.83	554	9388	14.844	1.575	1.189	0.302	19.18
2	Pure Mysore× NB4D2	538	95.76	554	9099	15.932	1.696	1.364	0.341	20.13
3	Pure Mysore× CSR2	550	95.03	552	9466	16.022	1.694	1.363	0.343	20.27
4	NISTARI× J2	463	98.80	504	9799	14.510	1.480	1.215	0.278	18.77
5	NISTRI× NB4D2	451	95.80	504	9799	15.999	1.624	1.272	0.306	18.87
6	NISTARI× CSR2	451	98.80	520	9799	15.844	1.616	1.254	0.301	18.63
7	MY1× J2	498	98.6	504	9099	13.333	1.464	1.165	0.266	18.21
8	MY1× NB4D2	578	98.46	512	8510	13.910	1.634	1.270	0.325	19.90
9	MY1× CSR2	586	99.16	528	8888	15.333	1.725	1.354	0.336	19.50
10	GNP× J2	512	97.10	504	8699	12.688	1.459	1.084	0.276	21.11
11	GNP× NB4D2	468	96.40	504	8688	13.666	1.584	1.237	0.286	18.05
12	GNP× CSR2	461	97.46	504	8233	13.311	1.616	1.296	0.328	20.11
13	BL24× J2	468	96.70	518	8222	12.688	1.584	1.285	0.370	21.77
14	BL24× NB4D2	479	97.03	506	8466	13.977	1.650	1.282	0.329	19.90
15	BL24× CSR2	490	96.50	518	8199	13.633	1.661	1.247	0.323	19.41
16	BL43× J2	535	99.03	510	8233	12.333	1.497	1.192	0.300	20.06
17	BL43× NB4D2	530	97.46	514	8455	14.044	1.661	1.347	0.356	21.43
18	BL43× CSR2	531	98.63	516	8233	14.122	1.730	1.218	0.368	20.91

The hybrid Pure Mysore× NB4D2 showed maximum significant heterosis (+39.97%) followed by Nistari× NB4D2 (+34.53%) and PM× J2 (+34.21%).

Cocoon weight

PM× NB4D2 revealed maximum significant mid parent value (+29.06%) followed by BL24× J2 (+27.42%) and PM× J2 (+26.35%).

Cocoon shell weight

Maximum significant mid parent value was recorded in PM× NB4D2 (+43.96%) followed by BL43× NB4D2 (+40.57%) and BL24× J2 (+33.81%).

Cocoon Shell Ratio

Highest significant mid parent value was recorded in BL43× NB4D2 (+21.60%) followed by BL43× J2 (+15.66%) and BL24× J2 (+14.47%).

Pupal weight

Table 4. Heterosis over mid parent and better parent value in polyvoltine× bivoltine F1 hybrids

Sl. No.	Hybrid		Fecun-dity	Hatch-ing (%)	Larval Span (hr)	Yield/10,000 larvae By No.	By Wt. (kg)	Cocoon Wt. (g)	Pupal Wt. (g)	Shell Wt. (g)	SR (%)	Total Hete-rosis. (%)
1	PM× J2 (L× L)	MPV	+4.57	-1.08	-7.97**	+7.03*	+34.21**	+26.35**	+14.97**	+30.69**	+5.77*	+114.54
		BPV	+3.79	-0.86	-0.72	-2.20	+10.96*	+13.07**	+1.54	+0.44	-11.17	+14.41
2	PM× NB4D2 (L× M)	MPV	-1.82	-2.03	-6.10**	+6.44	+39.97**	+29.06**	+26.33**	+43.96**	+14.65**	+150.46
		BPV	-8.13	-2.68	3.75	-0.60	+13.63**	+10.85**	+9.15*	+9.04*	-1.56	+36.45
3	PM× CSR2 (L× H)	MPV	+1.79	-0.12	-7.85**	+9.51**	+30.03**	+20.97**	+23.38**	+19.49**	+4.03	+101.13
		BPV	-3.82	-0.17	0.00	+1.31	+0.77	-0.41	+4.87	-16.94	-16.59	-31.04
4	NISTARI× J2 (L× L)	MPV	-0.32	+2.37**	-5.08**	+4.57	+25.41**	+20.32**	+15.73**	+20.61**	+2.49	+86.10
		BPV	-10.68	+2.21*	-9.68**	+2.08	+8.47	+6.27	+2.33	-7.44	-13.02	-19.46
5	NISTARI × NB4D2 (L× M)	MPV	-9.43	-1.63	-2.89 **	+7.60*	+34.53**	+24.87**	+17.71**	+29.40**	+6.28*	+106.44
		BPV	-22.98	-2.64	-5.62**	+7.53*	+14.10**	+5.94	+1.81	-2.13	-7.77	-11.76
6	NISTARI× CSR2 (L× H)	MPV	-8.08	+2.08**	-1.52	+6.02	+23.48**	+16.72**	+13.36**	+5.11	-5.44	+51.73
		BPV	-21.00	+1.65*	-5.80**	+4.88	-0.35	-5.02	-3.54	-27.02	-23.45	-79.65
7	MY1× J2 (M× L)	MPV	-2.32	+2.71**	-7.18**	+0.06	+10.91*	+11.23**	+7.50	+8.70	-1.35	+30.26
		BPV	-3.86	+2.00*	-9.68**	-5.21	-0.33	+5.14	-1.82	-11.21	-15.62	-40.59
8	MY1× NB4D2 (M× M)	MPV	+6.31	+1.65*	-3.58**	-4.07	+12.69**	+17.87**	+13.86**	+29.19**	+11.21**	+85.13
		BPV	-1.31	+0.07	-4.12**	-7.04	-0.79	+6.66	+1.63	+3.83	-2.71	+1.92
9	MY1× CSR2 (M× H)	MPV	+9.25*	+3.01**	-2.22*	-0.87	+15.43**	+17.31**	+18.76**	+14.74**	-1.29	+74.12
		BPV	+2.63	+2.02**	-4.35**	-4.87	-3.56	+1.43	+4.21	-16.21	-17.40	-36.65
10	GNP× J2 (M× L)	MPV	+4.80	+1.04	-2.89**	-4.07	+12.32**	+18.10**	+16.03**	+14.42**	+1.69	+61.44
		BPV	-1.09	+0.45	-9.68**	-9.38	-4.65	+5.38	-1.35	-7.99	-12.78	-41.09
11	GNP× NB4D2 (M× M)	MPV	-10.39	-0.58	-0.59	-1.79	+17.02**	+20.67**	+25.35**	+19.62**	+0.73	+70.04
		BPV	-20.12	-2.03	-5.62**	-5.10	-2.54	+3.37	+4.37	-5.32	-8.49	-41.48
12	GNP× CSR2 (M× H)	MPV	-10.47	+1.14	-2.33*	-7.92	+5.49	+15.71**	+21.60**	+10.18*	-1.92	+4.45
		BPV	-19.19	+0.27	-8.70**	-11.89	-16.28	-4.98	-0.31	-20.56	-17.23	-98.87
13	BL24× J2 (H× L)	MPV	-5.32	-0.02	-2.82**	-14.30	+0.56	+17.39**	+18.03**	+33.81**	+14.47**	+61.80
		BPV	-9.58	0.03	-7.53**	-14.35	-2.66	+13.71**	+8.25	+13.32**	-0.45	+4.19
14	BL24× NB4D2 (H× M)	MPV	-9.42	-0.56	-2.50**	-9.66	+5.31	+16.33**	+14.49**	+26.13**	+9.47**	+49.59
		BPV	-18.26	-1.39	-5.24**	-7.52	-0.32	+7.72*	+2.61	+5.00	-2.57	-0.61
15	BL24× CSR2 (H× H)	MPV	-6.04	-0.50	-2.27*	-13.38	-4.07	+10.50**	+8.93*	+9.28*	+1.53	+3.98
		BPV	-14.24	-0.72	-6.52**	-12.25	-14.26	-2.35	-4.03	-17.82	-15.90	-88.09
16	BL43× J2 (H× L)	MPV	+6.40	+2.27**	-2.86**	-13.89	-4.43	+11.00**	+13.68**	+28.59**	+10.18**	+50.94
		BPV	+3.22	+2.45**	-8.60**	-14.24	-7.80	+7.49*	+0.42	0.0	-7.03	-24.09
17	BL43× NB4D2 (H× M)	MPV	-1.18	-0.24	+0.19	-9.46	+6.18	+17.08**	+24.73**	+40.57**	+21.60**	+99.47
		BPV	-9.50	-0.96	-3.75**	-7.64	+0.16	+8.40*	+7.79	+13.72**	+4.91	+13.13
18	BL43× CSR2 (H× H)	MPV	+0.44	+1.58*	-1.15	-12.72	+0.39	+15.09**	+10.27*	+21.25**	+8.57**	+43.72
		BPV	-6.94	+1.47	-6.52**	-11.89	-10.55	+1.68	-6.26	-10.87	-12.57	-4.56

* and ** Significantly different at 5% and 1% respectively. L, Low; M, Medium and H, High cocoon weight breeds.

Highest significant mid parent value was recorded in PM × NB4D2 (+26.33%) followed by GNP× NB4D2 (+25.35%) and BL43× NB4D2 (+24.73%).

Cocoon shape measurement

Variability in cocoon shape in F1 hybrids between low, medium and high cocoon- weighed silkworm breeds is presented in Table 5. Among the eighteen F1 hybrids, GNP× CSR2 (M× H), GNP× J2 (M× L) and PM× CSR2 (L× H) exhibited more uniformity in cocoon shape with standard deviation less than 8 and CV% ranging from 4.17 to 4.50. However, two hybrids viz., GNP × NB4D2 (M× M) and PM× J2 (L× L) exhibited CV% of 4.95 and 4.96 respectively, though their SD value more than 8, were relatively uniform in cocoon shape (Table 5).

Table 5. Cocoon shape measurment in F1 hybrids between low, medium and high polyvoltine and bivoltine breeds

Sl. No.	Hybrid	Cocoon length (cm)	Cocoon width (cm)	Length/Width Ratio	Coefficient of variation (CV%)
1	PM× J2 (L× L)	3.67 ± 0.12	1.88 ± 0.07	194.60 ± 9.93	4.96
2	PM× NB4D2 (L× M)	3.64 ± 0.13	1.96 ± 0.08	199.55 ± 10.19	5.11
3	PM× CSR2 (L× H)	3.61 ± 0.12	2.05 ± 0.08	176.16 ± 7.93	4.50
4	NISTARI× J2 (L× L)	3.57 ± 0.14	1.67 ± 0.08	212.82 ± 12.44	5.84
5	NISTARI× NB4D2 (L× M)	3.63 ± 0.18	1.72 ± 0.07	212.52 ± 12.79	6.02
6	NISTARI× CSR2(L× H)	3.66 ± 0.16	1.95 ± 0.10	187.74 ± 11.36	6.05
7	MY1× J2 (M× L)	3.52 ± 0.146	1.66 ± 0.08	212.19 ± 12.87	6.07
8	MY1× NB4D2 (M× M)	3.62 ± 0.13	1.69 ± 0.09	214.62 ± 14.37	6.69
9	MY1× CSR2 (M× H)	3.63 ± 0.14	1.95 ± 0.09	186.89 ± 10.24	5.48
10	GNP× J2 (M× L)	3.23 ± 0.13	1.88 ± 0.07	170.40 ± 7.54	4.42
11	GNP× NB4D2 (M× M)	3.28 ± 0.13	1.91 ± 0.11	169.85 ± 8.40	4.95
12	GNP× CSR2 (M× H)	3.10 ± 0.09	2.10 ± 0.07	147.74 ± 6.16	4.17
13	BL24× J2 (H× L)	3.43 ± 0.14	1.80 ± 0.07	190.36 ± 10.26	5.39
14	BL24× NB4D2 (H× M)	3.35 ± 0.13	1.76 ± 0.06	191.44 ± 10.95	5.72
15	BL24× CSR2 (H× H)	3.37 ± 0.14	1.79 ± 0.07	187.19 ± 10.94	5.84
16	BL43× J2 (H× L)	3.49 ± 0.11	1.72 ± 0.08	203.65 ± 10.78	5.29
17	BL43× NB4D2 (H× M)	3.61 ± 0.16	1.81 ± 0.09	200.91 ± 10.92	5.44
18	BL43× CSR2 (H× H)	3.46 ± 0.13	1.98 ± 0.11	175.12 ± 9.20	5.25

Values are mean±SD of 100 cocoons. L stands for low; M for medium and H for high cocoon-weighed breeds.

Discussion

In the present study, manifestation of hybrid vigour and cocoon uniformity were studied in the crosses involving low, medium and high cocoon weight polyvoltine and bivoltine silkworm breeds in order to know the level of hybrid vigour and variability in cocoon shape. It is clear from the data that among the F1 hybrids, PM× NB4D2 (L × M) showed superiority for yield / 10,000 larvae, cocoon weight, shell weight and pupal weight. Roy *et al.* (1997) have observed comparative performance of multivoltine× bivoltine and bivoltine× multivoltine hybrids during different seasons of West Bengal where they found that most of quantitative characters of multivoltine× bivoltine hybrids were found superior to bivoltine× multivoltine hybrids except for the fecundity and larval span.

Study on hybrid vigour revealed that different characters in multivoltine× bivoltine hybrids expressed positive heterosis for various economic traits. It was interesting to note that maximum total heterosis was observed in the hybrid involving low and medium cocoon- weight multi× bivoltine hybrid followed by low and low, medium and medium, low and high, high and medium silkworm breeds. Similar result was reported in the lines selected for pupal weight in the interline hybrids of the silkworm (Rajanna and Puttaraju, 1998a, b). Tayade (1987) observed high hybrid vigour for cocoon weight, cocoon shell weight and cocoon yield in F1 hybrid between Hosa Mysore and NB4D2. In another study, Singh and Rao (1996) have found high heterosis in multivoltine hybrids during favourable as well as unfavourable seasons.

Subba Rao and Sahai (1989) have found significant hybrid vigour for cocoon yield, survival rate, cocoon weight, filament length and filament size in bivoltine hybrids. Recently, Rajanna and Puttaraju (1998a, b) have studied hybrid vigour in the interline hybrids selected for pupal weight and observed positive heterosis for several quantitative characters in interline hybrids of NB18. High hybrid vigour for cocoon shell weight, cocoon weight and filament size in crosses between recessive trimoulter and tetramoulter silkworm strains was reported (Ravindra Singh *et al.*, 1990). Very high heterosis for cocoon weight and cocoon shell weight was found in F1 hybrid between low yielding multivoltine and bivoltine silkworm breeds (Rao *et al.*, 1998). Attempts have been made to study hybrid vigour in backcrosses (Singh and Hirobe, 1964; Ravindra Singh *et al.*, 1992) in three way crosses (Das *et al.*,1994), single and double crosses (Kremsky, 1983).

Study on cocoon shape variability is useful to identify suitable silkworm parents/hybrids for breeding as well as evaluation of commercial hybrids, as the uniformity in cocoon shape helps to get uniform filament size in semi automatic and automatic reeling machines (Mano, 1994). Extensive studies have been carried out on cocoon shape variation in parental silkworm breeds and their hybrids (Nakada 1989, 1994, 1998; Ravindra Singh *et al.,* 1998a).

Results of the present study give some informations to at least three areas. Firstly, it shows variability in quantitative characters and cocoon shape in F1 hybrids between low, medium and high cocoon - weighed polyvoltine and bivoltine silkworm breeds. Secondly, study on hybrid vigour demonstrated maximum total heterosis in low× medium, low× low and medium× medium cocoon weight F1 hybrids. Finally, the study of hybrid vigour and cocoon shape variability may be useful in identification of suitable parents / hybrids for breeding / commercial exploitation.

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