

Heterosis Studies in Some Elite Multivoltine Silkworm (*Bombyx mori* L.) Races with Popular Bivoltine NB₄D₂

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Ten multivoltine female parental lines were crossed with popular bivoltine male silkworm breed NB₄D₂. Three types of heterosis parameters viz., heterosis over mid-parental value (hybrid vigour), heterobeltiosis (useful heterosis) and standard heterosis (standard check) were estimated for 15 economically important quantitative traits. The interaction among the hybrids and parents indicated significant effect for maximum characters. The heterotic effect of new hybrid combination was compared with popular hybrids viz., Pure Mysore × NB₄D₂ and Nistari × NB₄D₂. Varied heterotic effect was observed for different traits for different hybrid combination. The results inferred that the crosses viz., BL₂₃ × NB₄D₂ ranked top for 14 traits followed by Hosa Mysore × NB₄D₂ for 11 traits; PA₁₂ × NB₄D₂ for 9 traits; BL₂₄ × NB₄D₂ for 8 traits; Kolar Gold × NB₄D₂ for 7 traits; WAI₁ × NB₄D₂ for 6 traits and MU₁₁ × NB₄D₂ for 5 traits. Among these, the best hybrids Kolar Gold × NB₄D₂ and MU₁₁ × NB₄D₂ were identified for longer filament length and fine denier. Similarly for higher cocoon yield and silk productivity BL₂₃ × NB₄D₂ and BL₂₄ × NB₄D₂ were found to be superior. These hybrid combinations are suitable for commercial exploitation at large scale.

Key words: Heterosis, Multivoltine, Bivoltine, Silkworm germplasm, *Bombyx mori* L.

Introduction

The successful introduction of F₁ hybrids of multivoltine female and bivoltine male silkworm strains was the major

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contributory factor for sustainable sericulture in India (Nagaraju, 2002). The tropical multivoltine silkworm races can be reared throughout the year as they have genetic adaptation to survive and reproduce even under high temperature, but which spin inferior quality silk with neatness defects. During 1960s crossbreeding programme was introduced with the objective of improving the multivoltine silkworm races (Tazima, 1959, 1988). In India at present more than 90% of the silk is produced from the polyvoltine × bivoltine hybrids, particularly Pure Mysore × NB₄D₂ and Nistari × NB₄D₂ (Govindan *et al.*, 1996; Rayar, 2001; Mal Reddy *et al.*, 2002). During the last three decades these cross combinations are being utilized for commercial production of silk in India, but the poor yarn quality and neatness defects of these cross breeds necessitates the demand for replacement of these parental lines. Subsequently, several new cross combination were tested, but due to varied technical reasons they failed. Varied silkworm germplasm stocks contribute immensely to the development of viable and hardy silkworm hybrids for commercial exploitation (Nirmal Kumar and Sreerama Reddy, 1994). Central Sericultural Germplasm Resource Centre (CSGRC), Hosur (Latitude: 12°45'N, Longitude: 77°51'E, Altitude: 942 meter above MSL) is a premier institute, which is maintaining 63 multivoltine silkworm genetic resources collected from different geographical regions possessing large amount of genetic variability, which could be exploited well for breeding programme. In the present study, ten elite multivoltine silkworm accessions reported as a best combiner and productive pure breeds (Kumaresan *et al.*, 2000, 2002) were selected as female component and crossed with well known bivoltine pure breed NB₄D₂ as a male component to exploit the hybrid vigour potential of their F₁s. The popular commercial hybrids viz., Pure Mysore × NB₄D₂ and Nistari × NB₄D₂ were considered as control to compare the heterotic effect of the new hybrid combination.

Materials and Methods

Ten elite multivoltine silkworm inbred strains considered as female parents *viz.*, Hosa Mysore, Kolar Gold, G, PA₁₂, MU₁, MU₁₁, WAI₁, MHMP (Y), BL₂₃ and BL₂₄ were crossed with male bivoltine NB₄D₂ and ten multi × bivoltine hybrid combination obtained. The crossing was done followed by a simple line × tester model. Two control hybrids *viz.*, Pure Mysore × NB₄D₂ (Check 1) and Nistari × NB₄D₂ (Check 2) were also raised simultaneously to compare the heterotic effect of new hybrid combination. Rearing of parental lines followed by hybrids along with control hybrids were undertaken during March - May, 2003 at CSGRC, Hosur. Two replications of three hundred larvae each after third moult was retained for each cross combinations. The standard rearing techniques recommended were followed (Krishnaswamy, 1978). Fifteen economically important quantitative characters *viz.*, weight of 10 matured larvae (g) (LWT), fifth age larval duration (hrs) (VLD), total larval duration (hrs) (TLD), single cocoon weight (g) (CWT), single shell weight (cg) (SWT), shell ratio (%) (SR), cocoon yield by weight (kg)/10,000 larvae (YWT), silk productivity (g/day/10,000 larvae) (SILK), cocoon length (cm) (CL), cocoon width (cm) (CW), cocoon length/width ratio (L/W), cocoon volume (cm³) (VOL), filament length (m) (FL), non-broken filament length (m) (NBF) and denier (DEN) were considered to study the heterosis following the standard procedure (Falconer, 1989; Naseema Begum *et al.*, 2002). Heterosis parameters were derived from the following formulae:

Heterosis % over Mid Parental Values (MPV)

$$= \frac{F_1 - MPV}{MPV} \times 100$$

Heterosis % over Better Parental Values (BPV) (Heterobeltiosis)

$$= \frac{F_1 - BPV}{BPV} \times 100$$

% Improvement over Control Hybrid (SH) (Standard Heterosis)

$$= \frac{F_1 - Control}{Control} \times 100$$

ANOVA was estimated for all the fifteen parameters by using the computer packages developed by Indostat Service Pvt. Ltd., Hyderabad, India. Critical differences (CD) obtained for heterosis parameters of economic traits of new hybrids were compared with control hybrids to see the significant effect of hybrid vigour. The heterosis parameters of check varieties were also compared with new hybrids to see the effect of standard heterosis. The best hybrid combination for desired parameters were eval-

uated through Evaluation Index (E.I.) method (Mano *et al.*, 1993), which was arrived at by the following formula:

$$\text{Evaluation Index (E.I.)} = \frac{A-B}{C} \times 10 + 50$$

Where, A = Mean of the particular trait for a hybrid, B = Overall mean of the particular trait (the experimental mean), C = Standard deviation, 10 = Standard and 50 = Constant. The hybrids that score index values for the traits above 50 are considered to have greater economic value.

Results and Discussion

Mean performance of parental lines and their hybrids along with check varieties for fifteen economic parameters is presented in Table 1. The pooled ANOVA revealed that the parental lines selected for the study are significantly varied for all the traits, whereas, the hybrid combination obtained have showed significant variation in cocoon quality parameters. The interaction among the hybrids and parents indicated significant effect for all the traits except for total larval duration and cocoon length/width ratio (Table 2).

In the present study, heterotic effect was observed for different traits in different hybrids, which corroborates the findings of earlier report (Gamo and Hirabayashi, 1983; Naseema Begum *et al.*, 2002). Harada (1961) found a relationship between MPV and F₁ hybrid values. Falconer (1989) stated that the genes by which two lines differ will not be the same for all pairs of lines, so different pairs of lines will have different value of MPV and will show different amount of heterosis.

The positive heterosis over mid-parental values (hybrid vigour) was obtained for different hybrids *viz.*, Hosa Mysore × NB₄D₂ for LWT, CWT, SWT and YWT; Kolar Gold × NB₄D₂ for SWT and SR; PA₁₂ × NB₄D₂ for SWT, SR and SILK; G × NB₄D₂ for SR, SILK and YWT; MU₁ × NB₄D₂ for SR and SILK; MHMP (Y) × NB₄D₂ for SR, YWT and SILK and BL₂₄ × NB₄D₂ for SR, YWT and SILK. Further, the significant improvement was noticed in the new hybrid combination when compared with the check varieties, which indicates the possibilities of replacing local varieties of female components such as Pure Mysore and Nistari with these inbreed lines. It was also recommended by the earlier report that the hybrid combination of Kolar Gold × NB₄D₂ and G × NB₄D₂ can be utilized for commercial exploitation (Tribhuwan Singh, 2001; Narayanaswamy *et al.*, 2002).

Silk productivity observed in the above hybrids has been reported as a breeding index to evaluate silkworm breeds for hybridization (Singh *et al.*, 1990; Thiagarajan

Table 1. Mean performance of parental lines and hybrids for growth and economic parameters

Parents/Hybrids	Weight of 10 matured larvae (g)	Fifth age larval duration (hrs)	Total larval duration (hrs)	Single cocoon weight (g)	Single shell weight (cg)	Shell ratio (%)	Cocoon yield by 10,000 larvae	Silk productivity (g)/day/10,000 larvae	Cocoon weight (kg)/10,000 larvae	Cocoon width (cm)	Cocoon length/width ratio	Cocoon volume (cm ³)	Filament length (m)	Non-broken filament length (m)	Denier
Hosa Mysore	27.20	138	546	1.24	19.0	15.60	12.0	310.8	3.41	1.60	2.15	5.80	514.5	435.0	2.17
Kolar Gold	31.30	136	544	1.34	19.3	14.61	12.2	291.0	3.20	1.64	1.95	5.60	548.0	448.5	1.64
G	31.85	168	576	1.29	17.8	13.91	9.4	184.9	3.01	1.70	1.80	5.42	598.0	460.0,	1.28
PA ₁₂	29.33	130	538	1.23	16.6	13.60	11.9	285.2	3.20	1.60	2.00	5.30	516.7	303.9	2.78
MU ₁	30.51	136	544	1.27	17.7	14.20	11.8	242.2	3.24	1.50	2.20	4.90	432.5	308.0	2.15
MU ₁₁	27.90	126	534	1.20	16.0	13.40	11.1	273.1	3.15	1.52	2.10	4.81	413.0	344.0	2.30
WAI ₁	27.02	147	555	1.32	19.5	14.90	13.5	303.0	3.20	1.64	1.95	5.63	440.0	300.0	2.50
MHMP(Y)	27.35	138	546	1.14	16.9	14.85	11.1	271.9	3.21	1.52	2.11	4.93	495.0	329.0	2.40
BL ₂₃	28.20	142	550	1.29	19.9	15.54	11.2	302.9	3.13	1.63	1.92	5.40	307.8	188.7	2.55
BL ₂₄	27.60	144	552	1.25	19.9	16.05	12.6	326.2	3.10	1.55	2.00	4.85	274.5	178.6	2.91
Pure Mysore	21.00	214	658	0.99	14.6	14.90	8.5	139.7	3.10	1.50	2.10	4.50	307.0	243.5	2.44
Nistari	27.32	136	544	1.16	14.3	12.50	10.0	208.9	3.60	1.43	2.51	5.00	399.0	303.0	1.91
NB ₄ D ₂	28.50	178	630	1.76	30.1	17.20	13.7	325.3	3.60	1.61	2.21	6.20	767.7	711.8	2.85
Hosa Mysore × NB ₄ D ₂	32.20	151	555	1.58	27.6	17.53	14.0	387.1	3.42	1.63	2.10	6.01	666.8	666.8	2.18
Kolar Gold × NB ₄ D ₂	30.44	166	570	1.43	27.6	19.33	9.5	281.8	3.35	1.70	2.00	6.20	752.9	752.9	1.93
G × NB ₄ D ₂	29.61	172	576	1.47	25.3	17.30	13.8	333.2	3.30	1.63	2.03	5.73	771.2	735.6	1.91
PA ₁₂ × NB ₄ D ₂	31.80	148	552	1.52	27.5	18.30	12.6	375.5	3.40	1.60	2.13	5.60	687.0	655.2	2.13
MU ₁ × NB ₄ D ₂	30.93	154	558	1.44	26.9	18.80	12.1	376.2	3.30	1.60	2.10	5.35	710.9	679.6	2.13
MU ₁₁ × NB ₄ D ₂	30.52	151	555	1.42	25.7	18.10	12.7	357.1	3.21	1.60	2.01	5.40	782.7	782.7	2.02
BL ₂₃ × NB ₄ D ₂	31.90	151	555	1.50	28.2	18.91	13.5	400.4	3.40	1.63	2.10	5.90	774.2	738.1	2.04
BL ₂₄ × NB ₄ D ₂	31.22	154	558	1.46	27.5	19.00	14.3	400.3	3.33	1.64	2.03	5.90	674.7	674.7	2.10
Pure Mysore × NB ₄ D ₂	29.00	175	579	1.47	25.7	17.51	13.9	335.8	3.32	1.65	2.02	5.92	637.8	637.8	2.01
Nistari × NB ₄ D ₂	32.70	154	558	1.52	26.2	17.32	13.5	359.5	3.41	1.60	2.20	5.70	713.3	713.3	1.98

Table 2. Analysis of variance for economic parameters and cocoon size variables of parental lines and hybrids

Source of variations	df	Weight of 10 matured larvae	Fifth age larval duration	Total larval duration	Single cocoon weight	Single shell weight	Shell ratio	Cocoon yield by weight/10,000 larvae	Silk productivity
Treatment	24	13.703***	725.020***	1507.500***	0.056***	0.0051***	8.057***	4.992***	8721.24***
Hybrids	9	1.942	139.201	139.222	0.005	0.0002**	1.044*	3.777*	2559.77
Parents	12	14.277***	1190.463***	2860.625***	0.061***	0.0031***	3.063***	4.419**	6649.57**
Hybrids vs. Parents	1	119.939***	896.929***	17.239	0.506***	0.0773***	142.072***	22.647***	101249.08***
Checks	1	13.487*	441.000*	441.000*	0.002	0.00003	0.036	0.213	559.86
Checks vs. Hybrids	1	0.821	158.687	158.5	0.001	0.0003	2.279*	2.359	612.18
Checks vs. Parents	1	26.409**	866.237**	110.7	0.181***	0.0189***	25.616***	17.655***	22791.29***
Error	24	3.083	62.447	70.287	0.003	0.0001	0.334	1.222	1590.09
Total	49	8.268	385.724	772.898	0.029	0.0025	4.114	3.055	5054.39

Source of variations	df	Cocoon length	Cocoon width	Cocoon length/width ratio	Cocoon volume	Filament length	Non-broken filament length	Denier
Treatment	24	0.104***	0.020***	0.063***	1.499***	53662.93***	85101.97***	0.2614***
Hybrids	9	0.045**	0.008*	0.004	1.057***	3664.74***	3758.98**	0.0166
Parents	12	0.129***	0.021***	0.121***	0.896***	36138.34***	39283.69***	0.4493***
Hybrids vs. Parents	1	0.518***	0.143***	0.004	15.464***	779655.13***	1423975.56***	0.5842***
Checks	1	0.0002	0.004	0.006	0.166	5698.33**	5698.33*	0.0008
Checks vs. Hybrids	1	0.007	0.013	0.008	0.879	8217.85***	2933.82	0.0169
Checks vs. Parents	1	0.098**	0.009	0.003	1.491*	157241.25***	366750.11***	0.3093**
Error	72	0.014	0.004	0.008	0.278	540.15	982.02	0.0249
Total	99	0.036	0.008	0.022	0.573	26555.59	42164.01	0.1413

***Significance at P < 0.001; **Significance at P < 0.01; *Significance at P < 0.05.

Table 3. Heterosis over mid parent, better parent and check varieties for economic parameters of different hybrid combination.

Hybrids	Weight of 10 matured larvae				Fifth age larval duration				Total larval duration			
	Heterosis(%) over				Heterosis(%) over				Heterosis(%) over			
	Mid-parent	Better-parent	Check-1	Check-2	Mid-parent	Better-parent	Check-1	Check-2	Mid-parent	Better-parent	Check-1	Check-2
Hosa Mysore × NB ₄ D ₂	15.64	13.01**	10.95	-1.52	-4.43	9.42	-13.71	-1.95	-5.61	1.65	-4.15	-0.54
Kolar Gold × NB ₄ D ₂	1.86	-2.73	4.96	-6.84	5.73	22.06*	-5.14	7.79	-2.90	4.78	-1.55	2.15
G × NB ₄ D ₂	-1.83	-7.03**	2.10	-9.37	-0.58	2.38	-1.71	11.69	-4.48	0.00	-0.52	3.23
PA ₁₂ × NB ₄ D ₂	10.02	8.40**	9.65	-2.67	-3.90	13.85	-15.43	-3.90	-5.48	2.60	-4.66	-1.08
MU ₁ × NB ₄ D ₂	4.89	1.38	6.67	-5.32	-1.91	13.24	-12.00	0.00	-4.94	2.57	-3.63	0.00
MU ₁₁ × NB ₄ D ₂	8.33	7.19**	5.25	-6.58	-0.66	19.84*	-13.71	-1.95	-4.64	3.93	-4.15	-0.54
WAI ₁ × NB ₄ D ₂	18.88	15.84**	13.74	0.96	2.15	12.93	-5.14	7.79	-3.80	2.70	-1.55	2.15
MHMP (Y) × NB ₄ D ₂	13.84	11.59**	9.56	-2.75	3.16	18.12*	-6.86	5.84	-3.57	3.85	-2.07	1.61
BL ₂₃ × NB ₄ D ₂	12.50	11.95**	9.91	-2.44	-5.63	6.34	-13.71	-1.95	-5.93	0.91	-4.15	-0.54
BL ₂₄ × NB ₄ D ₂	11.37	9.66**	7.66	-4.44	-4.35	6.94	-12.00	0.00	-5.58	1.09	-3.63	0.00
Pure Mysore × NB ₄ D ₂ \$	17.24	1.85		-11.24	-10.71	-1.69		13.64	-10.09	-8.10		3.76
Nistari × NB ₄ D ₂ \$\$	17.11	14.75	12.66		-1.91	13.24	-12.00		-4.94	2.57	-3.63	
Hybrids	Single cocoon weight (Average)				Single shell weight (Average)				Shell ratio (Average)			
	Heterosis(%) over				Heterosis(%) over				Heterosis(%) over			
	Mid-parent	Better-parent	Check-1	Check-2	Mid-parent	Better-parent	Check-1	Check-2	Mid-parent	Better-parent	Check-1	Check-2
Hosa Mysore × NB ₄ D ₂	5.60##	-10.20	7.68##	4.28**	12.42	-8.31	7.39##	5.34**	6.97	2.06#	0.08	1.18
Kolar Gold × NB ₄ D ₂	-7.58**##	-18.82**##	-2.65	-5.73**	11.74	-8.31	7.39##	5.34**	21.67***##	12.59***##	10.40##	11.62**
G × NB ₄ D ₂	-3.96	-16.89**##	-0.34	-3.49**	5.64	-15.95**##	-1.56	-3.44**	11.21**	0.65	-1.30	-0.22
PA ₁₂ × NB ₄ D ₂	1.27	-14.06##	3.06	-0.20	17.77**	-8.64	7.00##	4.96**	19.03***##	6.50***##	4.43##	5.58**
MU ₁ × NB ₄ D ₂	-5.27##	-18.54**##	-2.31	-5.4**	12.55	-10.63	4.67##	2.67**	19.94***##	9.42***##	7.30##	8.48**
MU ₁₁ × NB ₄ D ₂	-4.04##	-19.27***##	-3.20	-6.25**	11.50	-14.62##	0.00	-1.91	18.59***##	5.42***##	3.37##	4.50**
WAI ₁ × NB ₄ D ₂	-1.33	-13.83	3.33	0.07	7.26	-11.63	3.50##	1.53	9.31	2.03	0.05	1.14
MHMP (Y) × NB ₄ D ₂	0.00	-17.69***##	-1.29	-4.41**	8.94	-14.95**	-0.39	-2.29**	10.67**	3.19##	1.19	2.30*
BL ₂₃ × NB ₄ D ₂	-1.90	-15.19##	1.70	-1.51	12.80	-6.31	9.73##	7.63**	15.61**	10.12***##	7.98##	9.16**
BL ₂₄ × NB ₄ D ₂	-3.35	-17.35***##	-0.88	-4.02**	10.00	-8.64	7.00##	4.96**	14.16**	10.42***##	8.27##	9.46**
Pure Mysore × NB ₄ D ₂ \$	6.90	-16.61	-3.16	14.99	-14.62		-1.91	9.25		1.98		1.10
Nistari × NB ₄ D ₂ \$\$	3.93	-13.89	3.26		18.02	-12.96	1.95		16.75	0.87	-1.09	

Table 3. continued.

Hybrids	Cocoon yield by weight/10,000 larvae				Silk productivity				Cocoon length			
	Heterosis(%) over				Heterosis(%) over				Heterosis(%) over			
	Mid-parent	Better-parent	Check-1	Check-2	Mid-parent	Better-parent	Check-1	Check-2	Mid-parent	Better-parent	Check-1	Check-2
Hosa Mysore × NB ₄ D ₂	9.32	2.60	0.49	3.93	21.73	19.02	15.29	7.70	-2.11**	-4.20	2.83##	0.29
Kolar Gold × NB ₄ D ₂	-26.70##	-30.67***##	-32.09##	-29.77**	-8.55	-13.36	-16.08	-21.61	-0.73**	-6.03##	0.87	-1.61
G × NB ₄ D ₂	19.08##	0.73	-1.34	2.04	30.65	2.46	-0.76	-7.29	0.33**	-7.48**##	-0.69	-3.14**
PA ₁₂ × NB ₄ D ₂	-1.35	-7.62**##	-9.52##	-6.42*	23.03	15.46	11.84	4.48	-0.24*	-5.66##	1.26	-1.23
MU ₁ × NB ₄ D ₂	-4.91	-11.41***##	-13.23##	-10.26**	32.59	15.66	12.03	4.66	-4.18**	-8.55**##	-1.84	-4.25**
MU ₁₁ × NB ₄ D ₂	2.51	-6.96**##	-8.88##	-5.75*	19.37	9.80	6.36	-0.64	-4.27**	-9.89**##	-3.28##	-5.66**
WAJ ₁ × NB ₄ D ₂	-4.23	-4.91##	-6.87##	-3.67	11.14	7.33	3.96	-2.88	3.13**	-2.13	5.05##	2.46
MHMP (Y) × NB ₄ D ₂	7.03	-3.02	-5.02	-1.76	17.56	7.92	4.53	-2.35	0.89**	-4.18	2.86##	0.32
BL ₂₃ × NB ₄ D ₂	8.40	-1.22	-3.25	0.07	27.48	23.10	19.23	11.38	0.21*	-5.91##	0.99	-1.50
BL ₂₄ × NB ₄ D ₂	9.30	4.93##	2.77	6.29*	22.89	22.72	19.21	11.36	0.23*	-6.70##	0.15	-2.32
Pure Mysore × NB ₄ D ₂ ^s	25.89	2.10		3.43	44.44	3.24		-6.58	-0.06	-6.84		-2.46
Nistari × NB ₄ D ₂ ^{ss}	14.16	-1.28	-3.31		34.58	10.51	7.05		-4.70	-4.91	2.53	
Cocoon width												
Hybrids	Heterosis(%) over				Cocoon length/width ratio				Cocoon volume			
	Mid-parent	Better-parent	Check-1	Check-2	Mid-parent	Better-parent	Check-1	Check-2	Mid-parent	Better-parent	Check-1	Check-2
	Mid-parent	Better-parent	Check-1	Check-2	Mid-parent	Better-parent	Check-1	Check-2	Mid-parent	Better-parent	Check-1	Check-2
Hosa Mysore × NB ₄ D ₂	0.71	-0.79**	-1.21	2.84	-3.58	-4.98	4.11	-2.55	0.43	-3.00	1.52	6.11**
Kolar Gold × NB ₄ D ₂	2.44	2.32**	1.88	6.06**	-3.99	-9.63**	-0.99	-7.33**	5.49##	0.03	4.69	9.42**
G × NB ₄ D ₂	-1.99	-2.99**	-1.40	2.65	1.40	-8.05	0.74	-5.71	-1.42	-7.65**	-3.34	1.02
PA ₁₂ × NB ₄ D ₂	-2.22	-3.60**	-4.00	-0.06	1.26	-3.71	5.50	-1.25	-2.47##	-9.60**##	-5.39##	-1.11
MU ₁ × NB ₄ D ₂	0.29	-3.90**##	-4.31##	-0.38	-5.13	-6.24	2.73	-3.85	-3.31##	-13.63**##	-9.61##	-5.52**
MU ₁₁ × NB ₄ D ₂	0.98	-2.62**	-3.03	0.95	-6.00*	-8.91**	-0.20	-6.59**	-1.97#	-12.94**##	-8.88##	-4.76
WAJ ₁ × NB ₄ D ₂	3.20##	3.17**	2.79	7.01**	-0.77	-6.60	2.33	-4.22	11.63**##	6.50**	11.46##	16.50**
MHMP (Y) × NB ₄ D ₂	0.32	-3.29**	-3.70	0.25	-0.21	-2.49	6.84	0.00	3.03##	-7.55**	-3.24	1.13
BL ₂₃ × NB ₄ D ₂	-0.24	-0.55**	-0.97	3.10	-0.31	-6.83	2.08	-4.45	1.66	-4.90	-0.47	4.02
BL ₂₄ × NB ₄ D ₂	2.69	0.00	-0.42	3.66	-3.10	-8.23	0.55	-5.89	6.44##	-5.10**	-0.68	3.81
Pure Mysore × NB ₄ D ₂ ^s	5.44	0.43		4.11	-5.88	-8.73		-6.40	10.72	-4.45		4.52
Nistari × NB ₄ D ₂ ^{ss}	3.06	-3.53	-3.94		-8.59	-13.97	6.84		1.29	-8.58	-4.32	

Table 3. continued.

Hybrids	Filament length				Non-broken filament length				Denier			
	Heterosis(%) over				Heterosis(%) over				Heterosis(%) over			
	Mid-parent	Better-parent	Check-1	Check-2	Mid-parent	Better-parent	Check-1	Check-2	Mid-parent	Better-parent	Check-1	Check-2
Hosa Mysore × NB ₄ D ₂	4.02	-13.13	4.55	-6.51	16.30	-6.31	4.55	-6.51	-13.26***##	0.46##	8.05	9.63
Kolar Gold × NB ₄ D ₂	14.45	-1.92	18.04	5.55	29.78	5.78	18.04	5.55	-13.85***##	17.93	-3.92	-2.52
G × NB ₄ D ₂	12.94	0.46	20.91	8.12	25.55	3.35	15.33	3.12	-7.506***##	49.22	-5.12	-3.73
PA ₁₂ × NB ₄ D ₂	6.98	-11.74	7.71	-3.69	29.02	-7.94	2.73	-8.15	-24.44	-23.49	5.66	7.21
MU ₁ × NB ₄ D ₂	18.48	-7.39	11.47	-0.33	33.82	-4.52	6.55	-4.73	-14.88***##	-1.02***##	5.71	7.26
MU ₁₁ × NB ₄ D ₂	32.59	1.96	22.72	9.73	48.28	9.97	22.72	9.73	-21.36**	-11.95**	0.60	2.07
WAI ₁ × NB ₄ D ₂	19.76	-5.80	13.38	1.38	36.53	-2.96	8.29	-3.17	-19.40**	-13.76**	7.10	8.67
MHMP (Y) × NB ₄ D ₂	12.22	-7.71	11.08	-0.68	29.89	-5.04	5.97	-5.24	-19.77**	-12.25**	4.62	6.15
BL ₂₃ × NB ₄ D ₂	43.97	0.85	21.38	8.53	63.94	3.70	15.72	3.48	-24.37	-19.84	1.34	2.82
BL ₂₄ × NB ₄ D ₂	29.49	-12.11	5.79	-5.41	51.56	-5.20	5.79	-5.41	-27.16	-26.46	4.12	5.65
Pure Mysore × NB ₄ D ₂ ^s	18.70	-16.91	-10.58	33.54	-10.39	-	-	-10.58	-23.82	-17.33	1.46	
Nistari × NB ₄ D ₂ ^{ss}	22.28	-7.08	11.84	40.59	0.22	11.84	-	-	-16.64	3.87	-1.44	

^sindicate Check 1; ^{ss}indicate Check 2.

**Significance at 1% and *Significance at 5% level against Check 1.

#Significance at 1% and ##Significance at 5% level against Check 2.

et al., 1993). Further, the desirable negative heterosis was observed in all the hybrids for TLD and VLD. The filament length showed very high hybrid vigour, which ranged from 18 to 44% for five hybrids viz., MU₁ × NB₄D₂, MU₁₁ × NB₄D₂, WAI₁ × NB₄D₂, BL₂₃ × NB₄D₂ and BL₂₄ × NB₄D₂. Similarly, almost all the hybrids showed high level of hybrid vigour (16 to 64%) for non-broken filament length. The denier exhibited desirable negative heterosis for all the hybrids, and most of them have shown better values over either of the check varieties. Significant heterotic effect was recorded for cocoon volume in case of Kolar Gold × NB₄D₂, WAI₁ × NB₄D₂, MHMP (Y) × NB₄D₂ and BL₂₄ × NB₄D₂ hybrids.

Most of the hybrids for one or more characters recorded positive heterobeltiotic effect. The hybrid Kolar Gold × NB₄D₂ has showed more heterobeltiosis for CWT, VLD, SR, VOL, NBF; MU₁₁ × NB₄D₂ for CWT, VLD, SWT, NBF

and DEN; MHMP (Y) × NB₄D₂ has showed improvement for LWT, VLD and DEN. Similarly, the silk productivity has showed positively in the combination of BL₂₄ × NB₄D₂. The considerable amount of heterosis over BPV for the cocoon volume has been exhibited by almost all the hybrids and that are better than either of the check varieties.

Among the three types of heterosis, as far as breeders are concerned, standard heterosis (SH) is more important since the hybrids to be released are expected to out perform the superior local variety or hybrid (standard check). The results indicated that the hybrids Kolar Gold × NB₄D₂, PA₁₂ × NB₄D₂, MU₁ × NB₄D₂, BL₂₃ × NB₄D₂ and BL₂₄ × NB₄D₂ have showed significantly higher value for SH for SWT and SR over either of the check varieties. The hybrid BL₂₃ × NB₄D₂ has showed 6.29% SH for YWT while BL₂₄ × NB₄D₂ exhibited higher SH for silk productivity. Fur-

Table 4. Evaluation index values (E.I.) for the economic characters of different hybrid combination.

Hybrids	Weight of 10 matured larval larvae	Fifth age larval duration	Total larval duration	Single cocoon weight	Single shell weight	Shell ratio	Cocoon yield by weight/10,000 larvae	Silk productivity
Hosa Mysore × NB ₄ D ₂	57.70	41.55	41.55	71.80	59.41	42.10	57.80	58.50
Kolar Gold × NB ₄ D ₂	43.25	57.90	57.90	39.50	58.90	66.83	22.54	26.75
G × NB ₄ D ₂	36.35	64.44	64.44	46.80	35.72	38.74	55.80	42.30
PA ₁₂ × NB ₄ D ₂	54.60	38.30	38.30	57.43	58.40	52.50	46.94	55.01
MU ₁ × NB ₄ D ₂	47.40	44.82	44.82	40.53	51.85	59.40	42.93	55.21
MU ₁₁ × NB ₄ D ₂	43.94	41.55	41.55	37.80	39.75	49.95	47.64	49.50
WAI ₁ × NB ₄ D ₂	64.42	57.90	57.90	58.28	48.82	42.00	49.81	47.04
MHMP (Y) × NB ₄ D ₂	54.34	54.63	54.63	43.83	38.80	44.72	51.80	47.62
BL ₂₃ × NB ₄ D ₂	55.20	41.55	41.55	53.07	64.95	61.01	53.72	62.50
BL ₂₄ × NB ₄ D ₂	49.80	44.82	44.82	45.10	58.40	61.72	60.22	62.50
Pure Mysore × NB ₄ D ₂	31.30	67.71	67.71	47.87	39.75	41.90	57.23	43.03
Nistari × NB ₄ D ₂	61.83	44.82	44.82	58.07	45.30	39.25	53.65	50.20
Hybrids	Cocoon length	Cocoon width	Cocoon length/width ratio	Cocoon volume	Filament length	Non-broken filament length	Denier	Average E.I. value
Hosa Mysore × NB ₄ D ₂	58.52	51.30	55.70	55.24	39.15	42.40	63.50	53.10
Kolar Gold × NB ₄ D ₂	50.00	64.50	37.12	60.72	57.80	62.00	35.73	49.42
G × NB ₄ D ₂	43.05	50.70	43.42	46.90	61.75	58.03	33.00	48.10
PA ₁₂ × NB ₄ D ₂	51.60	39.60	60.83	43.33	43.51	39.74	57.94	49.20
MU ₁ × NB ₄ D ₂	38.00	38.14	50.62	36.05	48.70	45.30	58.11	46.80
MU ₁₁ × NB ₄ D ₂	31.52	43.52	39.90	37.30	64.25	68.80	46.20	45.54
WAI ₁ × NB ₄ D ₂	68.40	68.30	49.20	72.42	51.35	47.82	61.32	56.33
MHMP (Y) × NB ₄ D ₂	58.61	40.81	65.80	47.03	48.20	44.45	55.60	50.05
BL ₂₃ × NB ₄ D ₂	50.44	52.30	48.40	51.81	62.40	58.61	47.94	53.70
BL ₂₄ × NB ₄ D ₂	46.72	54.80	42.80	51.50	40.90	44.20	54.40	50.83
Pure Mysore × NB ₄ D ₂	46.10	56.47	40.70	52.63	32.90	35.80	44.81	47.05
Nistari × NB ₄ D ₂	57.20	39.70	65.71	45.20	49.21	53.00	41.53	50.00

ther, the cocoon volume indicated higher SH in case of WAI₁ × NB₄D₂. The filament length and non-broken filament length have showed more SH in case of Kolar Gold × NB₄D₂, G × NB₄D₂, MU₁₁ × NB₄D₂ and BL₂₃ × NB₄D₂. The denier exhibited negative SH for Kolar Gold × NB₄D₂ and G × NB₄D₂ (Table 3).

The mean data obtained in all the hybrid combinations were subjected to multiple traits evaluation index (Mano *et al.*, 1993), which is the standard method to select the best hybrid combination based on single or multiple traits. The result inferred that the crosses viz., BL₂₃ × NB₄D₂ ranked best for 14 traits followed by Hosa Mysore × NB₄D₂ (11 traits); PA₁₂ × NB₄D₂ (9 traits); BL₂₄ × NB₄D₂ (8 traits); Kolar Gold × NB₄D₂ (7 traits); WAI₁ × NB₄D₂ (6 traits) and MU₁₁ × NB₄D₂ (5 traits) (Table 4). Among these best hybrids Kolar Gold × NB₄D₂ and MU₁₁ × NB₄D₂ were identified for longer filament length and fine denier. Similarly, for higher cocoon yield and silk productivity BL₂₃ × NB₄D₂ and BL₂₄ × NB₄D₂ were found to be the superior. Vidyumalala *et al.* (1998) has also confirmed that BL₂₄ × NB₄D₂ is the best hybrid suited for commercial exploitation. For higher cocoon volume the combination of WAI₁ × NB₄D₂ was found to have greater hybrid vigour. These hybrid combinations may be utilized for the commercial exploitation at large scale after further evaluation of multi-locational trial.

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