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Genetic Manifestation of Hybrid Vigor in Cross Breeds of Mulberry Silkworm, *Bombyx mori* L.

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Abstract: The genetic manifestation of hybrid vigor among newly developed silkworm hybrid combinations over the parents was analyzed for the identification of superior cross breeds. Ten homozygous inbred polyvoltine breeds as Lines viz., APMG1, APMG2, APMG3, APMG4, APMW1, APMW2, APMW3, APMW4, APMW5 and APMW6 and three bivoltine breeds as Tester viz., APS8, APS12 and APS45 were used for the study. Adopting the Line×Tester method, thirty hybrid combinations were prepared and reared at standard conditions. The data was measured on the nine important genetic traits viz., fecundity, yield per 10,000 larvae, pupation%, cocoon weight, shell weight, shell ratio%, filament length, reliability and neatness%. The data was analyzed for their Mid Parent Heterosis (MPH) and Better Parent Heterosis (BPH), six hybrid combinations viz., APMG1×APS8, APMG1×APS45, APMG3×APS12, APMW1×APS8, APMW2×APS8 and APMW4×APS45 were shown as significant heterotic combinations over mid parents for all the economical traits studied. The hybrid combination, APMW2×APS45 with seven traits and APMG1×APS8, APMG1×APS12, APMG3×APS12, APMW1×APS8 and APMW1×APS8 exhibited positive heterosis for six out of nine traits over better parent heterosis. Further, based on the evaluation index the study sturdily demonstrate that two new hybrid combinations viz., APMW1×APS8 (59.58) and APMG1×APS8 (58.68) were adjudicated as superior heterotic hybrid combinations and recommended for large scale laboratory trial.

Key words: Silkworm, performance, mid parent heterosis, better parent heterosis, evaluation index

INTRODUCTION

The silkworm, *Bombyx mori* L. is an important economic insect and also a tool to convert mulberry leaf protein into silk. Industrial and commercial use of silk, the historical and economic importance of production and its application in all over the world finely contributed to the silkworm promotion as a powerful laboratory model for the basic research in biology (Ramesh-Babu *et al*., 2009). The success of silkworm breeding depends on the ability of the

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breeder to assemble and recombine the genetic variability to isolate the potential combiner from the genetic resource material based on the expression of the various qualitative and quantitative traits over generations. In silkworm, majority of the characters that contribute to the yield of silk are under the control of polygenic nature. Developing of potential hybrid required for the field has become a very difficult task to silkworm breeders. In spite of continuous efforts for the development of sericulture through various conventional silkworm breeding programs; still there is a demand for productive superior hybrids to fulfill the needs of sericulture industry. In consideration of the crop stability and adaptability to fluctuating environmental conditions, development of productively and qualitatively superior cross breed varieties is necessary.

The purpose of hybrid preparation is to produce a heterotic effect rather than to provide genetic variation and also to provide the productive hybrid for commercial exploitation. In the tropical countries like Indian sericulture, the hybrid comprises female of polyvoltine with male of bivoltine are successfully exploited commercially as a cross breed. As a result, nearly 90% of the total silk produced is derived from the polyvoltine cross breeds (polyvoltine×bivoltine) in India (Umadevi *et al*., 2005). In this context, some of the silkworm breeders have made successful attempts in the identification of new productively superior cross breed varieties (Datta, 1984; Nagaraju *et al*., 1996; Rao *et al*., 2004; Lakshmi *et al*., 2008). So, there is an immediate need to identify productively superior silkworm hybrids for reliable crops and for sustainability of sericulture industry in the country.

The various attempts were made earlier by the silkworm breeders in manifestation of hybrid vigor by adopting the combining ability studies or Line×Tester analysis methods (Bhargava *et al*., 1993; Datta *et al*., 2001; Rao *et al*., 2004). The silkworm breeder has to give due consideration on the performance of all quantitative and qualitative parameters of hybrid combinations while evaluating the silkworm hybrids for its commercial exploitation. Keeping the objectives in view, the present study was aimed to identify the potential cross breeds (poly×bivoltine) based on their performance, heterosis and evaluation index methods.

MATERIALS AND METHODS

Parental Silkworm Breeds

For the present study ten polyvoltine breeds as Line viz., APMG1, APMG2, APMG3, APMG4, APMW1, APMW2, APMW3, APMW4, APMW5, APMW6 and three bivoltine breeds as Tester *viz.,* APS8, APS12 and APS45 were drawn and the experiment was carried out during January, 2007 to February, 2008 in the Silkworm Breeding and Molecular Genetics Laboratory, Andhra Pradesh State Sericulture Research and Development Institute (APSSRDI), Hindupur, India. By crossing the polyvoltine female and bivoltine male parents, thirty silkworm hybrid combinations were prepared. The mother moth examination for hybrid as well as parental layings was carried out to confirm the pebrine free infection.

Silkworm Rearing

The disease free layings of parents and hybrid combinations were incubated in a well disinfected rearing house after surface disinfection with the 2% formalin solution. After hatching, the larvae were brushed on the freshly chopped mulberry leaf and reared under standard rearing conditions. The chawkie silkworm larvae (young silkworm larvae up to 3rd instar) were reared at the temperature of 26-28°C with a Relative Humidity (RH) of 85-90%. After resuming from the 3rd moult, 300 larvae were retained in each bed with three replications for all hybrid combinations and parental breeds. The late age rearing was maintained at 24-26°C with a relative humidity of 65-75% as suggested by Datta (1992). The data pertaining to the nine important genetic traits viz., fecundity, yield per 10,000 larvae, pupation%, cocoon weight, shell weight, shell ratio%, filament length, reliability and neatness% were pooled and analyzed to asses the hybrid performance. The analysis of hybrid combinations was carried out on the mean values of parental breeds with their hybrid combinations. The genetic manifestation of hybrid vigor was carried out as percentage of increase among hybrid combinations (F_1) over the mid parent and better parent performance on the genetic traits with assistance of statistical analysis.

Statistical Methods Adopted for Hybrid Vigor Manifestation

Mid Parent Heterosis (MPH) and Better Parent Heterosis (BPH) are calibrated as per the procedure adopted by Bhargava *et al*. (1993). The percent of MPH and BPH with respect to a particular trait was calculated as below:

$$\text{Mid parent heterosis (MPH)} = 100\,(A-B)/B$$

$$\text{Better parent heterosis (BPH)} = 100\,(A-C)/C$$

Where:
A = Actual performance of the hybrid
B = Mean performance of the female and male parents
C = Performance of better parent

Multiple Evaluation Index

The promising hybrid combinations were identified based on the average values of multiple Evaluation Index (EI) method (Mano *et al*., 1993). The hybrid combinations were adjudicated as promising based on the average values obtained for the genetic traits on multiple evaluation index values were calculated with the assistance of the following formula.

$$\text{Evaluation index (EI)} = \frac{A-B}{C} \times 10 + 50$$

Where:
A = Value obtained for a trait for the hybrid
B = Overall mean of particular trait
C = Standard deviation
10 = Standard unit
50 = Fixed value

RESULTS AND DISCUSSION

Performance of the Polyvoltine (Line)

The rearing performance on the nine genetical traits for parental breeds pertaining to the ten polyvoltine (Line) and three bivoltine (Tester), utilized for the development of superior cross breed. Among the polyvoltine parents, highest fecundity (number of eggs per brood) recorded for the APMW5 (501) and lowest was in APMW2 (478) with the average of 489 eggs per brood. The cocoon yield per 10,000 larvae by weight varied between 12.699 kg (APMW6) to 14.000 kg (APMW3) with an average yield of 13.539 kg. The average pupation rate recorded was 93.53% with the maximum of 95.33% (APMW1) and minimum of 88.90%

(APMW6). Average of 1.418 g was recorded for single cocoon weight with the highest of 1.445 g (APMW3) and lowest of 1.395 g (APMW4). With regard to shell weight, the average was recorded 0.239 g with the maximum of 0.255 g (APMW3) and minimum of 0.228 g (APMW1). Maximum filament length was recorded in APMW3 (825 mts.) and minimum in APMW1 (711). The average reliability was observed 74.1% with the highest of 77% (APMG3) and lowest of 71% (APMW1). Highest neatness was recorded in APMG4 (82%) and lowest in APMW5 (70%) with an average of 77% (Table 1).

Performance of the Bivoltine (Tester)

Among the bivoltine testers, the highest fecundity was recorded in APS8 (511) and lowest in APS45 (499). For the trait cocoon yield per 10,000 larvae by weight, ranged between 16.954 kg (APS45) to 17.854 kg (APS8) was revealed. The average pupation rate was recorded 87.17%. The highest single cocoon weight was recorded in APS8 (1.885 g) followed by APS12 (1.879 g) and APS45 (1.865). With regard to shell weight, the average was recorded 0.363 g with the maximum of 0.368 g (APS12) and minimum of 0.358 g (APS45). Maximum filament length in APS12 (904 mts.) and minimum in APS45 (886 mts.) was recorded. The highest neatness in APS8 (89%) and lowest in APS45 (87%) was disclosed (Table 1).

Performance of the Hybrid Combinations

The silkworm rearing performance on economical traits among new silkworm hybrid combinations, number of eggs per brood ranged between 451 (APMG4×APS12) to 521(APMG3×APS45) with an average of 489 (Table 2). With regard to cocoon weight per 10,000 larvae by weight varied between 15.130 kg (APMG2×APS12) to 19.483 kg (APMW2×APS45). The pupation rate differs from 90.00 (APMW3×APS12) to 95.84% (APMW6×APS12) with an average of 93.89%. The highest single cocoon weight was observed in APMW1×APS8 (2.004 g) and lowest in APMG4×APS8 (1.645 g). Average shell ratio was observed 18.95% with the highest of 20.37% in APMG4×APS12 and lowest of 17.42% in APMG4×APS45. The maximum filament length was observed in APMG3×APS12 (978 mts.) and minimum in APMG2×APS8 (745 mts.).

Manifestation of Hybrid Vigor

Six hybrids viz., APMG1×APS8, APMG1×APS45, APMG3 ×APS12, APMW1×APS8, APMW2×APS8 and APMW4×APS45 were established as good heterotic combinations with significant hybrid vigor over mid parents for all the economic characters studied. High heterotic effect for fecundity (5.57%) was shown by APMG3×APS45 followed by

Table 1: Mean rearing performance on the genetic traits for the lines and testers

Breed	Fecundity (No.)	Yield/10,000 larvae (kg)	Pupation rate (%)	Cocoon weight (g)	Shell weight (g)	Shell ratio (%)	Filament length (mts)	Reliability (%)	Neatness (%)
Polyvoltine parents (Lines)									
APMG1	484	13.451	94.00	1.421	0.244	17.17	721	74	78
APMG2	479	13.624	94.44	1.434	0.240	16.74	745	75	80
APMG3	488	13.412	94.00	1.408	0.241	17.12	812	77	77
APMG4	496	13.820	94.11	1.412	0.239	16.93	768	73	82
APMW1	495	13.025	95.33	1.399	0.228	16.30	711	71	80
APMW2	478	13.827	94.00	1.439	0.237	16.47	734	74	78
APMW3	491	14.000	92.00	1.445	0.255	17.65	825	74	76
APMW4	483	13.854	95.00	1.395	0.235	16.85	775	76	72
APMW5	501	13.680	93.50	1.405	0.229	16.30	781	75	70
APMW6	490	12.699	88.90	1.423	0.241	16.94	820	72	73
Bivoltine parents (Testers)									
APS8	511	17.854	86.00	1.885	0.362	19.20	895	84	89
APS12	507	17.025	88.00	1.879	0.368	19.58	904	82	88
APS45	499	16.954	87.50	1.865	0.358	19.20	886	85	87

Table 2: Mean rearing performance on the genetic traits of new silkworm hybrid combinations

Hybrid combinations	Fecundity (No.)	Yield/10,000 larvae (kg)	Pupation rate (%)	Cocoon weight (g)	Shell weight (g)	Shell ratio (%)	Filament length (mts)	Reliability (%)	Neatness (%)
APMG1×APS8	512	16.546	94.00	1.958	0.377	19.25	941	91.00	90
APMG1×APS12	474	17.460	94.13	1.845	0.369	20.00	955	84.50	86
APMG1×APS45	497	18.630	93.50	1.958	0.360	18.39	870	87.10	88
APMG2×APS8	470	15.440	94.10	1.710	0.325	19.01	745	95.00	85
APMG2×APS12	489	15.130	95.00	1.689	0.338	20.01	901	89.00	88
APMG2×APS45	481	18.680	94.31	1.995	0.362	18.15	758	87.00	86
APMG3×APS8	458	16.261	94.90	1.742	0.342	19.63	888	86.00	91
APMG3×APS12	510	18.432	93.12	1.980	0.370	18.69	978	84.12	87
APMG3×APS45	521	16.497	94.33	1.765	0.345	19.55	825	87.52	80
APMG4×APS8	463	15.470	93.87	1.645	0.333	20.24	936	89.17	81
APMG4×APS12	451	15.841	94.40	1.689	0.344	20.37	785	80.14	88
APMG4×APS45	499	18.897	92.40	1.980	0.345	17.42	796	85.19	86
APMW1×APS8	504	18.181	95.33	2.004	0.389	19.41	944	86.00	86
APMW1×APS12	487	17.002	94.13	1.840	0.339	18.42	950	87.52	77
APMW1×APS45	495	17.691	94.40	1.868	0.358	19.16	955	80.00	76
APMW2×APS8	521	18.201	94.93	1.910	0.366	19.16	881	84.96	85
APMW2×APS12	501	17.419	94.40	1.850	0.338	18.27	847	87.65	76
APMW2×APS45	487	19.483	94.67	1.997	0.371	18.58	948	88.51	75
APMW3×APS8	518	15.383	90.53	1.721	0.345	20.05	865	89.00	78
APMW3×APS12	459	16.160	90.00	1.710	0.328	19.18	812	88.56	81
APMW3×APS45	476	17.730	92.40	1.860	0.339	18.23	825	83.20	82
APMW4×APS8	485	15.374	92.13	1.680	0.320	19.05	935	86.40	79
APMW4×APS12	499	16.856	93.00	1.789	0.325	18.17	912	91.12	87
APMW4×APS45	492	19.400	93.58	1.857	0.351	18.90	859	84.00	82
APMW5×APS8	495	16.322	94.19	1.741	0.330	18.95	881	87.15	87
APMW5×APS12	479	15.485	94.90	1.647	0.309	18.76	901	85.41	76
APMW5×APS45	486	17.755	94.80	1.901	0.350	18.41	921	83.42	75
APMW6×APS8	487	16.715	94.00	1.792	0.340	18.97	859	87.56	88
APMW6×APS12	475	17.006	95.84	1.788	0.330	18.46	914	82.00	88
APMW6×APS45	501	17.470	95.40	1.850	0.329	17.78	854	90.14	87

APMW2×APS8 (5.36). The significant hybrid vigor was found to exhibit in APMW2×APS45 (26.59%) for the cocoon yield per 10,000 larvae followed by APMW4×APS45 (25.94%), APMG4×APS45 (22.81%). Five hybrid combinations were found to exhibit negative heterosis for yield. For the trait pupation, all the hybrid combinations showed positive heterosis with maximum of 8.36% in APMW6×APS12, followed by APMW6×APS45 (8.16%). Maximum heterosis of 22.05% was observed for the single cocoon weight in APMW1×APS8 followed by APMW2×APS45 (22.08%). The highest of 31.86% for shell weight was observed in APMW1×APS8 followed by APMW2×APS45 (24.71%) and in all the hybrids positive heterosis was observed. Maximum of 19.60% heterosis was observed in APMW1×APS45 for the filament length. With regard to reliability maximum of 19.50% was observed in APMG2×APS8 and for the neat ness maximum of 9.64% (APMG3×APS8) heterosis was observed over mid parent (Table 3).

The hybrid combination, APMW2×APS45 was exhibited significant hybrid vigor over better parent for seven out of nine characters studied (Table 4). Some of the hybrids viz., APMG1×APS8, APMG1×APS12, APMG3×APS12, APMW1×APS8 and APMW1×APS8 exhibited positive heterosis for 9 out of 9 traits over better parent heterosis. Maximum significant hybrid vigor over better parent was found to be exhibit in APMG3×APS45 (4.41%) for the fecundity, yield per 10,000 larvae by weight in APMW2×APS45 (14.92), pupation rate in APMW6×APS12 (7.81), single cocoon weight in APMW2×APS45 (7.08%), shell weight in APMW1×APS8 (7.46%), shell ratio in APMG4×APS8 (5.41%), filament length in APMG3×APS12 (8.19%), reliability in APMG2×APS8 (13.10%) and neatness in APMG3×APS8 (2.25%).

Table 3: Manifestation of hybrid vigor in the new hybrid combinations over the mid parent

Hybrid combinations	Fecundity	Yield/10,000 larvae	Pupation rate	Cocoon weight	Shell weight	Shell ratio	Filament length	Reliability	Neatness
APMG1×APS8	2.91	5.71	4.44	18.45	24.42	5.87	16.46	15.19	7.78
APMG1×APS12	-4.34	14.58	3.44	11.82	20.59	8.83	17.54	8.33	3.61
APMG1×APS45	1.12	22.55	3.03	19.17	19.60	1.12	8.28	9.56	6.67
APMG2×APS8	-5.05	-1.90	4.30	3.04	7.97	5.76	-9.15	19.50	0.59
APMG2×APS12	-0.81	-1.27	4.14	1.96	11.18	10.19	9.28	13.38	4.76
APMG2×APS45	-1.64	22.18	3.67	20.95	21.07	1.00	-7.05	8.75	2.99
APMG3×APS8	-8.31	4.02	5.44	5.80	13.43	8.11	4.04	6.83	9.64
APMG3×APS12	2.51	21.12	2.33	20.47	21.51	1.83	13.99	5.81	5.45
APMG3×APS45	5.57	8.65	3.94	7.85	15.19	7.66	-2.83	8.05	-2.44
APMG4×APS8	-8.04	-2.32	4.24	-0.21	10.82	12.06	12.57	13.59	-5.26
APMG4×APS12	-10.07	2.71	3.67	2.64	13.34	11.57	-6.10	3.41	3.53
APMG4×APS45	0.30	22.81	1.76	20.84	15.58	-3.53	-3.75	7.84	1.78
APMW1×APS8	0.20	17.76	5.15	22.05	31.86	9.35	17.56	10.97	2.08
APMW1×APS12	-2.79	13.16	2.69	12.26	13.76	2.69	17.65	14.41	-8.06
APMW1×APS45	-0.40	18.02	3.27	14.46	22.18	7.99	19.60	2.56	-8.71
APMW2×APS8	5.36	14.90	5.48	14.92	22.20	7.43	8.16	7.54	2.10
APMW2×APS12	1.73	12.92	3.74	11.51	11.74	1.35	3.42	12.37	-8.16
APMW2×APS45	-0.31	26.59	4.32	20.88	24.71	4.18	17.04	11.33	-8.81
APMW3×APS8	3.39	-3.42	1.72	3.36	11.83	8.80	0.58	12.66	-5.45
APMW3×APS12	-8.02	4.17	0.00	2.89	5.30	3.04	-6.07	13.54	-1.22
APMW3×APS45	-3.84	14.56	2.95	12.39	10.60	-1.06	-3.57	4.65	0.61
APMW4×APS8	-2.41	-3.03	1.80	2.44	7.20	5.67	11.98	8.00	-1.86
APMW4×APS12	0.81	9.17	1.64	9.29	7.79	-0.27	8.64	15.34	8.75
APMW4×APS45	0.20	25.94	2.55	13.93	18.38	4.89	3.43	4.35	3.14
APMW5×APS8	-2.17	3.52	4.95	5.84	11.68	6.78	5.13	9.62	9.43
APMW5×APS12	-4.96	0.86	4.57	0.30	3.52	4.57	6.94	8.80	-3.80
APMW5×APS45	-2.80	15.92	4.75	16.27	19.25	3.74	10.50	4.28	-4.46
APMW6×APS8	-2.70	9.42	7.49	8.34	12.77	5.00	0.17	12.26	8.64
APMW6×APS12	-4.71	14.43	8.36	8.30	8.37	1.07	6.03	6.49	9.32
APMW6×APS45	1.31	17.83	8.16	12.53	7.17	-1.56	0.12	14.83	8.75

Table 4: Manifestation of hybrid vigor in the new hybrid combinations over the better parent

Hybrid combinations	Fecundity	Yield/10,000 larvae	Pupation rate	Cocoon weight	Shell weight	Shell ratio	Filament length	Reliability	Neatness
APMG1×APS8	0.20	-7.33	0.00	3.87	4.14	0.26	5.14	8.33	1.12
APMG1×APS12	-6.51	2.56	0.14	-1.81	0.27	2.12	5.64	3.05	-2.27
APMG1×APS45	-0.40	9.89	-0.53	4.99	0.56	-4.22	-1.81	2.47	1.15
APMG2×APS8	-8.02	-13.52	-0.36	-9.28	-10.22	-1.03	-16.76	13.10	-4.49
APMG2×APS12	-3.55	-11.13	0.59	-10.11	-8.15	2.18	-0.33	8.54	0.00
APMG2×APS45	-3.61	10.18	-0.14	6.97	1.12	-5.47	-14.45	2.35	-1.15
APMG3×APS8	-10.37	-8.92	0.96	-7.59	-5.52	2.23	-0.78	2.38	2.25
APMG3×APS12	0.59	8.26	-0.94	5.42	0.54	-4.59	8.19	2.59	-1.14
APMG3×APS45	4.41	-2.70	0.35	-5.36	-3.63	1.83	-6.88	2.96	-8.05
APMG4×APS8	-9.39	-13.35	-0.26	-12.73	-8.01	5.41	4.58	6.15	-8.99
APMG4×APS12	-11.05	-6.95	0.31	-10.11	-6.52	3.99	-13.16	-2.27	0.00
APMG4×APS45	0.00	11.46	-1.82	6.17	-3.63	-9.23	-10.16	0.22	-1.15
APMW1×APS8	-1.37	1.83	0.00	6.31	7.46	1.08	5.47	2.38	-3.37
APMW1×APS12	-3.94	-0.14	-1.26	-2.08	-7.88	-5.93	5.09	6.73	-12.50
APMW1×APS45	-0.80	4.35	-0.98	0.16	0.00	-0.16	7.79	-5.88	-12.64
APMW2×APS8	1.96	1.94	0.99	1.33	1.10	-0.22	-1.56	1.14	-4.49
APMW2×APS12	-1.18	2.31	0.43	-1.54	-8.15	-6.71	-6.31	6.89	-13.64
APMW2×APS45	-2.40	14.92	0.71	7.08	3.63	-3.22	7.00	4.13	-13.79
APMW3×APS8	1.37	-13.84	-1.60	-8.70	-4.70	4.39	-3.35	5.95	-12.36
APMW3×APS12	-9.47	-5.08	-2.17	-8.99	-10.87	-2.06	-10.18	8.00	-7.95
APMW3×APS45	-4.61	4.58	0.43	-0.27	-5.31	-5.05	-6.88	-2.12	-5.75
APMW4×APS8	-5.09	-13.89	-3.02	-10.88	-11.60	-0.82	4.47	2.86	-11.24
APMW4×APS12	-1.58	-0.99	-2.11	-4.79	-11.68	-7.24	0.88	11.12	-1.14
APMW4×APS45	-1.40	14.43	-1.49	-0.43	-1.96	-1.53	-3.05	-1.18	-5.75
APMW5×APS8	-3.13	-8.58	0.74	-7.64	-8.84	-1.30	-1.56	3.75	-2.25
APMW5×APS12	-5.52	-9.05	1.50	-12.35	-16.03	-4.20	-0.33	4.16	-13.64
APMW5×APS45	-2.61	4.72	1.39	1.93	-2.23	-4.09	3.95	-1.86	-13.79
APMW6×APS8	-4.70	-6.38	5.74	-4.93	-6.08	-1.20	-4.02	4.24	-1.12
APMW6×APS12	-6.31	-0.11	7.81	-4.84	-10.33	-5.76	1.11	0.00	0.00
APMW6×APS45	0.40	3.04	7.31	-0.80	-8.10	-7.36	-3.61	6.05	0.00

Table 5: Evaluation index values on the genetic traits for the new hybrid combinations

Hybrid combinations	Fecundity	Yield/10,000 larvae	Pupation rate	Cocoon weight	Shell weight	Shell ratio	Filament length	Reliability	Neatness	Avg. EI value
APMG1×APS8	62.44	45.68	50.83	61.69	66.86	54.08	59.60	63.53	63.38	58.68
APMG1×APS12	41.82	52.84	51.81	51.73	62.57	64.21	61.85	43.49	55.31	53.96
APMG1×APS45	54.30	62.01	47.06	61.69	57.74	42.28	48.17	51.51	59.34	53.79
APMG2×APS8	39.65	37.01	51.59	39.84	38.97	50.70	28.05	75.86	53.29	46.11
APMG2×APS12	49.96	34.59	58.38	37.99	45.94	64.37	53.16	57.36	59.34	51.23
APMG2×APS45	45.62	62.40	53.17	64.95	58.82	39.01	30.14	51.20	55.31	51.18
APMG3×APS8	33.14	43.45	57.62	42.65	48.09	59.22	51.07	48.12	65.39	49.86
APMG3×APS12	61.36	60.46	44.19	63.62	63.11	46.37	65.55	42.32	57.33	56.03
APMG3×APS45	67.33	45.30	53.32	44.68	49.70	58.05	40.93	52.80	43.21	50.59
APMG4×APS8	35.86	37.25	49.85	34.11	43.26	67.51	58.79	57.89	45.23	47.75
APMG4×APS12	29.34	40.16	53.85	37.99	49.16	69.20	34.49	30.05	59.34	44.84
APMG4×APS45	55.39	64.10	38.76	63.62	49.70	29.21	36.26	45.62	55.31	48.66
APMW1×APS8	58.10	58.49	60.87	65.74	73.30	56.21	60.08	48.12	55.31	59.58
APMW1×APS12	48.88	49.25	51.81	51.29	46.48	42.80	61.05	52.80	37.16	49.06
APMW1×APS45	53.22	54.65	53.85	53.76	56.67	52.86	61.85	29.62	35.14	50.18
APMW2×APS8	67.33	58.65	57.85	57.46	60.96	52.83	49.94	44.91	53.29	55.91
APMW2×APS12	56.48	52.52	53.85	52.17	45.94	40.71	44.47	53.20	35.14	48.28
APMW2×APS45	48.88	68.69	55.89	65.12	63.64	44.89	60.72	55.85	33.13	55.20
APMW3×APS8	65.70	36.57	24.66	40.80	49.70	64.84	47.37	57.36	39.18	47.35
APMW3×APS12	33.69	42.66	20.66	39.84	40.58	53.09	38.84	56.01	45.23	41.17
APMW3×APS45	42.91	54.96	38.76	53.05	46.48	40.10	40.93	39.48	47.24	44.88
APMW4×APS8	47.79	36.50	36.73	37.19	36.28	51.27	58.63	49.35	41.19	43.88
APMW4×APS12	55.39	48.11	43.29	46.80	38.97	39.30	54.93	63.90	57.33	49.78
APMW4×APS45	51.59	68.04	47.66	52.79	52.91	49.28	46.40	41.95	47.24	50.88
APMW5×APS8	53.22	43.93	52.27	42.57	41.65	50.01	49.94	51.66	57.33	49.17
APMW5×APS12	44.54	37.37	57.62	34.28	30.38	47.38	53.16	46.30	35.14	42.91
APMW5×APS45	48.34	55.15	56.87	56.66	52.38	42.62	56.38	40.16	33.13	49.08
APMW6×APS8	48.88	47.01	50.83	47.06	47.01	50.26	46.40	52.92	59.34	49.97
APMW6×APS12	42.37	49.29	64.71	46.71	41.65	43.24	55.25	35.79	59.34	48.70
APMW6×APS45	56.48	52.92	61.39	52.17	41.11	34.10	45.60	60.88	57.33	51.33

Multiple Evaluation Index Values

With an objective for identification of the superior hybrid combinations based on Evaluation index values were calculated for the each genetic trait and presented in the Table 5. Among the hybrids evaluated, 13 combinations were scored more than 50 evaluation index value (Table 6, Fig. 1). The top ranked hybrid combinations based on the average evaluation index values viz., APMW1×APS8 (59.58) and APMG1×APS8 (58.68) were identified for further study (Fig. 2, 3).

Heterosis, the function of various gene frequencies, over dominance observed to be highly variable and basically it depends on the characters as well as parental strains utilized in the hybridization programs (Falconer, 1988). Hybrid vigor is very important in silkworms breeding (Toyama, 1906; Harada, 1961) and it has been successfully utilized at commercial level all over the world. Majority of the genetic traits under the control of polygenic nature and influenced by environment in goats as revealed by Singh *et al*. (2009) and silkworm is not exceptional (Gokulamma and Reddy, 2005). In the present study, the hybrid vigor was observed over Mid Parent Heterosis (MPH) and Better Parent Hetrerosis (BPH) in many crosses involving polyvoltine x bivoltine breeds might be due to the complementary gene action of the parents. Highest heterosis was observed for cocoon yield by weight (26.59%) and shell weight (31.86%) revealed the magnitude of genetic diversity of the parental material and the predominance of the complimentary type of gene action in the parents is in conformity with the observations of Sengupta *et al*. (1971). Genetically, hybrid vigor is manifested high in single cross hybrids as compared to three way and double cross hybrids and results obtained was corroborate with the earlier studies of Watanabe (1961) and

Table 6: Average EI values of the hybrid combinations

Hybrid combinations	Average evaluation index value	Rank
APMW1×APS8	59.58	1
APMG1×APS8	58.68	2
APMG3×APS12	56.03	3
APMW2×APS8	55.91	4
APMW2×APS45	55.20	5
APMG1×APS12	53.96	6
APMG1×APS45	53.79	7
APMW6×APS45	51.33	8
APMG2×APS12	51.23	9
APMG2×APS45	51.18	10
APMW4×APS45	50.88	11
APMG3×APS45	50.59	12
APMW1×APS45	50.18	13
APMW6×APS8	49.97	14
APMG3×APS8	49.86	15
APMW4×APS12	49.78	16
APMW5×APS8	49.17	17
APMW5×APS45	49.08	18
APMW1×APS12	49.06	19
APMW6×APS12	48.70	20
APMG4×APS45	48.66	21
APMW2×APS12	48.28	22
APMG4×APS8	47.75	23
APMW3×APS8	47.35	24
APMG2×APS8	46.11	25
APMW3×APS45	44.88	26
APMG4×APS12	44.84	27
APMW4×APS8	43.88	28
APMW5×APS12	42.91	29
APMW3×APS12	41.17	30

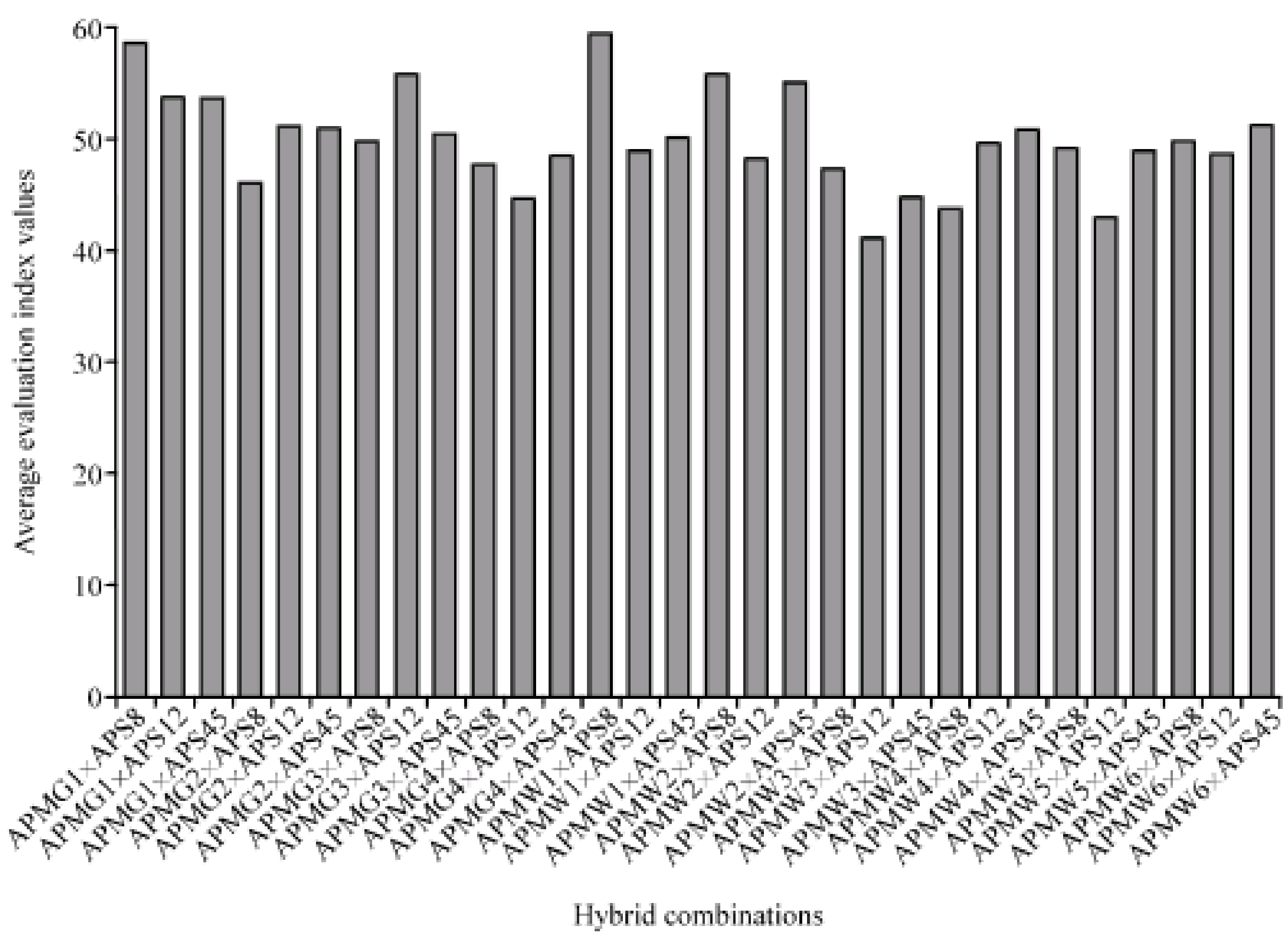

Fig. 1: Evaluation of hybrid combinations

Yokoyama (1963). The present study clearly showed heterosis for many yield contributing genetic characters but no single hybrid combination found to be positive heterosis for all the

Fig. 2: Silkworm larvae and cocoons of APMW1×APS8 hybrid combination

Fig. 3: Silkworm larvae and cocoons of APMG1×APS8 hybrid combination

economical traits are in agreement with the observations of Datta *et al.* (2001). The high degree of heterosis in specific crosses for some characters in this study may be due to additive gene effects (Udupa and Gowda, 1988; Rao *et al.*, 2004, 2006). Expression of hybrid vigor was very high in some economic characters like cocoon yield, cocoon weight and shell weight. In the present observation, thirteen hybrid combinations manifested heterosis over mid parent for fecundity. Majority of the hybrid combinations were manifested positive heterosis over the mid and better parent for cocoon yield, cocoon weight and shell weight (Table 3 and 4). Further, it is corroborate with the earlier studies for the evaluation and identification of prospective polyvoltine×bivoltine hybrids/cross breeds (Singh *et al.*, 1998, 2000; Rao *et al.*, 2004; Umadevi *et al.*, 2005; Ramesha *et al.*, 2008).

In the present study of silkworm hybrid evaluation, we targeted certain quantitative as well as qualitative traits that contribute to the better performance of the breed/hybrids. Based on the expression of heterosis over mid parent and better parent for different important economical characters, they could be utilized for improvement of specific characters in specific hybridization programs.

CONCLUSION

Among the newly developed thirty silkworm hybrid combinations evaluated in the present study, two hybrids viz., APMW1×APS8 and APMG1×APS8 were adjudicated as superior heterotic hybrid combinations based on genetic manifestation of hybrid vigor studies and average multiple evaluation index values. These hybrid combinations are recommended for large scale laboratory trials and further for commercial exploitation at the farmer's level.

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ANNEX

Systematic classification of domesticated silkworm, *Bombyx mori* L.

Domain/Kingdom	:	Animalia
Sub domain	:	Eukaryota
Infra domain	:	Metazoan
Phylum	:	Arthropoda
Sub-phylum	:	Hexapoda
Class	:	Insecta
Sub-class	:	Pterygota
Order	:	Lepidoptera
Sub-order	:	Glossata
Infra order	:	Ditrysia
Super family	:	*Bombycoidea*
Family	:	*Bombycidae*
Genus	:	*Bombyx*
Species	:	*mori*

REFERENCES

Bhargava, S.K., V. Thiagarajan and R.K. Datta, 1993. Hybrid vigor in the silkworm, *Bombyx mori* L. Giornale Ital. Entomol., 6: 461-465.

Datta, R.K., 1984. Improvement of silkworm races (*Bombyx mori* L.) in India. Sericologia, 24: 393-415.

Datta, R.K., 1992. Guidelines for Bivoltine Rearing. Bulletin of central silk board, Bangalore.

Datta, R.K., D. Raghavendra Rao, K.P. Jayaswal, V. Premalatha and R. Singh *et al*., 2001. Heterosis in relation to combining ability in multivoltine and bivoltine strains of the silkworm. Indian J. Seric., 40: 1-6.

Falconer, D.S., 1988. Introduction to Quantitative Genetics. 3rd Edn., Longman, London.

Gokulamma, K. and Y.S. Reddy, 2005. Role of nutrition and environment on the consumption, growth and utilization indices of selected silkworm races of *Bombyx mori* L. Indian J. Seric., 44: 165-170.

Harada, C., 1961. Heterosis of quantitative characters in the silkworm. Bull. Seric. Exp., 17: 50-52.

Lakshmi, H., M. Ramesh-Babu, J. Prasad and A. Chandrashekharaiah, 2008. Identification of promising cross breed APM1×APS98 in mulberry silkworm through manifestation of hybrid vigour. Bull. Ind. Acad. Ser., 12: 1-11.

Mano, Y., S. Nirmal Kumar, H.K. Basavaraja, N. Mal Reddy and R.K. Datta, 1993. A new method to select promising silkworm breeds/combinations. Indian Silk, 31: 53-59.

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

Ramesh-Babu, K., S. Ramakrishna, Y. Harish-Kumar-Reddy, G. Lakshmi, N.V. Naidu, S. Sadak-Basha and M. Bhaskar, 2009. Metabolic alterations and molecular mechanism in silkworm larvae during viral infection: A review. Afr. J. Biotechnol., 8: 899-907.

Ramesha, C., S.V. Seshagiri, K.I. Basha and C.G.P. Rao, 2008. Synthesis of superior polyvoltine crossbreeds of silkworm (*Bombyx mori* L.). National Seminar on Scenario of Seri-biotechnological Research in India, August 28-30, S.V. Mahila University, Tirupati, A.P., India.

Rao, C.G.P., Chandrashekaraiah, C. Ramesh, K.I. Basha, S.V. Seshagiri and H. Nagaraju, 2004. Identification of superior polyvoltine hybrids (polyvoltine X bivoltine) of silkworm, *Bombyx mori* L. Int. J. Indust. Entomol. 8: 43-49.

Rao, C.G.P., S.V. Seshagiri, C. Ramesh, K.I. Basha, H. Nagaraju and A. Chandrashnd-Rashekaralah, 2006. Evaluation of genetic potential of the polyvoltine silkworm (*Bombyx mori* L.) germplasm and identification of parents for breeding programme. J. Zhejiang Univ. Sci. B., 7: 215-220.

Sengupta, K., R.K. Datta, S.N. Biswas and B.D. Singh, 1971. Heterosis in multivoltine silkworm (*Bombyx mori* L.) yield performance of F1 hybrids of Nistari and four evolved multivoltines breeds. Indian J. Ser., 10: 6-13.

Singh, R., R.P. Sudhakara and R.K. Datta, 1998. Studies on hybrid vigor in different crosses of the silkworm. Sericologia, 38: 121-128.

Singh, R., G.V. Kalpana, P.R. Sudhakar, M.M. Ahsan, R.K. Datta and M. Rekha, 2000. Studies on combining ability and heterosis in the silkworm *Bombyx mori* L. Indian J. Ser., 39: 43-48.

Singh, M.K., B. Rai and N.P. Singh, 2009. Environmental and genetic effects of growth traits in Jamunapari kids. Indian J. Anim. Sci., 79: 582-586.

Toyama, 1906. Breeding method of silkworms. Jap. Sangyo-Shimpo, 158: 283-286.

Udupa, S.M. and B.L.V. Gowda, 1988. Heterotic expression in silk productivity of different crosses of silkworm, *Bombyx mori* L. Sericologia, 28: 395-400.

Umadevi, K., V.N. Sudha, D.P. Prakashmurthy, D.R. Raghavendra, S. Ravindra, V. Premalatha and B.K. Kariappa, 2005. Evaluation of new multivoltine×bivoltine hybrid 'Cauvery' (BL67×CSR101) of the silkworm, *Bombyx mori* L. Indian J. Ser., 44: 131-133.

Watanabe, H., 1961. Studies on variability of larval body and cocoon weight between single and three way cross or double cross hybrids in the silkworm, *Bombyx mori* L. J. Sericult. Sci. Jap., 30: 463-467.

Yokoyama, T., 1963. On the application of heterosis in Japanese sericulture. Proc. Int. Genet. Symp. Suppl. Cytologia, 1: 527-531.