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ANALYSIS OF HETEROSIS IN NEW DOUBLE HYBRID COMBINATIONS IN BIVOLTINE SILKWORM, *Bombyx mori.* L.

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ABSTRACT
Bivoltine Silkworm double hybrids are expected to possess additional genetic plasticity to buffer against deleterious effects of highly fluctuating ambient conditions prevailing in tropical country like India. The Phenomena of Heterosis and its utility in silkworm breeding studies are widely popular and the estimates of heterosis over mid parent and better parent values are immensely useful in measuring the genetic potential of any silkworm combination. Utilising ten new bivoltine breeds developed in a breeding study, twenty one foundation crosses were made in a selective fashion and a concise study on estimation of heterosis was taken up with short-listed six foundation crosses and nine double hybrid combinations, to measure heterosis over mid parent and better parent. The study taken up reveals that positive heterosis and heterobeltiosis, in ten double hybrids subjected was mainly restricted to few traits such as fecundity (6.48 and 1.95) and cocoon weight (3.60 and 2.88) and both heterosis and heterobeltiosis on all the traits of fibre quality such as filament length, filament size, raw silk, reelability and neatness were only in decrement. However, a new double hybrid (SLD2 x SLD4) x (SLD8 x SLD9) has shown desirable manifestation of heterosis in nine out of thirteen traits and heterobeltiosis in seven out of thirteen traits taken up for the study, which may be attributed to better genetic advancement obtained in the breeding study.

KEY WORDS: Double hybrids, Heterosis, Heterobeltiosis.

INTRODUCTION

Double hybrids of bivoltine silkworm are essentially preferred to overcome deleterious environmental effect expected in widely varying agro-climatic conditions. India, being a tropical country poses such challenges to any agricultural avocation in abundance, having wide fluctuations in ambient environmental conditions during different seasons in an year and sericultural farmers often requires a silkworm variety or hybrid, which can possess inherent buffer potential to mitigate such challenges.

Heterosis, expressed as the improvement in a character shown by a hybrid over their mid or better parental value, is a vital measure of genetic progress made in plant and animal selection (Talebi, E and G.Subramanya, 2009). It is widely exploited for development of hybrid varieties in many crop and animal species (Falconer, 1981; Stuber, 1994; Nagaraju, 2002;Tayade, 1987). Heterosis breeding has been recognized as the most suitable breeding methodology for augumenting yield in Silkworm. The required goals of increasing productivity in the quickest possible time can be achieved only through heterosis breeding, which is a regular practice in this crop. The magnitude of heterosis in different cross combination is a basic requisite for identifying crosses that exhibit high amount of exploitable heterosis (Nirmal kumar, et al., 2010, 2011). Therefore, a concise study has been taken up to measure the extent of heterosis expected in double hybrids of bivoltine silkworm and thereby to assess their utility to encounter such challenges in raising commercial cocoon crops.

MATERIALS AND METHODS

Ten bivoltine breeds developed from a new breeding study completed at Satellite Silkworm Breeding Station, Coonoor, viz., SLD1, SLD2, SLD3, SLD4 (Spin oval or Chinese type cocoons), SLD5, SLD6, SLD7, SLD8, SLD9, SLD 10 (Spin dumbbell or Japanese type cocoons) were utilized for the study. These four oval breeds were crossed among them in a selective fashion as also, the six dumbbell breeds, to six oval foundation crosses and fifteen dumbbell foundation crosses, avoiding reciprocals. Thus, obtained twenty one foundation crosses were reared along with one each oval (CSR 2 x CSR 27) and dumbbell combination (CSR6 x CSR26) of ruling double hybrid, "Krishnaraja" in three replicates. Six foundation crosses, three each oval and dumbbell, were short-listed based on the consideration of multiple trait evaluation index suggested by Mano, *et al* (1993). Utilizing these six foundation crosses, nine double hybrid combinations were obtained again in a selective fashion, avoiding reciprocals. Standard rearing technology for rearing bivoltine silkworm (Datta, 1992) was followed. Observations on thirteen parameters covering pre-cocoon, cocoon and post-cocoon spheres such as fecundity, total larval duration, pupation rate, cocoon yield per 10000 larvae, cocoon weight, cocoon shell weight, shell percentage, average filament length, filament size, raw silk content, renditta, reelability and neatness were recorded.

The heterosis (H%) and hetero-beltiosis (HB%) were measured as the proportion of increment or decrement from the value of mid parent and better parents in various traits.

$$\text{Heterosis (H\%)} = \frac{\text{Hybrid value of a trait} - \text{Mid parent value (MPV) of a trait}}{\text{Mid parent value (MPV) of a trait}} \times 100$$

$$\text{Hetero-beltiosis (HB\%)} = \frac{\text{Hybrid value of a trait} - \text{Better parent value (BPV) of a trait}}{\text{Better parent value (BPV) of a trait}} \times 100$$

MPV = Mean of parent 1and 2

BPV= Better parent value

To ascertain the significance level between the hybrid combinations, CD (Critical Difference) was computed. CD = SE (Standard Error) x F-value at 5%.

To estimate the variation among the hybrids, CV (Co-efficient of Variation) was computed.

RESULTS

Performance of twenty one new foundation crosses along with two controls and the performance of nine new double hybrids along with a ruling hybrid (Krishnaraja) as control were presented in Table-1 and Table-2. Heterosis and heterobeltiosis estimates on nine double hybrids along with the control hybrid were presented in Table-3 and Table-4.

Fecundity

The magnitude of heterosis ranged from 4.24 in (CSR2xCSR27) x (CSR6 x CSR26) to 9.91 in (SLD2 x SLD4) x (SLD8x SLD9). Mean heterosis for fecundity in ten double hybrid combinations studied was 6.48.

The magnitude of heterobeltiosis ranged from -0.37 in (SLD1 x SLD2) x (SLD5 x SLD9) to 3.89 in (SLD2 x SLD4) x (SLD8x SLD9). Mean heterobetiosis for fecundity in ten double hybrid combinations studied was 1.95.

Larval Duration

The magnitude of heterosis ranged from -0.49 in (SLD2 x SLD4) x (SLD8x SLD9) to 6.38 in (SLD3 x SLD4) x (SLD5 x SLD9). Mean heterosis for larval duration in ten double hybrid combinations studied was 4.47.

The magnitude of heterobetiosis ranged from -0.39 in (SLD2 x SLD4) x (SLD8x SLD9) to 6.48 in (SLD2 x SLD4) x (SLD5 x SLD9). Mean heterobetiosis for larval duration in ten double hybrid combinations studied was 4.80.

Pupation rate (%)

The magnitude of heterosis ranged from -0.49 in (SLD2 x SLD4) x (SLD8x SLD9) to 6.38 in (SLD3 x SLD4) x (SLD5 x SLD9). Mean heterosis for pupation rate in ten double hybrid combinations studied was 4.47.

The magnitude of heterobeltiosis ranged from -3.98 in (SLD3 x SLD4) x (SLD8x SLD9) to 0.35 in (SLD2 x SLD4) x (SLD8 x SLD9). Mean heterobetiosis for pupation rate in ten double hybrid combinations studied was -2.00.

Yield per 10000 larvae (Kgs)

The magnitude of heterosis ranged from -7.18 in (SLD3 x SLD4) x (SLD9x SLD10) to 12.44 in (SLD2 x SLD4) x (SLD8 x SLD9). Mean heterosis for yield per 10000 larvae in ten double hybrid combinations studied was -1.02.

The magnitude of heterobeltiosis ranged from -7.69 in (SLD3 x SLD4) x (SLD9x SLD10) to 12.07 in (SLD2 x SLD4) x (SLD8 x SLD9). Mean heterobeltiosis for yield per 10000 larvae in ten double hybrid combinations studied was -2.00.

Cocoon weight

The magnitude of heterosis ranged from 0.17 in (SLD2 x SLD4) x (SLD9x SLD10) to 10.67 in (SLD2 x SLD4) x (SLD8 x SLD9). Mean heterosis for cocoon weight in ten double hybrid combinations studied was 3.60.

The magnitude of heterosis ranged from -0.50 in (SLD3 x SLD4) x (SLD5x SLD9) to 9.70 in (SLD2 x SLD4) x (SLD8 x SLD9). Mean heterobeltiosis for cocoon weight in ten double hybrid combinations studied was 2.88.

Shell weight

The magnitude of heterosis ranged from -7.33 in (SLD3 x SLD4) x (SLD9x SLD10) to 10.26 in (SLD2 x SLD4) x (SLD8 x SLD9). Mean heterosis for shell weight in ten double hybrid combinations studied was -0.87.

The magnitude of heterobetiosis ranged from -8.41 in (SLD3 x SLD4) x (SLD9x SLD10) to 8.71 in (SLD2 x SLD4) x (SLD8 x SLD9). Mean heterobeltiosis for shell weight in ten double hybrid combinations studied was -2.10.

Shell %

The magnitude of heterosis ranged from -7.54 in (SLD3 x SLD4) x (SLD8x SLD9) to 2.29 in (CSR2 x CSR27) x (CSR6 x CSR26). Mean heterosis for shell % in ten double hybrid combinations studied was -4.34.

The magnitude of heterobeltiosis ranged from -8.90 in (SLD3 x SLD4) x (SLD9x SLD10) to 1.13 in (CSR2 x CSR27) x (CSR6 x CSR26). Mean heterosis for shell % in ten double hybrid combinations studied was -5.14.

Average Filament Length

The magnitude of heterosis ranged from -12.18 in (SLD2 x SLD4) x (SLD5x SLD9) to 0.48 in (CSR2 x CSR27) x (CSR6 x CSR26). Mean heterosis for average filament length in ten double hybrid combinations studied was -7.92.

The magnitude of heterobeltiosis ranged from -13.62 in (SLD3 x SLD4) x (SLD9x SLD10) to -0.09 in (CSR2 x CSR27) x (CSR6 x CSR26). Mean heterobeltiosis for average filament length in ten double hybrid combinations studied was -9.21.

Filament Size

The magnitude of heterosis ranged from 1.98 in (SLD2 x SLD4) x (SLD8x SLD9) to 17.07 in (SLD1 x SLD2) x (SLD5 x SLD9). Mean heterosis for filament size in ten double hybrid combinations studied was 12.35.

The magnitude of heterobeltiosis ranged from 1.57 in (SLD2 x SLD4) x (SLD8x SLD9) to 18.03 in (SLD1 x SLD2) x (SLD5 x SLD9). Mean heterobeltiosis for filament size in ten double hybrid combinations studied was 13.19.

TABLE-1. Performance of new foundation crosses.

Sl No	Breed	Fecundity	LD (D:Hrs)	Pupation Rate	Yield/ 10000 larvae (kgs)	CW (g)	SW (g)	Shell (%)	Filament Length (m)	Filament Size	Raw Silk (%)	Renditta	Reel-ability (%)	Neat-ness (pts)
1	**SLD 1 x SLD2**	**544**	**21.06**	**9564**	**18.373**	**1.807**	**0.415**	**23.0**	**1095**	**2.44**	**18.3**	**5.46**	**85.0**	**94**
2	SLD 1 x SLD3	512	22.05	9028	15.893	1.606	0.328	20.4	1012	2.75	17.4	6.28	82.0	91
3	SLD 1 x SLD4	508	22.12	9254	15.947	1.634	0.348	21.3	1005	2.74	17.0	5.84	81.0	91
4	SLD 2 x SLD3	522	22.04	9135	15.573	1.571	0.325	20.7	1008	2.84	17.1	6.32	83.0	92
5	**SLD 2 x SLD4**	**566**	**21.05**	**9724**	**17.987**	**1.825**	**0.425**	**23.3**	**1125**	**2.58**	**18.1**	**5.23**	**86.0**	**93**
6	**SLD3 x SLD4**	**532**	**21.05**	**9652**	**18.654**	**1.817**	**0.418**	**23.0**	**1145**	**2.52**	**18.7**	**5.63**	**85.0**	**93**
7	SLD5 x SLD6	498	22.12	9321	16.64	1.593	0.345	21.7	960	2.92	17.3	5.85	81.0	91
8	SLD5 x SLD7	472	22.05	9254	17.227	1.586	0.348	21.9	1012	2.88	17.4	5.74	81.0	91
9	SLD5 x SLD8	512	22.12	9256	15.627	1.523	0.323	21.2	998	2.95	17.7	6.36	81.0	92
10	**SLD5 x SLD9**	**496**	**21.06**	**9568**	**17.854**	**1.785**	**0.408**	**22.9**	**1158**	**2.48**	**18.4**	**5.32**	**86.0**	**94**
11	SLD5 x SLD10	472	22.14	9154	15.624	1.807	0.397	22.0	998	2.84	17.3	5.86	81.0	92
12	SLD6 x SLD7	454	22.15	9237	15.398	1.606	0.354	22.0	1012	2.94	17.6	5.51	82.0	92
13	SLD6 x SLD8	478	22.12	9156	15.695	1.634	0.348	21.3	1026	2.77	17.1	5.84	81.0	92
14	SLD6 x SLD9	462	22.04	9265	15.752	1.571	0.325	20.7	1030	2.83	17.3	6.23	83.0	92
15	SLD6 x SLD10	442	22.14	9342	16.864	1.61	0.344	21.4	953	2.78	17.1	5.84	81.0	91
16	SLD7 x SLD8	482	22.15	9141	15.317	1.636	0.352	21.5	1024	2.65	17.4	5.63	83.0	91
17	SLD7 x SLD9	498	22.01	9189	15.864	1.523	0.348	22.8	1025	2.85	17.7	5.86	81.0	92
18	SLD7 x SLD10	476	22.05	9321	16.854	1.586	0.358	22.6	1054	2.95	17.4	5.77	81.0	91
19	**SLD8 x SLD9**	**504**	**21.04**	**9541**	**17.867**	**1.793**	**0.414**	**23.1**	**1160**	**2.54**	**18.7**	**5.28**	**85.0**	**94**
20	SLD8 x SLD10	470	22.12	9245	17.125	1.618	0.335	20.7	958	2.94	16.5	6.18	81.0	92
21	**SLD9 x SLD10**	**492**	**21.08**	**9587**	**18.451**	**1.804**	**0.428**	**23.7**	**1095**	**2.54**	**18.4**	**5.46**	**85.0**	**94**
22	CSR2 x CSR27	552	22.10	9356	17.545	1.785	0.395	22.1	1056	2.65	18.0	5.78	83.0	93
23	CSR6 x CSR26	534	22.20	9257	17.456	1.738	0.375	21.6	1045	2.71	17.8	5.95	82.0	92
	Mean	499	22.02	9328	16.765	1.672	0.368	22.0	1041	2.74	17.6	5.79	82.6	92
	CD 5%	13.66	0.06	79.28	0.47	0.05	0.02	0.40	25.97	0.07	0.24	0.14	0.77	0.45
	CV%	6.32	2.56	1.96	6.43	6.21	9.58	4.21	5.76	5.85	3.18	5.56	2.16	1.14

LD = Larval Duration, CW= Coccon weight, SW= Shell weight.

TABLE-2. Performance of new double hybrids.

Sl No	Hybrid	Fecundity	LD (D:Hrs)	Pup. Rate	Yld/ 10000 Larvae (kgs)	CW (g)	SW (g)	Shell (%)	Fil. Length (m)	Fil. Size	Raw Silk (%)	Renditta	Reel-ability (%)	Neat. (Pts)
1	(SLD 1 x SLD2) x (SLD5 x SLD9)	542	22.08	9254	17.580	1.887	0.402	21.30	1054	2.88	17.40	6.54	81.0	92
2	(SLD 1 x SLD2) x (SLD8 x SLD9)	566	22.12	9358	17.114	1.824	0.406	22.26	1008	2.85	17.60	6.28	82.0	91
3	(SLD 1 x SLD2) x (SLD9 x SLD10)	548	22.08	9462	18.240	1.915	0.422	22.04	1005	2.87	17.50	5.84	81.0	91
4	(SLD2 x SLD4) x (SLD5 x SLD9)	562	22.14	9358	17.240	1.842	0.408	22.15	1002	2.78	17.14	6.32	83.0	92
5	**(SLD2 x SLD4) x (SLD8 x SLD9)**	**588**	**21.10**	**9758**	**20.158**	**2.002**	**0.462**	**23.08**	**1125**	**2.58**	**18.80**	**5.23**	**86.0**	**94**
6	(SLD2 x SLD4) x (SLD9 x SLD10)	570	22.05	9368	18.654	1.817	0.406	22.34	1002	2.79	17.80	5.63	85.0	92
7	(SLD3 x SLD4) x (SLD5 x SLD9)	548	22.16	9432	17.540	1.808	0.388	21.46	1054	2.91	17.40	5.85	81.0	91
8	(SLD3 x SLD4) x (SLD8 x SLD9)	556	22.10	9268	17.857	1.886	0.404	21.42	1025	2.86	17.39	5.74	81.0	91
9	(SLD3 x SLD4) x (SLD9 x SLD10)	538	22.12	9345	17.220	1.816	0.392	21.59	989	2.91	17.68	6.36	81.0	92
10	(CSR2 x CSR27) x (CSR6 x CSR26)	566	22.20	9245	17.760	1.857	0.415	22.35	1055	2.95	18.00	5.45	83.0	92
	Mean	558	22.09	9385	17.936	1.865	0.411	22.00	1032	2.84	17.7	5.92	82.4	92
	CD 5%	11	0.07	113	0.69	0.05	0.02	0.42	31	0.08	0.35	0.33	1.39	0.69
	CV %	2.70	1.71	1.59	5.10	3.22	5.02	2.52	3.98	3.69	2.63	7.32	2.23	1.00

LD = Larval Duration, CW= Coccon weight, SW= Shell weight

TABLE-3. Estimates of Heterosis on various economic traits in new double hybrid combinations.

Sl No	Combination	Fec	LD (D:Hrs)	Pup. Rate	Yield/ 10000 Larvae(Kgs)	CW (g)	SW (g)	Shell (%)	Fil Length(m)	Fil Size	Raw Silk(%)	Rend. itta	Reel. (%)	Neat. (Pts)
1	(SLD 1 x SLD2) x (SLD5 x SLD9)	4.23	5.10	-3.26	-2.94	5.07	-2.19	-7.19	-6.39	17.07	-5.18	21.34	-5.26	-2.13
2	(SLD 1 x SLD2) x (SLD8 x SLD9)	8.02	6.09	-2.03	-5.55	1.33	-1.93	-3.43	-10.56	14.46	-4.86	16.95	-3.53	-3.19
3	(SLD 1 x SLD2) x (SLD9 x SLD10)	5.79	4.89	-1.18	-0.93	6.09	0.24	-5.61	-8.22	15.26	-4.63	6.96	-4.71	-3.19
4	(SLD2 x SLD4) x (SLD5 x SLD9)	5.84	6.38	-2.99	-3.79	2.05	-1.92	-4.11	-12.18	9.88	-6.08	19.92	-3.49	-1.60
5	**(SLD2 x SLD4) x (SLD8 x SLD9)**	**9.91**	**-0.49**	**1.31**	**12.44**	**10.67**	**10.26**	**0.13**	**-1.49**	**1.98**	**2.17**	**-0.38**	**0.58**	**0.53**
6	(SLD2 x SLD4) x (SLD9 x SLD10)	7.75	4.41	-2.97	2.40	0.17	-4.69	-4.33	-9.73	10.28	-2.47	5.43	-0.58	-1.60
7	(SLD3 x SLD4) x (SLD5 x SLD9)	6.61	6.77	-1.85	-3.91	0.39	-6.05	-6.49	-8.43	16.40	-6.20	6.95	-5.26	-2.67
8	(SLD3 x SLD4) x (SLD8 x SLD9)	7.34	4.03	-3.42	-2.21	4.49	-2.88	-7.07	-11.02	13.04	-7.01	5.32	-4.71	-2.67
9	(SLD3 x SLD4) x (SLD9 x SLD10)	5.08	5.78	-2.85	-7.18	0.33	-7.33	-7.54	-11.70	15.02	-4.69	14.80	-4.71	-1.60
10	(CSR2 x CSR27) x (CSR6 x CSR26)	4.24	1.76	0.66	1.49	5.45	7.79	2.29	0.48	10.07	0.56	-7.00	0.61	-0.54
	Mean	6.48	4.47	-1.86	-1.02	3.60	-0.87	-4.34	-7.92	12.35	-3.84	9.03	-3.11	-1.87
	CD 5%	1.17	1.61	1.13	3.95	2.39	4.06	2.24	3.06	3.00	2.14	5.75	1.62	0.84
	CV%	25.12	50.31	-85.31	-542.71	92.73	-651	-72.09	-53.92	33.91	-77.7	88.93	-72.7	-63.1

TABLE-4. Estimates of Heterobeltosis on various economic traits in new double hybrid combinations

Sl No	Combination	Fec	LD (D:Hrs)	Pup. Rate	Yield/ 10000 Larvae(kgs)	CW (g)	SW (g)	Shell (%)	Fil Length(m)	Fil Size	Raw Silk(%)	Rend.	Reel (%)	Neat. (Pts)
1	(SLD 1 x SLD2) x (SLD5 x SLD9)	-0.37	5.10	-3.28	-4.32	4.43	-3.13	-7.39	-8.98	18.03	-5.43	22.93	-5.81	-2.13
2	(SLD 1 x SLD2) x (SLD8 x SLD9)	4.04	6.30	-2.15	-6.85	0.94	-2.17	-3.64	-13.10	16.80	-5.88	18.94	-3.53	-3.19
3	(SLD 1 x SLD2) x (SLD9 x SLD10)	0.74	5.10	-1.30	-1.14	5.98	-1.40	-7.00	-8.22	17.62	-4.89	6.96	-4.71	-3.19
4	(SLD2 x SLD4) x (SLD5 x SLD9)	-0.71	6.48	-3.76	-4.15	0.93	-4.00	-4.94	-13.47	12.10	-6.85	20.84	-3.49	-2.13
5	**(SLD2 x SLD4) x (SLD8 x SLD9)**	**3.89**	**-0.39**	**0.35**	**12.07**	**9.70**	**8.71**	**-0.94**	**-3.02**	**1.57**	**0.53**	**0.00**	**0.00**	**0.00**
6	(SLD2 x SLD4) x (SLD9 x SLD10)	0.71	4.72	-3.66	1.10	-0.44	-5.14	-5.74	-10.93	8.14	-3.26	7.65	-1.16	-2.13
7	(SLD3 x SLD4) x (SLD5 x SLD9)	3.01	6.88	-2.28	-5.97	-0.50	-7.18	-6.70	-8.98	17.34	-6.95	9.96	-5.81	-3.19
8	(SLD3 x SLD4) x (SLD8 x SLD9)	4.51	4.13	-3.98	-4.27	3.80	-3.35	-7.27	-11.64	13.49	-7.01	8.71	-4.71	-3.19
9	(SLD3 x SLD4) x (SLD9 x SLD10)	1.13	6.09	-3.18	-7.69	-0.06	-8.41	-8.90	-13.62	15.48	-5.45	16.48	-4.71	-2.13
10	(CSR2 x CSR27) x (CSR6 x CSR26)	2.54	3.59	-1.19	1.23	4.03	5.06	1.13	-0.09	11.32	0.00	-5.71	0.00	-1.08
	Mean	1.95	4.80	-2.44	-2.00	2.88	-2.10	-5.14	-9.21	13.19	-4.52	10.68	-3.39	-2.24
	CD 5%	1.23	1.51	0.98	4.13	2.35	3.76	2.18	3.24	3.52	1.97	5.85	1.48	0.75
	CV%	87.83	43.92	-55.9	-288.6	113.78	-250.1	-59.33	-49.14	37.32	-60.7	76.49	-60.9	-47.1

TABLE-5. Character wise expression of heterosis in double hybrid combinations

Heterosis	Fecundity	Larval duration	Pupation rate	Yield/ 10000 larvae	Coccon weight	Shell weight	Shell %	Filament length	Filament size	Raw silk	Renditta	Reel ability	Neatness
Over MPV	6.48	4.47	-1.86	-1.02	3.60	-0.87	-4.34	-7.92	12.35	-3.84	9.03	-3.11	-1.87
Over BPV	1.95	4.80	-2.44	-2.00	2.88	-2.10	-5.14	-9.21	13.19	-4.52	10.68	-3.39	-2.24

Raw Silk content

The magnitude of heterosis ranged from -7.01 in (SLD3 x SLD4) x (SLD8x SLD9) to 2.17 in (SLD2 x SLD4) x (SLD8 x SLD9). Mean heterosis for raw silk content in ten double hybrid combinations studied was -3.84.

The magnitude of heterobeltiosis ranged from -7.01 in (SLD3 x SLD4) x (SLD8x SLD9) to 0.53 in (SLD2 x SLD4) x (SLD8 x SLD9). Mean heterosis for raw silk content in ten double hybrid combinations studied was -4.52.

Renditta

The magnitude of heterosis ranged from -7.00 in (CSR2 x CSR27) x (CSR6x CSR26) to 21.34 in (SLD1 x SLD4) x (SLD5 x SLD9). Mean heterosis for renditta in ten double hybrid combinations studied was 9.03.

The magnitude of heterobeltiosis ranged from -5.71 in (CSR2 x CSR27) x (CSR6x CSR26) to 22.93 in (SLD1 x SLD4) x (SLD5 x SLD9). Mean heterobeltiosis for renditta in ten double hybrid combinations studied was 10.68.

Reelability %

The magnitude of heterosis ranged from -5.26 in (SLD1 x SLD2) x (SLD5x SLD9) and (SLD3 x SLD4) x (SLD5 x SLD9) to 0.61 in (CSR2 x CSR27) x (CSR6 x CSR26). Mean heterosis for reelability in ten double hybrid combinations studied was -3.11.

The magnitude of heterobeltiosis ranged from -5.81 in (SLD1 x SLD2) x (SLD5x SLD9) and (SLD3 x SLD4) x (SLD5 x SLD9) to 0.00 in (SLD2 x SLD4) x (SLD8 x SLD9) and (CSR2 x CSR27) x (CSR6 x CSR26). Mean heterobeltiosis for reelability in ten double hybrid combinations studied was -3.39.

Neatness

The magnitude of heterosis ranged from -2.67 in (SLD3 x SLD4) x (SLD8x SLD9) and (SLD3 x SLD4) x (SLD5 x SLD9) to 0.53 in (SLD2 x SLD4) x (SLD8 x SLD9). Mean heterosis for neatness in ten double hybrid combinations studied was -1.87.

The magnitude of heterobeltiosis ranged from -3.19 in (SLD1 x SLD2) x (SLD8x SLD9) (SLD1 x SLD2) x (SLD9x SLD10) (SLD3 x SLD4) x (SLD5x SLD9) and (SLD3 x SLD4) x (SLD8x SLD9) to 0.00 in (SLD2 x SLD4) x (SLD8 x SLD9). Mean heterobeltiosis for neatness in ten double hybrid combinations studied was -2.24.

TABLE-6.Top two superior double hybrids in terms of heterosis for various characters

Traits	Heterosis over mid parent		Heterosis over better parent	
	Hybrid	Value	Hybrid	Value
Fecundity	(SLD2xSLD4)x(SLD8xSLD9)	9.91	(SLD3xSLD4)x(SLD8xSLD9)	4.51
	(SLD1xSLD2)x(SLD8xSLD9)	8.02	(SLD1xSLD2)x(SLD8xSLD9)	4.04
Larval Duration	(SLD2xSLD4)x(SLD8xSLD9)	-0.49	(SLD2xSLD4)x(SLD8xSLD9)	-0.39
	(CSR2xCSR27)x(CSR6xCSR26)	1.76	(CSR2xCSR27)x(CSR6xCSR26)	3.59
Pupation Rate	(SLD2xSLD4)x(SLD8xSLD9)	1.31	(SLD2xSLD4)x(SLD8xSLD9)	-0.35
	(CSR2xCSR27)x(CSR6xCSR26)	0.66	(CSR2xCSR27)x(CSR6xCSR26)	-1.19
Yield per 10000 larvae	(SLD2xSLD4)x(SLD8xSLD9)	12.44	(SLD2xSLD4)x(SLD8xSLD9)	12.07
	(CSR2xCSR27)x(CSR6xCSR26)	1.49	(CSR2xCSR27)x(CSR6xCSR26)	1.23
Cocoon weight	(SLD2xSLD4)x(SLD8xSLD9)	10.67	(SLD2xSLD4)x(SLD8xSLD9)	9.70
	(SLD1xSLD2)x(SLD9xSLD10)	6.09	(SLD1xSLD2)x(SLD9xSLD10)	5.98
Shell Weight	(SLD2xSLD4)x(SLD8xSLD9)	10.26	(SLD2xSLD4)x(SLD8xSLD9)	8.71
	(CSR2xCSR27)x(CSR6xCSR26)	7.79	(CSR2xCSR27)x(CSR6xCSR26)	5.06
Shell %	(CSR2xCSR27)x(CSR6xCSR26)	2.29	(CSR2xCSR27)x(CSR6xCSR26)	1.13
	(SLD2xSLD4)x(SLD8xSLD9)	0.13	(SLD2xSLD4)x(SLD8xSLD9)	-0.94
Filament Length	(CSR2xCSR27)x(CSR6xCSR26)	0.48	(CSR2xCSR27)x(CSR6xCSR26)	-0.09
	(SLD2xSLD4)x(SLD8xSLD9)	-1.49	(SLD2xSLD4)x(SLD8xSLD9)	-3.02
Filament Size	(SLD2xSLD4)x(SLD8xSLD9)	1.98	(SLD2xSLD4)x(SLD8xSLD9)	1.57
	(SLD2xSLD4)x(SLD5xSLD9)	9.88	(SLD2xSLD4)x(SLD9xSLD10)	8.14
Raw Silk	(SLD2xSLD4)x(SLD8xSLD9)	2.17	(SLD2xSLD4)x(SLD8xSLD9)	1.57
	(CSR2xCSR27)x(CSR6xCSR26)	0.56	(CSR2xCSR27)x(CSR6xCSR26)	0.00
Renditta	(CSR2xCSR27)x(CSR6xCSR26)	-7.00	(CSR2xCSR27)x(CSR6xCSR26)	-5.71
	(SLD2xSLD4)x(SLD8xSLD9)	-0.38	(SLD2xSLD4)x(SLD8xSLD9)	0.00
Reelability	(CSR2xCSR27)x(CSR6xCSR26)	0.61	(SLD2xSLD4)x(SLD8xSLD9)	0.00
	(SLD2xSLD4)x(SLD8xSLD9)	0.58	(CSR2xCSR27)x(CSR6xCSR26)	0.00
Neatness	(SLD2xSLD4)x(SLD8xSLD9)	0.53	(SLD2xSLD4)x(SLD8xSLD9)	0.00
	(CSR2xCSR27)x(CSR6xCSR26)	-0.54	(CSR2xCSR27)x(CSR6xCSR26)	-1.08

DISCUSSION

Estimation of heterosis in any breeding programmes is an essential measure to make decision on the selection of superior combination. It brings out status of genetic expression manifested in a given environment and also, a general understanding on the genetic potential of parental materials utilized. The study taken up reveals that heterosis and heterobeltiosis, in ten double hybrids subjected was mainly restricted to few traits such as fecundity and cocoon weight (Table-5), wherein manifestation was found to be in desired path of improvement. Subba rao and Sahai (1989) also, reported on high level of heterosis for cocoon yield, followed by cocoon weight. Harada (1961) reported high heterosis in cocoon shell weight, followed by cocoon weight, survival rate and filament length.

However, heterosis on eleven traits considered in the present study fell in decrement path, which is understandable as the manifestation of hybrid vigour was already exploited in parental combination while effecting the foundation crosses (Table-1). Hirobe (1957) also, reported that when the improvement of particular trait is high in parental materials, the magnitude of heterosis declines in the hybrids.

Further, it is noticeable that both heterosis and heterobeltiosis on all the traits of fibre quality such as filament length, filament size, raw silk, reelability and neatness were only in decrement in double hybrids. Therefore, it could be derived that positive manifestation of heterosis may not be expected and it is advisable to utilize parental materials possessing appropriate degree of trait in targeted level especially on fibre merits whereas amalgamation of other traits can be attempted in developing new double hybrids.

However, the manifestation of heterosis may be differing on the extent of genetic advancement and the distance achieved in new genetic materials in a breeding study as it is seen that a new double hybrid (SLD2 x SLD4) x (SLD8 x SLD9) has shown desirable manifestation of heterosis in nine out of thirteen traits and heterobeltiosis in seven out of thirteen traits taken up for the study (Table-6). This is in agreement of observation that manifestation of heterosis differ widely and such differences suggests that parental materials involved differ in their genetic makeup (Gamo and Hirabayshi, 1983; Tayade, 1987; Sathenhalli et al., 1989) and the high degree of heterosis in this specific cross can be due to due to additive gene effects as observed by Rao, et, 1998 and Udupa, S and V.Gowda, 1988. The control hybrid, (CSR2 x CSR27) x (CSR6 x CSR26),“Krishnaraja”, has secured top rank in three out of thirteen traits in heterosis and two out of thirteen in heterobeltiosis and second rank in six each traits in heterosis and heterobeltiosis, has clearly brings out the fact that status of genetic potential is fair and prominent in many traits and any improvement over this combination will only be marginal. Further, securing second or top rank in three each traits in terms of heterosis and heterobeltiosis by other hybrid combinations brings out that manifestation of heterosis or hybrid vigour depends on appropriate genetic constellation required for every trait and “doctoring” a genetic constellation of desirable extent in all traits of interest remains still at large.

However, the new bivoltine silkworm double hybrid, (SLD2 x SLD4) x (SLD8 x SLD9) developed in a breeding study, shows good promise as evidenced from this heterosis study, having secured top ranking in nine and seven out of thirteen traits covered over pre-cocoon, cocoon and post-cocoon spheres in terms of heterosis and heterobeltiosis.

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