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Development of New Productive Bivoltine Silkworm (*Bombyx mori* L.) Hybrid, $APS_{83} \times APS_{102}$

M. Ramesh Babu*, H. Lakshmi, J. Prasad, J. Seetharamulu and Chandrashekharaiah

Andhra Pradesh State Sericulture Research and Development Institute (APSSRDI), Kirikera - 515 211, Hindupur, Andhra Pradesh, India.

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Successful silkworm breeding attempts were made at Andhra Pradesh State Sericulture Research and Development Institute (APSSRDI), Hindupur, India in developing productive bivoltine silkworm hybrids. One hundred hybrid combinations involving 10 parents (five each of oval and peanut) were evaluated in complete diallel pattern and identified the combination $APS_{83} \times APS_{102}$ as most promising. This hybrid showed economic merit for the characters fecundity (524 eggs/laying), pupation percentage (96.0%), cocoon yield per 10,000 larvae by weight (19.0 kg), cocoon weight (1.85 g), shell weight (41.7 cg), shell ratio (22.5%), filament length (1,004 m), reelability (88.4%), raw silk recovery (18.4%) and neatness (92 point) over the control hybrid $APS_9 \times APS_8$. The breeding process and identification of $APS_{83} \times APS_{102}$ is discussed in the paper.

Key words: Silkworm, Productive, Bivoltine, Percent improvement, Heterosis

Introduction

Although, India ranks second (about 15,000 Tons) among the mulberry silk producing countries of the world that accounts for 16% global silk production the core production is of multivoltine × bivoltine type that lacks quality. Contrary to the projected potentiality for sericulture development in the country, the productivity and quality remained low owing largely to the adoption of polyvoltine oriented crossbreed by the farmers (above 95%). This necessitated the development of bivoltine sericulture in the country to improve qualitative bivoltine silk production catering to the demand of the reeling industry that consumes about 15,000 tons of bivoltine silk of which only less than half of the quantity is being imported. None the less, the tropical bivoltine sericulture that remained as an enigma for the silk industry in the last three decades, made significant progress with the re-orientation of breeding approaches in line to improve the quality oriented quantitative silk production through the development of many bivoltine silkworm breeds/hybrids (Datta, 1984; Basavaraja *et al.*, 1995) which are becoming popular.

Exploitation of hybrid vigour in silkworm ushered a new era contributing to many fold increase in silk productivity. Systematic breeding approaches coupled with appropriate selection procedures have contributed to synthesize genotypes of desirable constitution (Hirobe, 1957, Mano *et al.*, 1982; Tanaka and Ohi, 1994; Datta *et al.*, 2001). Several Chinese and Japanese breeders have achieved remarkable progress in the improvement of several quantitative and qualitative traits of economic value in silkworm, *Bombyx mori* (Yang Mingguan, 1982; He and Oshiki, 1984; Mano *et al.*, 1991; Chen *et al.*, 1994).

In the Indian sericulture scenario that is dominated by the cross breed (multivoltine × bivoltine) silk, the concept of breeding bivoltine breeds in India was initiated by Harada with the development of Kalimpong A (KA) in the year 1955 that was used widely in many commercial hybrids. Subsequently, various silkworm breeders at different research institutions contributed to the development of many bivoltine breeds/hybrids over years (Datta, 1984; Trag *et al.*, 1992; Malik *et al.*, 1999). Since majority of the developed hybrids yielded only about 18.0% of shell ratio on commercial scale besides being less adaptive to the prevailing conditions, they could not sustain for long and made the bivoltine sericulture unattractive to the farmers

*To whom correspondence should be addressed.
Andhra Pradesh State Sericulture Research and Development Institute (APSSRDI), Kirikera - 515 211, Hindupur, India.
Tel: +091-08556-247428; Fax: +091-08556-247505;
E-mail: babu_apssrdi@rediffmail.com

and reelers. However, in recent years successful breeding attempts contributed to the development of productive and qualitatively superior bivoltine silkworm hybrids, $CSR_2 \times CSR_4$, $CSR_2 \times CSR_5$, $CSR_{12} \times CSR_6$ and $CSR_3 \times CSR_6$ (Datta *et al.*, 2000a, b, 2001) at CSRTI, Mysore and $APS_9 \times APS_8$ and $APS_5 \times APS_4$ at APSSRDI, Hindupur which have become popular in the field through higher crop yields coupled with quality silk production. Yet, there remains considerable dearth for productive bivoltine silkworm hybrids for commercial utilization. The present investigation deals with the breeding process of the productive bivoltine hybrid, $APS_{83} \times APS_{102}$ and its merits over the control hybrid $APS_9 \times APS_8$.

Materials and Methods

The bivoltine genetic resource materials, APS_1 & APS_5 (Oval) and APS_4 & APS_8 (Peanut) maintained in bivoltine silkworm germplasm bank at APSSRDI, Hindupur constituted the initial breeding resource material for the development of the hybrid, $APS_{83} \times APS_{102}$. The selected initial parents were crossed in the pattern of oval × oval ($APS_{11} \times APS_5$) and peanut × peanut ($APS_4 \times APS_6$) and the resultant populations were raised *en masse* separately and continued for further breeding. The larvae were reared as per standard techniques recommended by Datta (1992). The conventional breeding protocols were followed and promising inbred lines were derived. The developed inbred lines were subjected for hybrid testing following complete diallel (Griffing, 1956) method and their performance was assessed through evaluation index method. Based on the merit for the targeted economic traits, the productive hybrid, $APS_{83} \times APS_{102}$ is selected.

Breeding method and selection procedure

Development of breeding line APS_{83} (Oval): The oval inbred line APS_{83} was evolved from the oval × oval combination, $APS_{11} \times APS_5$. The F_1 was reared as mass during January - February 2000. The larvae of this combination were plain and spun oval cocoons. Mass rearings with random mating were continued from F_1 to F_3 so as to allow recombination of genes. Cellular (batch) rearings were followed from F_4 onwards. During the course of breeding, the inbred lines were isolated through selection of desired characters such as cocoon shape, survival, cocoon yield and high cocoon shell ratio with better quality traits and controlled progeny mating. This process was continued in the subsequent generations and in each generation the selection pressure was applied and the individuals were selected from the batches showing uniformity for cocoon shape and above average values (for all the batches) for the traits cocoon weight, shell weight and shell ratio besides longer filament length, reelability and neatness. Moth mating was made between female and male from the selected cocoons and obtained layings for next generation. By F_{10}, among all the inbred lines APS_8 showed uniformity in cocoon shape and stabilization for the desired quantitative and qualitative traits and the same is found to be the potential combiner for hybrid preparation.

Characteristics of APS_{83}: The larvae are plain and bluish white in colour. Cocoons are white and oval in shape with medium grains. Larval duration is 22 – 23 days. The breeding plan and the generation wise performance for the important quantitative and qualitative characters for the inbred line APS_{83} are presented in Fig. 1 and Table 1 respectively.

Development of breeding line APS_{102} (Peanut): The peanut inbred line APS_{102} was evolved from the peanut × peanut combination, $APS_4 \times APS_6$. The F_1 was reared in mass during January - February 2000. The larvae were plain and spun peanut cocoons. Mass (composite) rearings with random mating were continued from F_1 to F_3 for free mixing of genes. Cellular (Batch) rearings were resorted

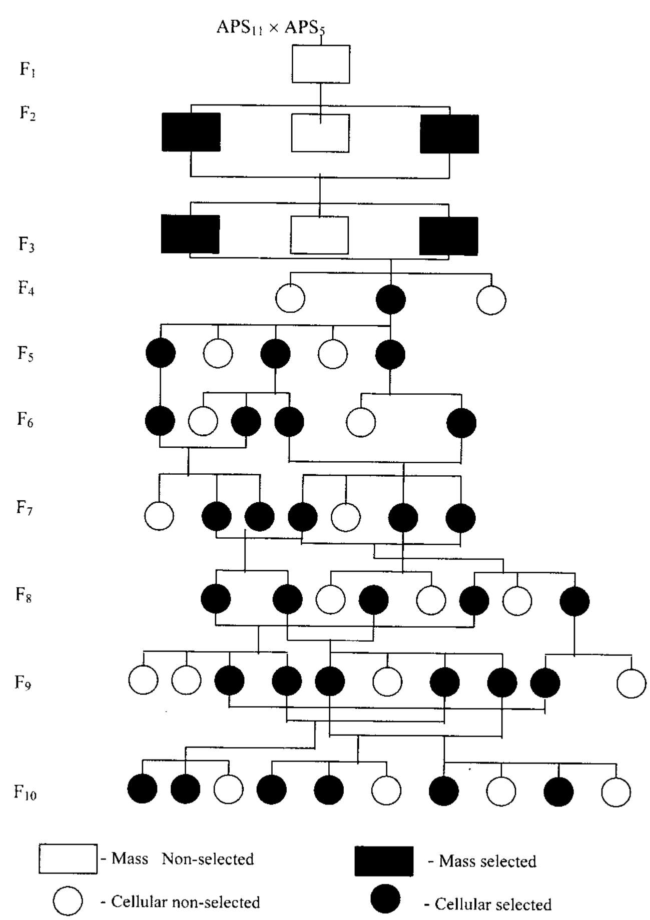

Fig. 1. Breeding plan of APS_{83} (Plain-Oval).

Table 1. Performance of APS_{83} (Generation-wise)

Generation	Fecundity (No.)	Pupation percentage (%)	Yield/ 10,000 L wt. (kg)	Cocoon weight (g)	Shell weight (cg)	Shell ratio (%)	Filament length (m)	Filament size (d)	Reelability (%)	Neatness (point)
F_1	445	94.0	20.5	1.80	43.2	24.0	1,327	2.50	83	91
F_2	495	91.7	18.1	2.00	43.7	21.9	1,008	2.46	80	90
F_3	510	92.9	20.9	2.07	44.6	21.6	1,056	2.54	81	90
F_4	576	95.2	18.5	1.80	39.8	22.1	921	2.59	73	88
F_5	520	90.0	14.6	1.53	35.2	23.0	932	2.64	83	89
F_6	524	89.3	13.9	1.69	37.7	22.3	998	2.52	79	87
F_7	536	90.0	14.2	1.68	37.0	22.1	1,028	2.26	80	90
F_8	530	96.1	14.8	1.40	31.5	22.5	989	2.66	83	88
F_9	518	92.7	13.8	1.45	33.8	21.7	839	2.72	82	87
F_{10}	513	89.2	14.7	1.61	36.0	22.4	1,021	2.57	87	90
F_{11}	536	94.0	13.5	1.41	32.5	23.0	989	2.39	81	89
F_{12}	508	93.9	16.9	1.71	38.1	22.3	1,129	2.51	87	91
F_{13}	610	89.1	15.3	1.67	35.1	21.1	994	2.62	87	89
F_{14}	548	90.2	15.4	1.65	34.8	21.1	918	2.64	80	87
Mean	537	89.9	16.4	1.72	37.7	21.7	1,007	2.59	82	89
S. D.	42.3	3.4	2.1	0.16	4.4	0.9	133.5	0.13	4.2	1.4

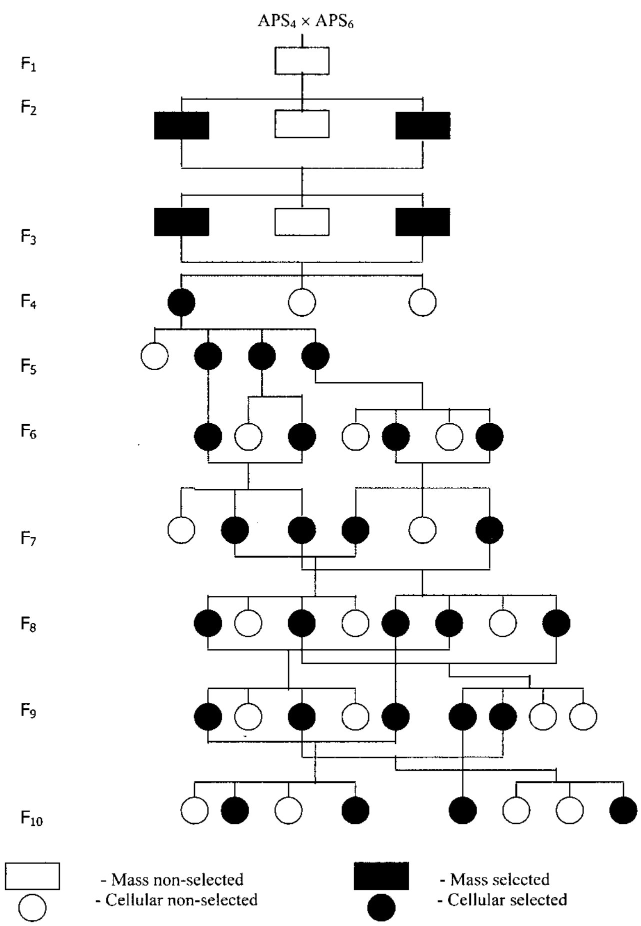

Fig. 2. Breeding plan of APS_{102} (Plain-Peanut).

from F_4 onwards. Selection pressure was applied for the targeted important characters like cocoon shape, pupation percentage, cocoon yield and high cocoon shell ratio, filament length, reelability and neatness at each generation. The individuals were selected from the batches showing cocoon uniformity and above average values (for all the batches) for the important quantitative and qualitative traits. By $F_{10,}$ among all the inbred lines APS_{102} showed uniformity in cocoon shape and stabilization for the desired quantitative and qualitative traits and the same is found to be the potential combiner for hybrid preparation.

Characteristics of APS_{102}: The larvae are plain and bluish white in colour. Cocoons are white and peanut in shape with medium grains. Larval duration is 22 – 23 days. The breeding plan and the generation wise performance for the important quantitative and qualitative characters for the inbred line APS_{102} are presented in Fig. 2 and Table 2 respectively.

Hybrid evaluation: After fixation, the newly developed inbred lines, APS_{83} and APS_{102} along with other newly evolved breeds were subjected for hybrid study following complete diallel method (Griffing, 1956) of Method I. A total of fifty hybrids including the reciprocal combinations were evaluated by Evaluation Index (EI) method as advocated by Mano *et al.* (1993). The hybrid, $APS_{83} \times APS_{102}$ was selected based on the average higher cumulative index value for the major silk contributing traits *viz.*, fecundity, pupation percentage, cocoon yield per 10,000 larvae by weight, cocoon weight, shell weight, shell ratio,

Table 2. Performance of APS_{102} (Generation-wise)

Generation	Fecundity (No.)	Pupation percentage (%)	Yield/ 10,000 L wt. (kg)	Cocoon weight (g)	Shell weight (cg)	Shell ratio (%)	Filament length (m)	Filament size (d)	Reelability (%)	Neatness (point)
F_1	508	90.1	17.3	1.89	41.1	21.8	923	2.64	79	86
F_2	457	92.9	17.0	1.78	38.2	21.5	908	2.46	77	83
F_3	471	93.4	17.2	1.82	39.5	21.7	1,011	2.41	78	87
F_4	508	94.1	17.7	1.82	39.5	21.7	887	2.43	78	85
F_5	525	94.9	17.4	1.81	39.2	21.5	882	2.55	77	89
F_6	467	96.3	15.4	1.78	37.9	21.3	985	2.34	79	86
F_7	501	89.5	14.7	1.64	32.5	19.8	822	2.53	81	88
F_8	518	92.8	17.7	1.75	36.9	21.2	979	2.90	76	89
F_9	502	90.0	14.8	1.59	33.9	21.3	829	2.68	78	86
F_{10}	481	88.8	16.3	1.85	38.4	20.8	993	2.48	84	89
F_{11}	512	95.0	18.1	1.65	34.6	20.9	961	2.56	81	88
F_{12}	500	87.5	17.1	1.79	36.9	20.6	1,026	2.44	84	89
F_{13}	465	93.0	16.3	1.62	33.7	20.9	977	2.52	85	89
F_{14}	505	88.2	14.8	1.62	34.1	20.9	881	2.73	84	89
Mean	494	91.8	16.6	1.74	36.5	21.0	952	2.58	81	88
S.D.	55.4	2.5	1.2	0.12	2.3	0.6	71.2	0.13	3.4	1.2

absolute silk content, filament length, raw silk recovery percent, reelability and neatness.

Characteristic features of the hybrid $APS_{83} \times APS_{102}$: The larvae are plain and bluish white in colour. Cocoons are white and intermediate in shape between oval and peanut. The larval period is 21 – 22 days. Further, this combination showed merit for quantitative and qualitative traits compared to the control hybrid. The percent improvement of evolved breed over control breeds (APS_9 and APS_8) and their hybrid with the control hybrid $APS_9 \times APS_8$ for different characters was calculated as for the formula followed by Datta *et al.* (2000a) as detailed below.

$$\text{Percent improvement} = \frac{\text{(Evolved breed/hybrid value} - \text{Control breed/hybrid value)}}{\text{Control breed/Hybrid value}} \times 100$$

The heterosis for different characters was also calculated based on mid parental value by following the formula.

$$\text{Heterosis \% (MPH)} = \frac{F_1 - \text{Mid Parent Value (MPV)}}{\text{Mid Parent Value}} \times 100$$

Results

Inbred lines

The generation wise mean values of the newly developed breeding lines APS_{83} (Oval) and APS_{102} (Peanut) are presented in Tables 1 and 2 respectively. The perusal of the data present that in APS_{83}, maximum pupation percentage of 96.1% is recorded in F_8 with overall mean of 89.9% at the end of F_{14} generation. APS_{102} showed maximum pupation percentage of 96.3% at F_6 with overall mean of 91.8% for 14 generations. The comparative average performance of the newly developed breeds with the respective control breeds is presented in Table 3. Further, the percent improvement of new breeds over control breeds APS_9 (Oval) and APS_8 (Peanut) are presented in Table 4. After stabilization both the new breeds APS_{83} and APS_{102} showed improvement in all metric traits over the control breeds. Maximum of 43.0% and 34.3% improvement is recorded for the trait filament length in the new breeds APS_{83} and APS_{102} respectively over the check varieties, APS_9 and APS_8 respectively.

Hybrid testing

The multiple trait evaluation index values for the newly evolved 50 hybrids including reciprocal combinations evolved at APSSRDI, Hindupur is presented in Tables 5 & 6. Among these hybrids 15 Oval × Peanut combinations and 16 reciprocal combinations recorded an average evaluation index above 50 are considered to possess economic merit. Among them, the combination $APS_{83} \times APS_{102}$ ranked first with E.I of 57.5 and 57.2 among Oval × Peanut and their reciprocal combination respectively. Considering the importance of utilizing the reciprocal combina-

Table 3. Comparative performance of new breeds with control breeds in the laboratory

Breed	Fecundity (No.)	Pupation percentage (%)	Yield/ 10,000 L wt. (kg)	Cocoon weight (g)	Shell weight (cg)	Shell ratio (%)	Filament length (m)	Filament size (d)	Raw silk (%)	Reelability (%)	Neatness (point)
Oval Breeds											
APS_{83}	537	89.9	16.4	1.72	37.7	21.7	1,007	2.54	17.8	82	89
APS_9 ©	515	86.5	13.6	1.51	30.1	19.9	704	2.62	15.5	78	86
Peanut Breeds											
APS_{102}	513	91.8	16.6	1.74	36.5	21.0	952	2.57	16.4	81	89
APS_8 ©	488	87.4	15.0	1.57	31.6	20.3	709	2.58	15.1	77	88

Table 4. Percent improvement of parental breeds over control breeds after stabilization

Breed	Fecundity (No.)	Pupation percentage (%)	Yield/ 10,000 L wt. (kg)	Cocoon weight (g)	Shell weight (cg)	Shell ratio (%)	Filament length (m)	Reelability (%)	Neatness (point)
Oval Breeds									
APS_{83}	537	89.9	16.4	1.72	37.7	21.7	1,007	82	89
APS_9 ©	515	86.5	13.6	1.51	30.1	19.9	704	78	86
Percent improvement	4.27	3.93	20.6	13.7	25.3	9.05	43.0	6	2.6
Peanut Breeds									
APS_{102}	494	91.8	16.6	1.74	36.5	21.0	952	81	89
APS_8 ©	488	87.4	15.0	1.56	31.6	20.3	709	77	88
Percent improvement	1.23	5.0	10.7	11.6	15.5	3.5	34.3	6	1.0

tions the average values for both direct and reciprocal combinations for all the 25 hybrid combinations are derived at as presented in Table 7. The data present that the hybrid $APS_{83} \times APS_{102}$ and its reciprocal combination recorded highest average evaluation index value of 57.4 and ranked first.

The laboratory performance of the new hybrid is presented in Table 8. This hybrid $APS_{83} \times APS_{102}$ showed promise with higher values for the traits higher pupation percentage (96.0%), cocoon yield by weight for 10,000 larvae (19.0 kg), cocoon weight (1.85 g), shell weight (41.7 cg), shell ratio (22.5%), absolute silk content for 10,000 larvae (4.27 kg), filament length (1,004 m), raw silk recovery (18.4%), reelability (88%) and neatness (92 point) over the control hybrid $APS_9 \times APS_8$ (90.8%, 16.6 kg, 1.70 g, 35.8 cg, 21.1%, 3.50 kg, 909 m, 16.7% 86.2%, and 89 point for respective traits). The new hybrid, showed higher percent improvement for absolute silk content (21.9), shell weight (16.5), cocoon yield per 10,000 larvae (14.5) and filament length (10.5).

Further, the hybrid exhibited positive heterosis (Table 9) to a varying degree for the characters under study compared to the control hybrid with higher heterosis recorded for the traits cocoon yield by weight for 10,000 larvae (15.2%), shell weight (12.4%) and reelability (8%).

Discussion

Successful silkworm breeding efforts contributed in the evolution of many productive and qualitatively superior bivoltine hybrids for commercial exploitation during the last decade (Basavaraja *et al.*, 1995, Datta *et al.*, 2000a, b, 2001). Many silkworm breeders in the sericultural countries succeeded in the development of bivoltine silkworm hybrids by exploiting the hybrid vigour reflected in the improvement of several qualitative and economic traits (Harada, 1961; Mano *et al.*, 1982; He *et al.*, 1991; Chen *et al.*, 1994; Datta *et al.*, 2000a, b, 2001).

Although India has made significant progress in the global silk production, there exists a great demand for quality bivoltine silk for internal consumption itself (about 15,000 Tons of bivoltine silk is required for sustaining multi - end and semi-automatic machines) that warrants more productive and qualitatively superior bivoltine hybrids. Accordingly, necessary emphasis is given to silkworm breeding for developing bivoltine hybrids yielding high quality raw silk besides better adaptability. In the present investigation, successful attempts are made in developing the productive bivoltine hybrid $APS_{83} \times APS_{102}$ that showed improvement and heterosis over the control hybrid for silk yielding traits. The data as presented in

Table 5. Performance of new hybrid combinations (Oval × Peanut)

Sl. no.	Combination	Fecundity (No.)	Pupation percentage (%)	Yield/ 10,000 L wt. (kg)	Cocoon weight (g)	Shell weight (cg)	Shell ratio (%)	Abs.silk content (kg)	Filament length (m)	Raw silk (%)	Reelability (%)	Neatness (point)	Avg. E.I.
1	$APS_{83} \times APS_{102}$	524	96.0	19.0	1.85	41.7	22.5	4.27	1,004	18.4	88	92	57.5
2	$APS_{75} \times APS_{102}$	510	97.0	19.2	1.89	41.6	22.1	4.24	923	18.7	85	90	55.2
3	$APS_{77} \times APS_{106}$	551	93.7	19.2	1.84	40.3	22.0	4.24	1,098	17.8	85	90	54.6
4	$APS_{79} \times APS_{100}$	500	96.1	17.9	1.84	42.3	23.0	4.18	1,042	19.4	87	86	53.6
5	$APS_{75} \times APS_{104}$	428	97.4	18.8	1.83	40.8	22.3	4.19	1,016	19.0	89	89	53.4
6	$APS_{77} \times APS_{100}$	518	92.9	17.8	1.80	41.2	23.0	4.18	1,182	18.6	80	89	52.9
7	$APS_{81} \times APS_{100}$	522	96.8	19.2	1.76	38.1	21.8	4.17	1,140	19.1	85	89	52.5
8	$APS_{75} \times APS_{108}$	555	94.4	18.7	1.86	39.5	21.3	3.97	1,137	17.4	87	90	52.3
9	$APS_{75} \times APS_{100}$	486	96.3	18.8	1.85	40.5	21.9	4.12	952	18.0	85	91	52.0
10	$APS_{81} \times APS_{104}$	516	97.3	19.6	1.88	38.7	20.6	4.03	1,113	17.9	88	87	51.5
11	$APS_{81} \times APS_{108}$	515	96.7	19.2	1.84	38.8	21.1	4.04	1,096	17.9	85	89	51.2
12	$APS_{77} \times APS_{102}$	515	89.9	17.6	1.86	41.1	22.2	3.89	1,136	17.6	88	90	51.1
13	$APS_{77} \times APS_{104}$	556	96.7	18.0	1.83	40.3	22.2	4.17	923	18.6	81	88	50.3
14	$APS_{79} \times APS_{104}$	487	95.3	17.9	1.81	40.6	22.5	4.01	1,071	17.4	85	89	50.2
15	$APS_{77} \times APS_{108}$	493	97.5	18.8	1.75	38.8	22.2	4.17	1,063	17.5	89	87	50.1
16	$APS_{83} \times APS_{104}$	453	94.2	17.5	1.75	39.5	22.7	3.96	1,146	18.9	89	88	49.5
17	$APS_{83} \times APS_{108}$	486	93.7	18.5	1.81	38.5	21.4	3.97	1,216	17.1	88	88	49.1
18	$APS_{79} \times APS_{108}$	456	95.4	19.3	1.86	38.7	20.8	4.02	1,102	16.2	85	91	49.0
19	$APS_{83} \times APS_{106}$	403	96.7	18.5	1.82	40.2	22.2	4.09	1,042	18.1	86	86	48.2
20	$APS_{75} \times APS_{106}$	595	93.0	17.9	1.87	41.6	22.3	3.99	944	14.9	72	91	47.4
21	$APS_{83} \times APS_{100}$	451	93.6	18.1	1.85	39.9	21.6	3.91	1,028	16.3	87	90	47.4
22	$APS_{81} \times APS_{102}$	473	95.7	19.1	1.86	37.7	20.3	3.87	1,044	17.2	86	89	46.5
23	$APS_{79} \times APS_{106}$	473	88.7	17.7	1.83	39.1	21.4	3.78	1,130	16.7	86	89	44.9
24	$APS_{79} \times APS_{102}$	485	94.1	18.5	1.57	39.6	21.6	3.99	975	17.2	82	91	44.4
25	$APS_{81} \times APS_{106}$	498	82.3	16.4	1.82	37.6	20.7	3.39	1,064	15.7	87	86	35.2

Table 6. Performance of new hybrid combinations (Peanut × Oval)

Sl. no.	Combination	Fecundity (No.)	Pupation percentage (%)	Yield/ 10,000 L wt. (kg)	Cocoon weight (g)	Shell weight (cg)	Shell ratio (%)	Abs.silk content (kg)	Filament length (m)	Raw silk (%)	Reelability (%)	Neat ness (point)	Avg. E.I.
1	$APS_{102} \times APS_{83}$	505	95.8	19.0	1.92	41.4	21.6	4.10	1,150	17.4	89	89	57.2
2	$APS_{106} \times APS_{83}$	604	95.9	19.3	1.93	42.7	22.1	4.27	1,010	17.9	84	90	56.5
3	$APS_{100} \times APS_{77}$	453	97.6	18.3	1.81	41.0	22.7	4.15	1,178	17.6	88	89	54.1
4	$APS_{104} \times APS_{75}$	597	96.8	18.6	1.92	41.4	21.7	4.03	1,056	17.6	85	89	53.9
5	$APS_{106} \times APS_{79}$	633	92.4	18.9	1.86	40.8	22.0	4.16	1,029	17.4	85	90	53.3
6	$APS_{104} \times APS_{79}$	570	97.4	18.2	1.79	40.6	22.7	4.12	1,037	16.6	85	88	53.1
7	$APS_{100} \times APS_{81}$	427	96.8	18.6	1.87	42.0	22.5	4.19	1,158	17.1	85	86	52.8
8	$APS_{102} \times APS_{75}$	469	96.5	18.9	1.93	40.9	21.3	4.02	1,004	18.4	83	90	52.5
9	$APS_{104} \times APS_{77}$	553	95.8	18.6	1.85	41.8	22.6	4.22	1,102	15.8	86	87	52.2
10	$APS_{102} \times APS_{77}$	436	94.7	18.7	1.88	41.2	22.1	4.12	1,167	16.3	85	89	52.1
11	$APS_{104} \times APS_{83}$	629	95.8	18.5	1.83	40.9	22.4	4.14	1,071	16.6	84	90	51.9
12	$APS_{106} \times APS_{81}$	611	95.3	18.6	1.85	39.3	21.3	3.95	1,008	17.6	85	91	51.7
13	$APS_{102} \times APS_{81}$	466	96.1	19.3	1.90	40.8	21.5	4.14	1,081	17.2	84	85	51.0
14	$APS_{100} \times APS_{75}$	482	96.9	18.9	1.79	39.5	22.1	4.18	1,033	16.1	85	90	50.9
15	$APS_{108} \times APS_{83}$	705	95.8	19.1	1.86	38.8	20.8	3.98	1,089	17.5	83	88	50.5
16	$APS_{100} \times APS_{79}$	428	97.3	18.2	1.88	42.0	22.4	4.08	1,033	16.4	84	88	50.3
17	$APS_{102} \times APS_{79}$	444	95.0	18.5	1.85	40.2	21.7	4.00	1,045	17.6	84	89	49.2
18	$APS_{100} \times APS_{83}$	408	95.0	18.0	1.85	40.7	22.0	3.96	1,144	16.3	80	89	48.2
19	$APS_{104} \times APS_{81}$	551	96.3	18.2	1.85	40.6	22.0	4.01	974	16.0	83	89	48.1
20	$APS_{108} \times APS_{81}$	546	96.2	19.1	1.81	37.9	20.8	3.99	921	17.1	80	90	46.2
21	$APS_{108} \times APS_{75}$	513	92.4	18.3	1.92	37.7	19.7	3.60	1,097	16.1	87	88	44.5
22	$APS_{106} \times APS_{75}$	629	86.7	17.2	1.91	40.4	21.2	3.64	1,094	17.3	82	87	44.4
23	$APS_{108} \times APS_{79}$	544	94.9	18.5	1.81	37.3	20.6	3.81	1,017	17.2	83	89	44.2
24	$APS_{106} \times APS_{77}$	622	84.0	16.8	1.89	40.8	21.6	3.64	955	17.1	82	89	43.0
25	$APS_{108} \times APS_{77}$	444	95.5	18.2	1.77	36.1	20.5	3.71	1,058	16.6	83	89	39.6

Table 7. Average evaluation index values for new hybrids

Sl. no.	Combination	E. I. value direct cross	E. I. value reciprocal cross	Average EI value of direct and reciprocal cross
1	$APS_{83} \times APS_{102}$	57.5	57.2	57.4
2	$APS_{75} \times APS_{102}$	55.2	52.5	53.8
3	$APS_{77} \times APS_{106}$	54.6	50.3	52.5
4	$APS_{79} \times APS_{100}$	53.6	50.3	51.9
5	$APS_{75} \times APS_{104}$	53.4	53.9	53.7
6	$APS_{77} \times APS_{100}$	52.9	54.1	53.5
7	$APS_{81} \times APS_{100}$	52.5	52.8	52.6
8	$APS_{75} \times APS_{108}$	52.3	44.5	48.4
9	$APS_{75} \times APS_{100}$	52.0	50.9	51.4
10	$APS_{81} \times APS_{104}$	51.5	48.1	49.8
11	$APS_{81} \times APS_{108}$	51.2	46.2	48.7
12	$APS_{77} \times APS_{102}$	51.1	52.1	51.6
13	$APS_{77} \times APS_{104}$	50.3	52.2	51.3
14	$APS_{79} \times APS_{104}$	50.2	53.1	51.6
15	$APS_{77} \times APS_{108}$	50.1	39.6	44.9
16	$APS_{83} \times APS_{104}$	49.5	51.9	50.7
17	$APS_{83} \times APS_{108}$	49.1	50.5	49.8
18	$APS_{79} \times APS_{108}$	49.0	44.2	46.6
19	$APS_{83} \times APS_{106}$	48.2	56.5	52.4
20	$APS_{75} \times APS_{106}$	47.4	44.4	45.9
21	$APS_{83} \times APS_{100}$	47.4	48.2	47.8
22	$APS_{81} \times APS_{102}$	46.5	51.0	48.7
23	$APS_{79} \times APS_{106}$	44.9	53.3	49.1
24	$APS_{79} \times APS_{102}$	44.4	49.2	46.8
25	$APS_{81} \times APS_{106}$	35.2	51.7	43.4

Table 8. Percent improvement in economic characters of $APS_{83} \times APS_{102}$ over control hybrid

Combination	Fecundity (No.)	Yield 10,000 L wt. (Kg)	Pupation percentage (%)	Cocoon weight (g)	Shell weight (cg)	Shell ratio (%)	Abs.silk content (kg)	Filament length (m)	Reelability (%)	Raw silk (%)	Neatness (point)
$APS_{83} \times APS_{102}$	524	19.0	96.0	1.85	41.7	22.5	4.27	1,004	88	18.4	92
$APS_9 \times APS_8$ ©	490	16.6	90.8	1.70	35.8	21.1	3.50	909	86	16.7	89
Percent improvement	6.9	14.5	5.7	8.8	16.5	6.6	21.9	10.5	3	4.2	2.7

Table 9. Hybrid vigour in new bivoltine hybrid $APS_{83} \times APS_{102}$

Breed/ Combination	Fecundity (No.)	Yield 10,000 L wt. (kg)	Pupation percentage (%)	Cocoon weight (g)	Shell weight (cg)	Shell ratio (%)	Filament length (m)	Raw silk (%)	Reelability (%)	Neatness (point)
APS_{83}	537	16.4	89.9	1.72	37.7	21.7	1,007	17.8	82	89
APS_{102}	494	16.6	91.8	1.74	36.5	21.0	952	16.9	80	89
Average	516	16.5	90.9	1.73	37.1	21.4	980	17.4	81	89
$APS_{83} \times APS_{102}$	524	19.0	96.0	1.85	41.7	22.5	1,004	18.4	88	92
MPH	1.7	15.2	5.7	6.9	12.4	5.4	2.5	6.1	8	4

Table 4 clearly indicate the superiority of the parental breeds APS_{83} (oval) and APS_{102} (peanut) over the respective control breeds *viz.,* APS_9 (oval) and APS_8 (peanut). The new hybrid $APS_{83} \times APS_{102}$ surpassed the control hybrid ($APS_9 \times APS_8$) in majority of qualitative and quantitative characters which can be attributed to the genotypic worth and the good combining ability of the parental materials developed. Further, the new hybrid also showed better improvement over the control hybrid for majority of the traits *viz.,* fecundity, pupation percentage, cocoon yield by weight, shell ratio, absolute silk content, filament length and raw silk and marginal improvement for the traits cocoon weight, reelability, raw silk and neatness. Such superiority of the new hybrids over the control hybrid is well established by many breeders (Datta *et al.*, 2000a, 2001). It is well established that the superiority of the hybrids is judged by their yield and yield attributes as compared to their parents through hybrid vigour (Hirobe, 1957; Harada, 1961; Kobayashi *et al.*, 1968; Subba Rao and Sahai, 1990; Mal Reddy *et al.*, 2003). In the present investigation also, the newly developed hybrid excelled in many characters of economic importance confirming the expression of hybrid vigour.

As observed by Kobari and Fujimoto (1966) that the selection for one character found to result in correlated changes in other quantitative characters of economic importance. Therefore, it is an absolute must for the breeder to balance the traits contributing to the increased qualitative productivity. It can be observed from the present study that there is considerable improvement in silk yield contributing traits such as shell weight, absolute silk content and filament length compared to the control hybrid, $APS_9 \times APS_8$. These observations corroborate with Datta *et al.*, (2000a, b, 2001). In contrast to Multivoltine × Bivoltine hybrids wherein the reciprocal combinations are not being used the bivoltine hybrids have an advantage of using the reciprocal combination even though there exists little difference in most of the combinations. These observations are well established by many for bivoltine hybrids. In the present study for the hybrid combination $APS_{83} \times APS_{102}$, the performance of its reciprocal combinations is on par with the direct cross so that its reciprocal combination can conveniently be utilized for commercial use that contribute to the effective utilization of seed cocoons of component races of component races, significant increase in the production of eggs, besides overall reduction in the cost of egg production. Considering the overall economic merit for the fitness, quantitative and qualitative traits, the new bivoltine hybrid $APS_{83} \times APS_{102}$ is adjudicated as the most promising for commercial exploitation.

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