Development and Evaluation of Silkworm hybrids (Poly x Bivoltine) of *Bombyx mori L.* for commercial exploitation

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Abstract: The concerted efforts of silkworm breeders contributed significantly for the evaluation and development of new silkworm hybrids suitable to eco-climatic conditions of tropical regions. Continuous renewal and change of existing hybrids with superior varieties and their commercialization is the need of the hour to meet the global demand. With this objective, an attempt has been made at Andhra Pradesh State Sericulture Research and Development Institute (APSSRDI), Hindupur, India and contributed for the development of potential cross breeds. In the present paper, thirty new hybrid combinations were prepared in Line x Tester method involving ten potential polyvoltine breeds with three testers such as APDR115, APS12 and HTO5. The relative merit of the hybrids over multiple traits was assessed by adopting widely used statistical methods such as Evaluation Index and subordinate function methods, the ranks were adjudicated to each of the hybrid combinations. Based on the evaluation methods and performance, five hybrid combinations were adjudicated as promising and chosen for further laboratory evaluation. Subsequently the superior and consistent hybrids would be exploited commercially at farmer level.

Key words: Silkworm, breeding, conventional method, crossbreed, evaluation, commercial exploitation.

1. Introduction

The silkworm, *Bombyx mori* L. is a lepidopteran economic insect which is known for the production of mulberry silk aptly named as "*the Queen of Natural Fibers*". Even though sericulture industry in India has been established as a major source among the agro-based industries, it is still in the process of achieving the required stability since the quality and quantity of silk produced as well as the unit production of silk remains low when compared with sericulturally advanced countries. Enrichment of silkworm breeds / hybrids have always been one of the important factors contributing to increase the productivity in sericulture sector. Continuous development, evaluation, renewal and change of existing breeds/hybrids with new superior varieties and their commercialization is the prime factor to increase silk quality and quantity (Chandrashekharaiah and Ramesh Babu, 2003). Among various reasons for low productivity, the lack of highly productive silkworm races suitable to environmental conditions prevailing in the Indian sub-continent stands prominent. In addition, Indian sericulture is mostly polyvoltine oriented and the quality of the breeds has deteriorated as a result of continuous and prolonged inbreeding. Thus, breeding emphasizes the need for developing promising genotype of known genetic potential to increase the productivity in plants and animals (Yokoyama, 1956). Hence, silkworm breeds play a vital role in the success of sericulture industry. Thus the breed development and improvement is a continuous process which aims at providing suitable genotypes with desired traits (Datta, 1984; Rao *et al*., 2006).

India has emerged today as the second largest producer of mulberry raw silk besides being producing all the varieties of commercially exploited silks of the world. Such an achievement was made possible as a result of significant breakthrough made in Research and Development in tropical sericulture. However, the bulk of silk production comes from polyvoltine and polyvoltine x bivoltine hybrids, which is largely suited for handloom sector. Enrichment of silkworm breeds has always been one of the important factors contributing to increase the productivity in sericulture. Continuous renewal and change of existing breeds/hybrids with new superior varieties and their commercialization is vital to increase silk quality and quantity. India demands an increasing supply of quality silk, accessible and at affordable prices which is produced in a minimized cost and sustainable way. Therefore, it becomes imperative or essential to develop the breeds that are stable under different environmental conditions. Even though sericulture industry in India has been established as a major source among the agro-based industries, it is still in the process of achieving the required stability. Among various reasons, the lack of highly productive silkworm races suitable to environmental conditions prevailing in the Indian sub-continent stands prominent.

The recent trend of global silk production centered mainly in tropical countries. India is the second largest producer of silk in the world next to China and more than ninety percent of the silk produced mainly by cross breeds (polyvoltine x bivoltine). In spite of continuous efforts for the development of sericulture through various breeding programs many hybrids have been developed by the breeders (Rao *et al*., 2004; Seshagiri *et al*., 2011, 2013), still there exists a wide gap between domestic requirement and production in India. To fulfill the gap and to face global competitiveness in silk production there is a need to develop more productive breeds or hybrids with quantitative and qualitative merit. Very limited number of polyvoltine cross breeds are available with all desired traits, which are not sufficient to meet the demand. The polyvoltine race, Pure Mysore (PM) is ruling the Indian Sericulture Industry for more than 50 years. At this juncture, there is a need for the development of quantitatively and qualitatively superior polyvoltine breeds and hybrids with high genetic plasticity to cater various climatic conditions of tropical countries. In the present study, an attempt was made to know the general combining ability of the new genotypes, specific combining ability and heterosis of their hybrids under Line x Tester programme in order to identify potential parents and to adjudicate the best hybrids for commercial exploitation at farmer’s level.

Of late, the approach of breeding new productive breeds by genetic manipulation through conventional breeding has emerged as one of the powerful tools in exploiting the commercial qualities. The systematic hybridization coupled with appropriate selection procedures have contributed to amalgamate the major economic traits of choice from selected breeds (Sreerama Reddy *et al*., 1992). The attempts to evolve highly productive bivoltine races have met with little success (Raju, 1990). Hence, prominent breeders and geneticists of Japan (Murakami, 1988 and Tazima, 1958) stressed the importance of polyvoltine breeding in the tropical regions of India. The silkworm, *Bombyx mori* L. offers one of the very important insects of choice with large number of strains which is best exemplified for utilization of heterosis by crossing them in different combinations (Datta and Nagaraju, 1987). In fact, silkworm is the only exception crop where hybrids are invariably used (Yokoyama, 1979). The systematic rearing of F1 hybrids was undertaken for the first time in Japan after establishing the superiority of hybrids (Toyama, 1905). The final results in silkworm breeding are judged by the superiority on the commercial traits of the parental races that appear in F1. The advantages of rearing F1 hybrids are that they exhibit shorter larval duration, lower mortality, higher cocoon and shell weight and longer filament length (Krishnaswami *et al*., 1973). An extensive study on the combining ability of silkworm was made to identify the superior and promising hybrid combinations for commercial exploitation in polyvoltine x bivoltine hybrids (Chouhan *et al*., 2000; Vasileva *et al*., 2004; Rao *et al*., 2004; Ravindra Singh *et al*., 2005, Seshagiri *et al*., 2009). Very limited number of polyvoltine cross breeds are available with all desired traits, which are not sufficient to meet the demand. At this juncture, there is a need for the development of quantitatively and qualitatively superior polyvoltine hybrids with high genetic plasticity to cater various climatic conditions.

2. Materials and Methods

In the present study, Ten polyvoltine silkworm breeds *viz*., MBL1, MBL2, MBL3, MBL4, MBL5, MBL6, MBL7, MBL8, MBL9 and MBL10 maintained at Andhra Pradesh State Sericulture Research and Development Institute (APSSRDI), Hindupur were subjected for hybrid testing by employing the Line x Tester method of crossing. Three productively superior bivoltine breeds such as APDR115, APS12 and HTO5 were utilized as testers. Thirty hybrid combinations were prepared and tested under Line x Tester mating design. All the hybrid combinations along with their parents were reared in three replications by following standard rearing techniques (Krishnaswami, 1973). Three hundred larvae were retained after 3rd moult in each replication. The data pertaining to eight economic traits viz., fecundity, hatching %, cocoon yield per 10,000 larvae by number, cocoon yield per 10,000 larvae by weight (kg), pupation rate (%), cocoon weight (g), cocoon shell weight (g) and cocoon shell ratio (%) was collected. The merit of the each of the hybrid combinations was analyzed through multiple trait evaluation index method (Mano *et al*., 1993) and Sub-ordinate function methods (Gower, 1971) as detailed. Based on the average Evaluation Index value ranks were assigned to all the hybrid combinations, the top ranked five hybrids in the both evaluation methods were considered as the potential and would be subjected for large scale laboratory trials and subsequently for commercial exploitation.

Multiple Trait Evaluation Index Method:

Evaluation index over multiple traits was calculated for each hybrid for all the traits as per the following formula which is suggested by Mano *et al*. (1993).

$$\text{Evaluation Index} = \frac{A - B}{C} \times 10 + 50$$

Where,

A = Value obtained for a trait by the specific hybrid

B = Overall mean value of particular trait over all the hybrids

C = Standard deviation of the trait over all the hybrids

10 = Constant used for change of scale

50 = Constant used for change of origin

Sub-ordinate function method

The subordinate function values for each character were calculated by using the following formula:

$$Xu = (Xi - Xmin)/ (Xmax - Xmin)$$

Where,

Xu = Subordinate function

Xi = Measurement of character of a tested genotype

Xmax = The maximum value of the character from all the tested genotypes

Xmin= The minimum value of the character among all the tested genotypes

3. Results

The data pertaining to eight economic traits *viz.*, fecundity, hatching %, cocoon yield per 10,000 larvae by number, cocoon yield per 10,000 larvae by weight, pupation rate, cocoon weight, cocoon shell weight, and cocoon shell ratio of thirty hybrid combinations are presented in Table 1. The perusal of the data reveals that the fecundity ranged from 492 (MBL4 x APDR115) to 371 (MBL8 x APS12) with an average of 428 where as hatching % was recorded to a maximum of 100% (MBL5 x HTO5, MBL5 x APS12) and minimum of 58.71(MBL6 x APS12). With regard to yield per 10,000 larvae by number, the combination MBL10 x APS12 was recorded the highest (9900) and lowest in MBL1 x APS12 (8425). Yield per 10,000 larvae by weight (kg), ranged to the maximum of 17.862 kg in MBL10 x APDR115 and minimum of 13.598 kg in MBL1 x APS12. The pupation rate found to the highest of 98.75 % in MBL3 APS12 and lowest of 82.00 in MBL1 x APS12. The cocoon weight ranged from the maximum of 1.974 g (MBL4 x APDR115) and minimum of 1.526 g (MBL3 x APDR115) with an average of 1.633g. The shell weight was maximum (0.379 g) in MBL4 x APDR115 and minimum in MBL7 x APS12 (0.265 g) and shell ratio (%) was highest in MBL2 x HTO5 (19.95) and lowest in MBL7 x APS12 (16.90).

Evaluation of the New Combinations: The new combinations were evaluated by the statistical methods *viz.*, multiple trait evaluation index (EI) and subordinate function method. The evaluation of data reveals that the average EI values ranged to the maximum of 66.31 (MBL4 x APDR115) and to a minimum of 39.40 (MBL2 x APS12). The combinations *viz*., five hybrids such as MBL4 x APDR115, MBL10 x APDR115, MBL10 x HTO5, MBL5 x APS12 and MBL3 x APDR115 were stood top and shown above 50 EI value under evaluation index method (Table 2). Further, under the subordinate function method also the combinations such as MBL4 x APDR115 (7.39), MBL10 x APDR115 (6.33), MBL10 x HTO5 (5.42) and MBL3 x APDR115, MBL5 x APS12 (5.23) were shown higher values and stood top (Table 3). In both the evaluation methods, the higher ranked five hybrid combinations were selected for further laboratory trials subsequently for commercial exploitation (Table 4).

4. Discussion

The silkworm breeding is the most important example where heterosis is being exploited commercially to the maximum extent. To achieve desired goals, cross breeding is widely used in commercial animal production as a means of exploiting heterosis (Sang, 1956 and Bowman, 1959). Development of productive silkworm strains suitable to local conditions play a pivotal role in the overall development of sericulture industry. The polygenic nature of the quantitative traits and role of different intensities of selection in changing the mean expression have been demonstrated in plants and animals. Selection cannot create new genes and however, it can increase the frequency of desirable genes existing in the population. Silkworms breeding which has been in practice since many decades in Japan where in desirable goals were achieved with certain specific objectives. The poor adaptability of the bivoltines to the fluctuating environmental conditions of the tropical climates makes them unsuitable for their commercial exploitation throughout the year . Keeping this in view in the present study, thirty hybrid combinations were evaluated.

The ultimate result in silkworm breeding is judged by the excellency of characters of the parental strains that appear in F_1. The superiority of the hybrids over parental strains is undoubtedly due to variable magnitude of heterosis for the quantitative characters in silkworm and the results of present study are corroborating the findings of Gamo (1976). Several attempts were made in India by eminent silkworm breeders to identify suitable hybrid combinations (Dandin *et al*., 2007). For this, it is necessary to test large number of hybrid combinations to identify the pure races which can be utilized for ultimate identification of the superior hybrid combinations. The wider variability observed for important economic traits in the hybrids can be attributed to the genetic diversity present with the resource material which is utilized in hybrids.

The exploitation of heterosis is an important step towards achieving desirable economic effects from the hybrids. The multiple trait evaluation of the thirty hybrid combinations revealed that, seventeen combinations which recorded average cumulative index values above 50 possess economic merit. Among them, the combination MBL4 x APDR115 ranked first followed by MBL10 x APDR115. These observations confirm the established fact as observed by Vidyunmala *et al*., (1998) and Ramesh Babu *et al*., (2002) that superiority of one or a couple of characters may not reflect the overall merit of the hybrid. Since the comprehensive merit of the hybrid over a range of traits depends on relative superiority of many individual traits, selection needs to be based on multiple traits contributing to overall silk output.

The fecundity, determined on the genotype of maternal parent and environmental conditions prevailing at the time of oviposition and it is one of the fitness components reflecting on the productivity. In the present study with regard to this trait, the newly evolved strains revealed that they differ from one another in the total number of eggs laid by a single female moth. The trait, yield per 10,000 larvae by number which showed variations among the hybrid combinations can be attributed to the heterosis, influence of environmental factors and interaction of alleles. As the cocoon yield is related to pupation rate and cocoon weight, it could be increased by emphasizing on these traits. Pupation rate is an important parameter which reflects the viability of the breed and the fluctuations observed among various hybrid combinations could be partially attributed to the influence of environmental conditions and the interaction of alleles responsible for expression of the trait (Sudhakar Rao, et al., 2006). The cocoon weight is considered to reflect the vigor of the silkworm breed and similarly the cocoon shell weight showed wider variations in different combinations.

Thus, the results of the present study are in agreement with the earlier works (Darlington, 1939) who pointed out the selection of resource material is a basic tool for generating desired hereditary changes in the improvement of commercial qualities. Selection of resource material for preparation of hybrid combinations increases the frequency of desirable genes that appears in the hybrid combinations in the expression of important economic characters (Lush). As the ultimate goal being the development of productive and qualitatively superior silkworm hybrids, it is envisaged for conducting a comprehensive hybrid test involving all the newly evolved polyvoltine strains. It has been pointed out by Toyama (1906) that the F1 hybrids in silkworm, *Bombyx mori* L. in several aspects are superior to their pure line parents and the present results are in support with the findings of Harada, 1961; Yokoyama, 1979. It is noteworthy to point out that most of the hybrid combinations excelled for the economic traits analyzed over their parents. Accordingly, based on the performance and with the help of statistical tools five hybrid combinations were shortlisted for further laboratory trials subsequently for commercial exploitation.

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Table 1. Rearing performance of new silkworm hybrid combinations

Sl.No.	Breed	Fecun-dity (No.)	Hatching %	Yeild/10,000 Larvae		Pupation rate (%)	Cocoon assessment		
				No.	Wt.(Kg)		Single cocoon Wt. (g)	Single shell Wt. (g)	SR %
1	MBL1 X APDR115	433	92.68	8850	14.819	88.25	1.675	0.332	19.84
2	MBL1 X HTO5	448	98.76	9125	15.425	98.00	1.658	0.307	18.52
3	MBL1 X APS12	466	94.06	8425	13.598	82.00	1.614	0.315	19.52
4	MBL2 X APDR115	448	91.36	9300	14.685	92.00	1.579	0.285	18.05
5	MBL2 X HTO5	459	97.42	9450	14.515	92.50	1.536	0.306	19.95
6	MBL2 X APS12	436	98.05	9050	13.969	90.00	1.544	0.265	17.17
7	MBL3 X APDR115	472	98.33	9775	14.912	97.25	1.526	0.303	19.86
8	MBL3 X HTO5	487	97.97	9425	14.840	94.00	1.575	0.311	19.77
9	MBL3 X APS12	412	98.08	9850	15.942	98.75	1.619	0.306	18.90
10	MBL4 X APDR115	492	98.43	9675	17.850	95.75	1.974	0.379	19.23
11	MBL4 X HTO5	421	98.07	9675	15.973	92.75	1.651	0.311	18.81
12	MBL4 X APS12	447	97.29	9625	14.861	94.75	1.544	0.271	17.55
13	MBL5 X APDR115	407	98.56	9650	15.450	95.75	1.601	0.302	18.86
14	MBL5 X HTO5	437	100.00	9725	15.526	96.50	1.597	0.308	19.30
15	MBL5 X APS12	395	100.00	9525	17.697	95.00	1.858	0.328	17.66
16	MBL6 X APDR115	421	59.50	9525	15.073	92.25	1.583	0.309	19.52
17	MBL6 X HTO5	465	71.76	9825	16.005	97.00	1.629	0.301	18.48
18	MBL6 X APS12	412	58.71	9725	15.088	97.00	1.552	0.287	18.50
19	MBL7 X APDR115	449	98.54	9400	15.425	93.00	1.617	0.295	18.24
20	MBL7 X HTO5	378	99.07	9550	15.755	93.00	1.650	0.302	18.30
21	MBL7 X APS12	389	98.54	9625	15.097	96.25	1.569	0.265	16.90
22	MBL8 X APDR115	399	95.73	9725	16.012	96.25	1.702	0.314	18.42
23	MBL8 X HTO5	378	99.56	9675	14.875	94.50	1.550	0.285	18.39
24	MBL8 X APS12	371	99.03	9500	15.594	94.25	1.642	0.313	19.06
25	MBL9 X APDR115	438	99.83	9400	15.487	93.00	1.648	0.309	18.77
26	MBL9 X HTO5	391	98.18	9600	15.528	93.75	1.618	0.314	19.39
27	MBL9 X APS12	416	98.01	9625	15.424	95.50	1.603	0.288	17.97
28	MBL10 X APDR115	439	99.03	9825	17.862	96.00	1.818	0.344	18.93
29	MBL10 X HTO5	445	99.19	9825	16.023	95.25	1.669	0.319	19.10
30	MBL10 X APS12	395	98.51	9900	15.820	94.75	1.598	0.298	18.63
	Average	**428**	**94.41**	**9528**	**15.50**	**94.17**	**1.633**	**0.306**	**18.72**
	Stand. Deviation	**32.63**	**10.89**	**320**	**0.97**	**3.25**	**0.10**	**0.02**	**0.78**
	CV (%)	**7.62**	**11.54**	**3.36**	**6.28**	**3.45**	**6.01**	**7.42**	**4.19**
	Minimum	**371**	**58.71**	**8425**	**13.60**	**82.00**	**1.526**	**0.265**	**16.90**
	Maximum	**492**	**100**	**9900**	**17.86**	**98.75**	**1.974**	**0.379**	**19.95**

Table 2. Evaluation index values of new silkworm hybrid combinations

Sl.No.	Breed	Fecu n-dity (No.)	Hatching	Yeild/10,000 Larvae		Pupation rate	Cocoon assessment			Avg. EI
				No.	Wt		Single cocoon Wt	Single shell Wt.	SR %	
1	MBL1 X APDR115	51.37	48.42	28.79	42.96	31.79	54.23	61.71	64.33	**47.95**
2	MBL1 X HTO5	56.12	53.99	37.39	49.19	61.80	52.54	50.62	47.50	**51.14**
3	MBL1 X APS12	61.48	49.68	15.51	30.42	12.55	48.06	54.09	60.16	**41.49**
4	MBL2 X APDR115	55.97	47.20	42.86	41.58	43.33	44.49	40.86	41.46	**44.72**
5	MBL2 X HTO5	59.49	52.76	47.55	39.84	44.87	40.11	50.31	65.68	**50.08**
6	MBL2 X APS12	52.29	53.34	35.05	34.23	37.17	40.87	32.04	30.23	**39.40**
7	MBL3 X APDR115	63.47	53.60	57.71	43.91	59.49	39.04	48.80	64.57	**53.82**
8	MBL3 X HTO5	68.07	53.27	46.77	43.17	49.49	44.03	52.42	63.34	**52.57**
9	MBL3 X APS12	45.09	53.37	60.06	54.50	64.11	48.52	50.10	52.35	**53.51**
10	MBL4 X APDR115	69.60	53.69	54.59	74.09	54.87	84.70	82.50	56.46	**66.31**
11	MBL4 X HTO5	47.84	53.36	54.59	54.82	45.64	51.83	52.16	51.22	**51.43**
12	MBL4 X APS12	55.66	52.64	53.02	43.39	51.80	40.93	34.69	35.12	**45.91**
13	MBL5 X APDR115	43.55	53.81	53.80	49.44	54.87	46.73	48.36	51.83	**50.30**
14	MBL5 X HTO5	52.75	55.13	56.15	50.22	57.18	46.28	51.08	57.45	**53.28**
15	MBL5 X APS12	39.88	55.13	49.90	72.52	52.57	72.93	59.88	36.50	**54.91**
16	MBL6 X APDR115	47.69	17.96	49.90	45.57	44.10	44.85	51.39	60.18	**45.21**
17	MBL6 X HTO5	61.33	29.21	59.27	55.14	58.72	49.59	47.92	46.92	**51.01**
18	MBL6 X APS12	45.09	17.23	56.15	45.73	58.72	41.69	41.74	47.18	**44.19**
19	MBL7 X APDR115	56.27	53.79	45.99	49.19	46.41	48.31	45.20	43.88	**48.63**
20	MBL7 X HTO5	34.67	54.28	50.68	52.57	46.41	51.70	48.30	44.62	**47.90**
21	MBL7 X APS12	38.04	53.79	53.02	45.81	56.41	43.42	32.04	26.74	**43.66**
22	MBL8 X APDR115	41.10	51.22	56.15	55.21	56.41	57.03	53.45	46.22	**52.10**
23	MBL8 X HTO5	34.67	54.73	54.59	43.54	51.03	41.53	40.86	45.78	**45.84**
24	MBL8 X APS12	32.37	54.24	49.11	50.92	50.26	50.86	53.12	54.29	**49.40**
25	MBL9 X APDR115	53.05	54.98	45.99	49.82	46.41	51.47	51.53	50.61	**50.48**
26	MBL9 X HTO5	38.65	53.46	52.24	50.24	48.72	48.42	53.45	58.49	**50.46**
27	MBL9 X APS12	46.16	53.31	53.02	49.18	54.10	46.89	42.18	40.47	**48.16**
28	MBL10 X APDR115	53.21	54.25	59.27	74.21	55.64	68.85	66.92	52.64	**60.62**
29	MBL10 X HTO5	55.20	54.39	59.27	55.33	53.33	53.67	55.78	54.88	**55.23**
30	MBL10 X APS12	39.88	53.77	61.62	53.24	51.80	46.43	46.49	48.90	**50.27**

Table 3. Subordinate function method values of the new silkworm hybrid combinations

Sl.No.	Breed	Fecun-dity (No.)	Hatching %	Yeild/10,000 Larvae		Pupa-tion rate (%)	Cocoon assessment			Cumula-tive SF value
				No.	Wt.(Kg)		Single cocoon Wt. (g)	Single shell Wt. (g)	SR %	
1	MBL1 X APDR115	0.51	0.82	0.29	0.29	0.37	0.33	0.59	0.97	**4.17**
2	MBL1 X HTO5	0.64	0.97	0.47	0.43	0.96	0.30	0.37	0.53	**4.66**
3	MBL1 X APS12	0.78	0.86	0.00	0.00	0.00	0.20	0.44	0.86	**3.13**
4	MBL2 X APDR115	0.63	0.79	0.59	0.25	0.60	0.12	0.17	0.38	**3.54**
5	MBL2 X HTO5	0.73	0.94	0.69	0.22	0.63	0.02	0.36	1.00	**4.59**
6	MBL2 X APS12	0.53	0.95	0.42	0.09	0.48	0.04	0.00	0.09	**2.61**
7	MBL3 X APDR115	0.84	0.96	0.92	0.31	0.91	0.00	0.33	0.97	**5.23**
8	MBL3 X HTO5	0.96	0.95	0.68	0.29	0.72	0.11	0.40	0.94	**5.05**
9	MBL3 X APS12	0.34	0.95	0.97	0.55	1.00	0.21	0.36	0.66	**5.03**
10	MBL4 X APDR115	1.00	0.96	0.85	1.00	0.82	1.00	1.00	0.76	**7.39**
11	MBL4 X HTO5	0.42	0.95	0.85	0.56	0.64	0.28	0.40	0.63	**4.72**
12	MBL4 X APS12	0.63	0.93	0.81	0.30	0.76	0.04	0.05	0.21	**3.74**
13	MBL5 X APDR115	0.30	0.97	0.83	0.43	0.82	0.17	0.32	0.64	**4.49**
14	MBL5 X HTO5	0.55	1.00	0.88	0.45	0.87	0.16	0.38	0.79	**5.07**
15	MBL5 X APS12	0.20	1.00	0.75	0.96	0.78	0.74	0.55	0.25	**5.23**
16	MBL6 X APDR115	0.41	0.02	0.75	0.35	0.61	0.13	0.38	0.86	**3.50**
17	MBL6 X HTO5	0.78	0.32	0.95	0.56	0.90	0.23	0.31	0.52	**4.57**
18	MBL6 X APS12	0.34	0.00	0.88	0.35	0.90	0.06	0.19	0.52	**3.24**
19	MBL7 X APDR115	0.64	0.96	0.66	0.43	0.66	0.20	0.26	0.44	**4.26**
20	MBL7 X HTO5	0.06	0.98	0.76	0.51	0.66	0.28	0.32	0.46	**4.02**
21	MBL7 X APS12	0.15	0.96	0.81	0.35	0.85	0.10	0.00	0.00	**3.23**
22	MBL8 X APDR115	0.23	0.90	0.88	0.57	0.85	0.39	0.42	0.50	**4.75**
23	MBL8 X HTO5	0.06	0.99	0.85	0.30	0.75	0.05	0.17	0.49	**3.66**
24	MBL8 X APS12	0.00	0.98	0.73	0.47	0.73	0.26	0.42	0.71	**4.29**
25	MBL9 X APDR115	0.56	1.00	0.66	0.44	0.66	0.27	0.39	0.61	**4.58**
26	MBL9 X HTO5	0.17	0.96	0.80	0.45	0.70	0.21	0.42	0.82	**4.52**
27	MBL9 X APS12	0.37	0.95	0.81	0.43	0.81	0.17	0.20	0.35	**4.10**
28	MBL10 X APDR115	0.56	0.98	0.95	1.00	0.84	0.65	0.69	0.67	**6.33**
29	MBL10 X HTO5	0.61	0.98	0.95	0.57	0.79	0.32	0.47	0.72	**5.42**
30	MBL10 X APS12	0.20	0.96	1.00	0.52	0.76	0.16	0.29	0.57	**4.47**

Table 4. Ranking of the new silkworm hybrid combinations

Sl. No.	Hybrid combination	EI value	Rank based on EI value	SF value	Rank Based on SF value
1	MBL4 X APDR115	66.31	1	7.39	1
2	MBL10 X APDR115	60.62	2	6.33	2
3	MBL10 X HTO5	55.23	3	5.42	3
4	MBL5 X APS12	54.91	4	5.23	5
5	MBL3 X APDR115	53.82	5	5.23	4
6	MBL3 X APS12	53.51	6	5.07	8
7	MBL5 X HTO5	53.28	7	5.05	6
8	MBL3 X HTO5	52.57	8	5.03	7
9	MBL8 X APDR115	52.10	9	4.75	9
10	MBL4 X HTO5	51.43	10	4.72	10
11	MBL1 X HTO5	51.14	11	4.66	11
12	MBL6 X HTO5	51.01	12	4.59	14
13	MBL9 X APDR115	50.48	13	4.58	13
14	MBL9 X HTO5	50.46	14	4.57	15
15	MBL5 X APDR115	50.30	15	4.52	16
16	MBL10 X APS12	50.27	16	4.49	17
17	MBL2 X HTO5	50.08	17	4.47	12
18	MBL8 X APS12	49.40	18	4.29	18
19	MBL7 X APDR115	48.63	19	4.26	19
20	MBL9 X APS12	48.16	20	4.17	21
21	MBL1 X APDR115	47.95	21	4.10	20
22	MBL7 X HTO5	47.90	22	4.02	22
23	MBL4 X APS12	45.91	23	3.74	23
24	MBL8 X HTO5	45.84	24	3.66	24
25	MBL6 X APDR115	45.21	25	3.54	26
26	MBL2 X APDR115	44.72	26	3.50	25
27	MBL6 X APS12	44.19	27	3.24	27
28	MBL7 X APS12	43.66	28	3.23	28
29	MBL1 X APS12	41.49	29	3.13	29
30	MBL2 X APS12	39.40	30	2.61	30