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HTO5 x HTP5 , THE NEW BIVOLTINE SILKWORM (*BOMBYX MORI* L.) HYBRID WITH THERMO-TOLERANCE FOR TROPICAL AREAS

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ABSTRACT : Silkworm breeders across the country contributed significantly to the development of many bivoltine breeds not only with improved economic merit but also suitable for variable climatic conditions so as to make tropical based sericulture a sustainable avocation. However, there is a considerable dearth for seasonal and regional specific breeds and also breeds suitable for rearing throughout the year. Silkworm breeding is a continuous process aimed at evolving improved superior breeds to satisfy the changing needs of sericulture industry. In this direction, silkworm breeding attempts made at Andhra Pradesh State Sericulture Research & Training Institute (APSSRDI), Hindupur, India contributed in the development of thermo-tolerant bivoltine hybrid, HTO_5 x HTP_5. Fifty hybrid combinations involving 10 parents (5 each of oval and peanut) were evaluated in complete diallel pattern and identified the combination HTO_5 x HTP_5 as most promising. This hybrid showed economic merit for the characters fecundity – 519 eggs/laying; Cocoon yield per 10000 larvae by weight – 17.2 kg; Survival rate – 94.0 % - Single Cocoon weight – 1.833 g; Single Shell weight – 0.399g; Shell percentage – 21.7 %; Filament length – 996 m; Reelability – 85.0 % and Neatness – 89 points. The breeding process of constituent parental lines and identification HTO_5 x HTP_5 are discussed in the paper.

Key words: Silkworm, *Bombyx mori* L., breeding, generation, hybrid, heterosis, percent improvement

INTRODUCTION

India with a total production of about 15,610 MT that accounts for about 15.13% of global mulberry raw silk production ranks second among the mulberry silk producing countries of the world next to China. Since the bulk production being multivoltine x bivoltine (cross breed) type that lacks quality necessitated the popularization of bivoltine sericulture in a big way. With the re-orientation of silkworm breeding approaches aimed at sustainability and increased qualitative silk production, unstinted and coordinated efforts by various silkworm breeders in the country (Datta, 1984; Basavaraja *et al*., 1995 Ramesh Babu *et al*., 2005 and Lakshmi, 2008) resulted in the development of many bivoltine silkworm breeds and hybrids over the last two decades. Taking cue of exploiting the heterosis, various silkworm breeding efforts have significantly transformed the sericulture scenario by increased qualitative and quantitative production and in fact, silkworm is the only animal where hybrids are used compulsorily on commercial scale (Yokoyama, 1956). Systematic breeding approaches adapted by various silkworm breeders in different sericulturally advanced countries (Hirobe, 1957, Mano *et al*., 1982; Yang Mingguan, 1982; He and Oshiki, 1984, Mano *et al*., 1991, Chen *et al*., 1994; Tanaka and Ohi, 1994 and Datta *et al*., 2001) have contributed to synthesize silkworm (*Bombyx mori* L) genotypes of desirable constitution and improvement of several quantitative and qualitative traits of economic value.

As regards to Indian silkworm breeding scenario, the concept of breeding bivoltine breeds was initiated by Harada (1955) with the development of Kalimpong A (KA) that was used widely in many commercial hybrids. Subsequently, silkworm breeders at different research institutions contributed to the development of many bivoltine breeds/hybrids over years (Narasimhanna *et al*., 1976; Krishnaswami, 1978; Datta, 1984; Datta *et al*., 2000a, 200b, 2001; Raju, 1990; Trag *et al*., 1992; Raju and Krishnamurthy, 1993, Nirmal Kumar, 1995; Krishna Rao, 1998, Malik *et al*., 1999, Ramesh Babu *et al.,* 2001, 2002, 2003, 2004 and 2005; Siddiqui *et al*., 2003; Sudhakara Rao, 2003; Sudhakara Rao *et al*., 2004, Guruswamy, 2006; Moorthy *et al*., 2007) through genetic improvement of multiple traits. To make sericulture more viable occupation in tropical agro based countries particularly in India sustenance of bivoltine sericulture under tropical conditions continue to pose a challenge to the breeders despite the development of a number of silkworm bivoltine breeds and hybrids over years (Zho, 2002; Tazima and Ohnuma, 1995; Suresh Kumar *et al*., 2002, 2003, 2004, 2006b; Sudhakara Rao *et al*., 2001, 2004, 2006, 2007, Shirota, 1992; Krishna Rao *et al*., 2003). However, there remains considerable dearth for region and season specific bivoltine silkworm hybrids for commercial utilization. In this direction, the present study deals with the breeding process of the high temperature tolerant bivoltine hybrid, HTO_5 x HTP_5 and its merit of multiple quantitative and qualitative traits.

MATERIALS AND METHODS

Four bivoltine silkworm breeds namely APS_{19} and APS_7 (oval) and APS_{24} and APS_{12} (peanut) maintained in the bivoltine silkworm germplasm bank at Andhra Pradesh State Sericulture Research and Development Institute, Hindupur (AP) which showed tolerance to high temperature and low humidity conditions constituted the initial parental materials for the development of the high temperature tolerant bivoltine hybrid, HTO_5 x HTP_5. Two breeding plans one each for oval (HTO_5) and peanut (HTP_5) lines were initiated with the crossings of APS_{19} x APS_7 and APS_{24} x APS_{12} respectively. The larval populations were reared as composite from F1 to F3 generation at the target environmental conditions (high temperature of 32±1°C and low humidity of 50±5%) continuously and high temperature and low humidity and normal conditions at alternative generations. The resultant lines *viz*., HTO_5 and HTP_5 showing tolerance to target environment and economic superiority were developed by following conventional breeding protocols at different generations. Ten major silk contributing traits *viz*., fecundity, cocoon yield per 10000 larvae by weight, pupation percentage, cocoon weight, shell weight, shell ratio, filament length and neatness were assessed for the lines and the superiority of new bivoltine hybrid, HTO_5 x HTP_5 was established in comparison with other newly developed bivoltine hybrids (50 combinations) through multiple trait evaluation index method of Mano *et al*., (1993) as detailed below.

Breeding method and selection procedure

Development of breeding line HTO_5 (Oval)

The new oval type breeding line HTO_5 was evolved from oval x oval combination of APS_{19} x APS_7. Composite layings were prepared and mass reared under the target environment of high temperature of 32±1°C and low humidity of 50±5% conditions from F1 to F3. On the basis of size and shape, further breeding was continued with medium oval type cocoons. The selected cocoons on their individual merit were pooled and mated *en masse* to raise progeny from F1 to F3. From F4, the breeding progenies were reared as cellular batches with five replications at normal and high temperature conditions in alternate generations so as to regain the economic merit which was deteriorated under high temperature conditions. The broods showing high survival (pupation) besides qualitative and quantitative merit were selected in successive generations. During the course of breeding, the inbred lines were isolated through selection of desired characters such as cocoon shape, survival, cocoon yield and cocoon shell ratio with better quality traits and controlled progeny mating. By F11 the line HTO_5 that exhibited uniformity for cocoon shape and consistency for the metric traits under study respectively was considered as fixed and confirmed with non-significant differences between F11 and F12. The breeding plan of the line HTO_5 is presented in Fig.1.

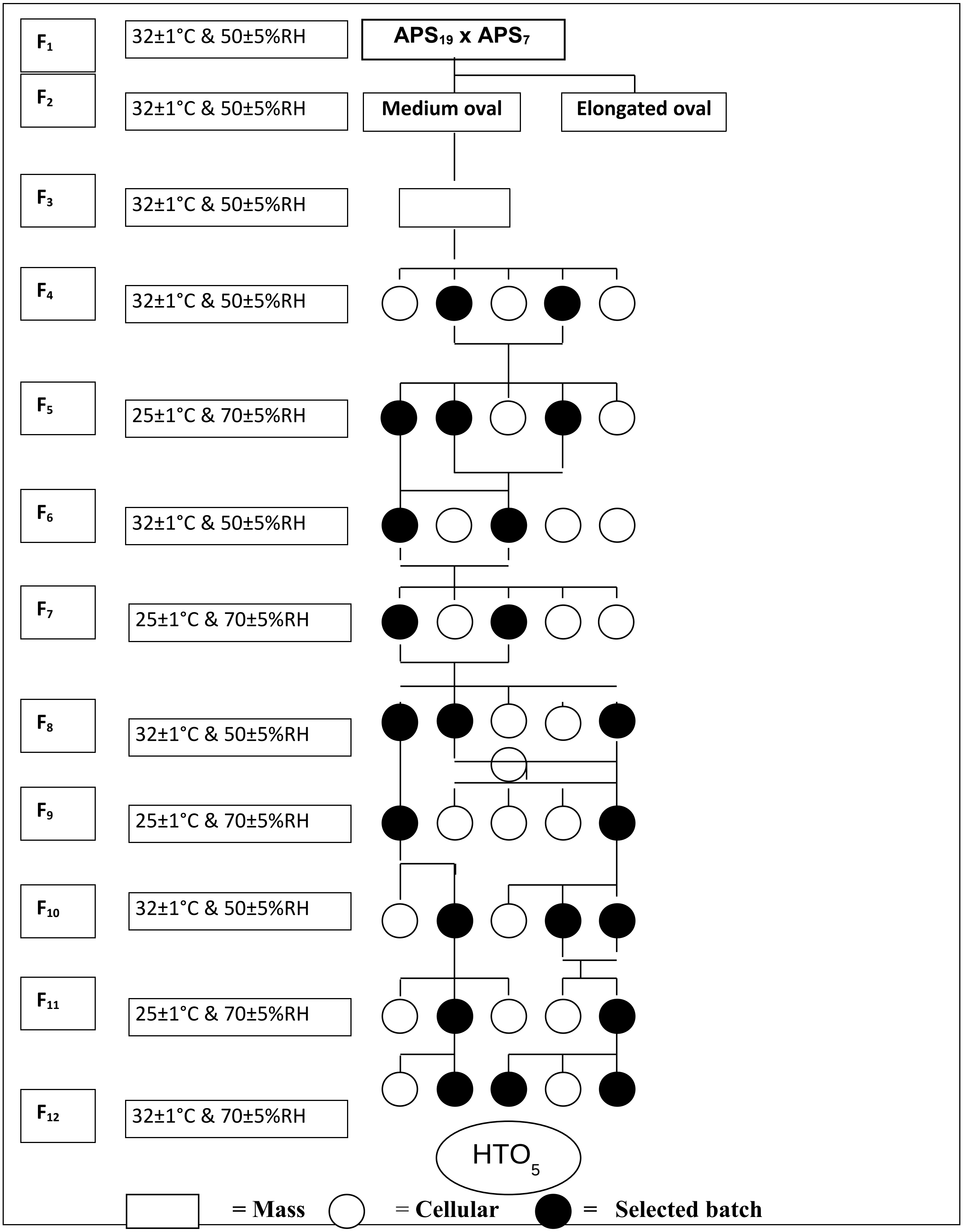

Fig**. 1. Breeding Plan of HTO$_5$**

Characteristics of HTO_5

The larvae are plain and bluish white in colour. Cocoons are white, oval in shape with medium grains. The larval duration is 22 – 23 days. The photographs of larvae and cocoons of HTO_5 are presented in Figs. 2 & 3 respectively.

Fig. 2. Larvae of HTO_5

Fig. 3. Cocoons of HTO_5

Table 1. Generation-wise performance of HTO_5

Generation	Fecundity (No.)	Survival (%)	ERR/ 10000 Larvae By Weight (kg)	Cocoon Weight (g)	Cocoon Shell Weight(g)	Cocoon Shell Ratio(%)	Filament Length(M)	NeatNess (p)
F1	444	91.3(72.9)	16.224	1.779	0.381	21.4	984	89
F2	489	90.8(72.8)	15.290	1.756	0.377	21.5	957	88
F3	488	90.7(72.2)	15.153	1.677	0.340	20.3	939	88
F4	482	87.7(69.5)	13.927	1.586	0.333	21.0	839	86
F5	468	87.6(69.4)	13.346	1.538	0.326	21.2	828	87
F6	505	90.6(72.2)	15.576	1.733	0.362	20.9	928	88
F7	511	89.0(70.6)	14.774	1.649	0.352	21.4	939	89
F8	500	91.7(73.3)	15.381	1.678	0.359	21.4	937	89
F9	514	91.2(72.7)	15.601	1.711	0.361	21.1	951	88
F10	505	89.5(71.1)	15.741	1.759	0.378	21.5	945	88
F11	523	92.9(74.6)	16.168	1.740	0.377	21.7	965	89
F12	508	94.6(76.6)	16.758	1.771	0.389	22.0	996	90
Mean	495	90.6(72.2)	15.388	1.698	0.361	21.3	934	88
CD at 5%	12.77	0.95	0.24	0.02	1.04	0.59	15.05	1.03

Development of breeding line HTP_5 (Oval)

The new oval type breeding line HTP_5 was evolved with the initial crossing of the parents females of APS24 crossed with males of productive bivoltine breed APS_{12} both having plain larvae and spinning white peanut cocoons and identified to possess tolerance to high temperature followed by further breeding and selection. Composite layings were prepared and mass reared under the target environment of high temperature of 32±1°C and low humidity of 50±5% conditions from F1 to F3. On the basis of size and shape, further breeding was continued with medium peanut type cocoons. The selected cocoons on their individual merit were pooled and mated *en masse* to raise progeny from F1 to F3. From F4, the breeding progenies were reared as cellular batches with five replications at normal and high temperature conditions in alternate generations so as to regain the economic merit which was deteriorated under high temperature conditions. The broods showing high survival (pupation) besides qualitative and quantitative merit were selected in successive generations. At F6, a back cross with APS_{12} was given for improvement of economic characters and the progenies were reared at high and normal room temperature conditions in alternate generations up to F12. During the course of breeding, low intensity of selection pressure was applied in early generations and due thrust was given on survival rate and other cocoon economic characters such as cocoon shape, survival, cocoon yield and cocoon shell ratio with better quality traits and controlled progeny mating at middle and late generations. The broods with higher survival besides other cocoon characters were selected at each of the succeeding generations from F6. By F10 the line HTP_5 exhibited uniformity for cocoon shape and consistency for the metric traits under study and considered as fixed and confirmed with non-significant differences between F11 and F12. The breeding plan of the line HTP_5 is presented in Fig.4 and Table 2 respectively.

Table 2. Generation-wise performance of HTP_5

Generation	Fecundity (No.)	Survival (%)	ERR/ 10000 Larvae by Weight (kg)	Cocoon Weight (g)	Cocoon Shell Weight (g)	Cocoon Shell Ratio (%)	Filament Length (M)	Neat-Ness (p)
F1	468	90.5(72.2)	16.146	1.776	0.381	21.5	927	89
F2	472	91.2(72.7)	16.085	1.757	0.377	21.5	954	88
F3	484	90.5(72.0)	15.438	1.699	0.347	20.5	895	85
F4	486	87.7(69.5)	13.915	1.579	0.334	21.2	889	86
F5	505	89.3(70.9)	14.517	1.618	0.343	21.2	818	87
F6	444	90.4(71.9)	15.656	1.725	0.364	21.1	923	84
F7	489	89.1(70.7)	15.117	1.689	0.353	20.9	949	87
F8	483	91.6(73.2)	16.512	1.795	0.376	21.0	990	89
F9	487	89.6(71.3)	15.604	1.733	0.369	21.3	990	87
F10	470	91.2(72.7)	15.359	1.678	0.357	21.3	865	90
F11	522	91.3(72.8)	16.344	1.783	0.380	21.3	1015	89
F12	511	91.0((72.5)	16.251	1.779	0.378	21.3	1021	90
Mean	485	90.3(71.9)	15.579	1.718	0.368	21.2	936	88
CD at 5%	23.73	1.65	0.451	0.047	1.513	0.484	49.3	2.63

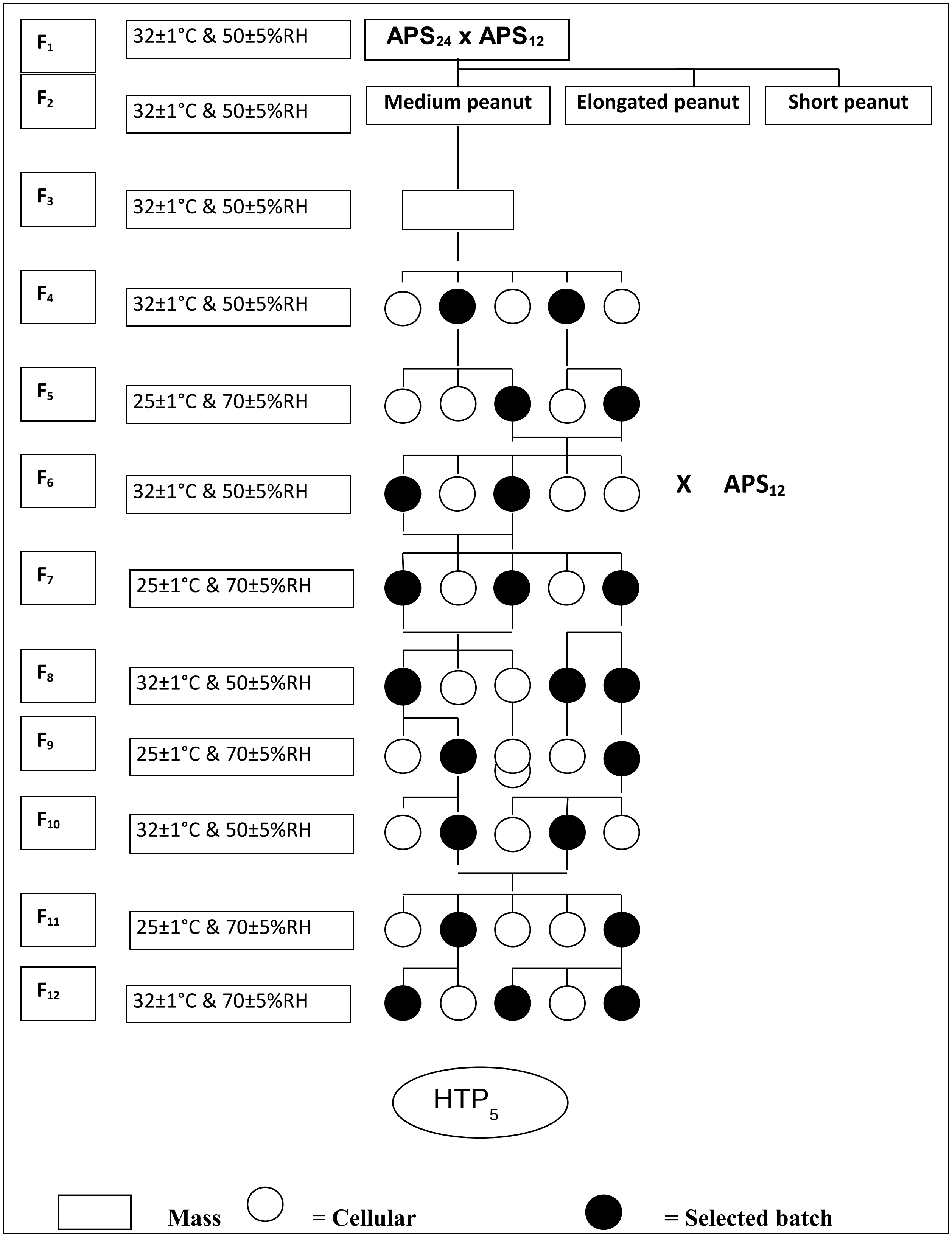

Fig. 4. Breeding Plan of HTP_5

Characteristics of HTP5

The larvae are plain and bluish white in colour. Cocoons are white, peanut in shape with medium grains. The larval duration is 22 – 23 days. The photographs of larvae and cocoons of HTP_5 are presented in Figs. 5 & 6 respectively.

Fig. 5. Late age Larvae of HTP_5

Fig. 6. Cocoons of HTP_5

Hybrid evaluation

The newly developed lines, HTO_5 (oval) and HTP_5 (peanut) along with other newly evolved breeds were subjected for hybrid study following complete diallel method (Method-1, Griffing, 1956). A total of fifty hybrids including the reciprocal combinations were evaluated by Evaluation Index Method (Mano *et al*., 1993). The superiority of the hybrid HTO_5 x HTP_5 was established with the average higher Evaluation Index value for the major silk contributing traits *viz.,* Fecundity, Hatching percentage, cocoon yield/10000 larvae by weight, survival rate, cocoon weight, cocoon shell weight, cocoon shell ratio, filament length and raw silk recovery (over green cocoons).

Characteristics of HTO5 x HTP5

The larvae are bluish white in colour and robust in nature (Fig.7). Cocoons are white and intermediate in shape between oval and peanut (Fig.8). The larval period is 21 – 22 days. The hybrid showed overall merit for quantitative and qualitative traits compared to the check hybrid' CSR_{18} x CSR_{19}. The percent improvement of evolved breeds (HTO_5 & HTP_5) over control breeds, CSR_{18} (oval) and CSR_{19} (peanut) and their hybrid with the check hybrid, CSR_{18} x CSR_{19} for different characters was calculated as for the formula (Datta *et al*., 2000a) as detailed below.

Fig. 7. Late age larvae of HTO5 x HTP_5

Fig. 8. Cocoons of HTO5 x HTP_5

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

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

$$\text{Heterosis \% (MPH)} = \frac{\text{F1 - Mid Parent Value (MPV)}}{\text{Mid Parent Value}} \times 100$$

RESULTS

The generation-wise mean values of the newly developed lines, HTO_5 and HTP_5 are presented in Tables 1 and 2 respectively. Analysis of the data present that the in HTO_5, the mean survival percentage (pupation %) recorded was 90.6% with a maximum of 91.7% at F8 that showed consistency in the later generations and recorded 94.6% at F12. HTP_5 recorded maximum survival of 91.6% at F8 with overall mean of 90.3%. The survival rate showed stability in later generations. The higher survival in the newly evolved lines indicates their productive merit over the control breeds (Table3). The comparative average performance of the new breeds and their superiority over cocoon traits through percent improvement with their respective control breeds in the laboratory is presented in Table 4. The new breeds HTO_5 and HTP_5 showed improvement in all metric traits under study over the control breeds. HTO_5 recorded highest percent improvement for the trait shell weight (16.0%) while HTP_5 for the trait fecundity (8.89%).

Table 3. Comparative performance of new breeds in the laboratory

Breed	Fecun-dity(No.)	Survival Rate(%)	Yield/10000 Larvae/ Weight (kg)	Cocoon weight(g)	Shell Weight(g)	Shell Ratio(%)	Filament Length (m)	Reel-ability(%)
Oval Breeds								
HTO5	501	92.2	16.1	1.745	0.377	21.9	906	84.1
CSR18 ©	476	91.0	13.9	1.525	0.325	21.2	803	81.2
Peanut Breeds								
HTP5	515	92.0	14.0	1.661	0.369	22.2	960	83.7
CSR19	473	90.0	14.2	1.575	0.342	21.7	838	82.9

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

Breed	Fecun-dity(No.)	Survival Rate(%)	Yield/10000 Larvae/ weight(kg)	Cocoon weight(g)	Shell Weight(g)	Shell Ratio(%)	Filament Length(m)
HTO5	5.25	1.32	15.83	14.4	16.0	3.30	12.8
HTP5	8.89	2.22	7.74	5.46	7.89	2.30	14.6

Hybrid Testing

The hybrid HTO_5 x HTP_4 showed economic merit for the 9 traits *viz.*, fecundity (519 eggs/laying), cocoon yield per 10000 larvae by weight (17.2 kg), survival rate (94.0 %), single cocoon weight (1.833 g), single shell weight (0.399g), shell percentage(21.7 %), filament length (996 m), reelability (85.0 %) and Neatness (89 p). The evaluation index (EI) values for multiple traits for the newly evolved 50 hybrid combinations (including reciprocal combinations) is presented in Table 5 (direct) and Table 6 (reciprocal). The analysis present that among the direct crosses, 11 crosses *viz*., HTO_1 x HTP_1 (57.3) , HTO_1 x HTP_3 (59.3), HTO_2 x HTP_1 (51.6), HTO_2 x HTP_3 (55.6), HTO_2 x HTP_4 (58.0), HTO_3 x HTP_3(56.7), HTO_4 x HTP_1 (59.0), HTO_4 x HTP_3(58.4), HTO_5 x HTP_2(61.7), HTO_5 x HTP_4(59.6) and HTO_5 x HTP_5(64.7) and among the reciprocal combinations, 15 combinations *viz.,* HTP_1 x HTO_3 (53.1), HTP_1 x HTO_4 (50.6), HTP_1 x HTO_5 (55..0), HTP_2 x HTO_1(50.9), HTP_2 x HTO_5 (55.2), HTP_3 x HTO_1(55.4), HTP_3 x HTO_2(54.5), HTP_4 x HTO_1(51.9), HTP_4 x HTO_3(50.4), HTP_4 x HTO_4(50.8), HTP_5 x HTO_1(54.1), HTP_5 x HTO_2 (54.9), HTP_5 x HTO_3(54.3), HTP_5 x HTO_4 (59.1) and HTP_5 x HTO_5(60.3) recorded average EI values for multiple traits (8) over 50 and are considered to possess economic merit.

The hybrid HTO5 x HTP5 (59.6) and its reciprocal cross (60.3) with highest EI over multiple traits excelled over other combinations. Further, the new combination recorded higher percent improvement over its control for all the 9 traits studied with highest (17.7%) improvement was recorded for the trait shell weight over the control hybrid (Table 7). The new hybrid also exhibited positive heterosis to a varying degree (Table 8) for different traits under study that ranged from a high of 13.9% (cocoon yield / 10000 larvae by weight) to a low of 1.31% (reelability) and establishes its superiority over the control hybrid.

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

Combi-nation	Fecun-dity(No.)	Survival Rate (%)	Yield/10000 Larvae/Wt.(kg)	Cocoon weight (g)	Shell Weight (g)	Shell Ratio (%)	Filament Length (m)	Raw Silk (%)	EI value
HTO1 x HTP1	526	93.3 (75.0)	17.7	1.894	0.424	22.41	999	17.9	57.3
HTO1 x HTP2	450	92.0 (73.6)	16.3	1.774	0.347	19.54	860	18.2	46.8
HTO1 x HTP3	536	93.9 (75.7)	18.8	2.004	0.421	21.01	1066	18.2	59.3
HTO1 x HTP4	453	81.4 (64.5)	15.2	1.864	0.404	21.70	836	17.1	45.9
HTO1 x HTP5	445	87.8 (69.6)	14.5	1.649	0.337	20.44	828	17.1	42.3
HTO2 x HTP1	535	95.4 (77.6)	18.7	1.957	0.397	20.31	829	16.0	51.6
HTO2 x HTP2	475	83.8 (66.3)	14.7	1.751	0.329	18.80	829	17.0	41.1
HTO2 x HTP3	445	94.0 (75.8)	18.9	2.012	0.421	20.92	1047	19.0	55.6
HTO2 x HTP4	516	93.9 (75.7)	18.2	1.941	0.418	21.55	1040	18.3	58.0
HTO2 x HTP5	473	83.1 (65.7)	15.5	1.868	0.361	19.32	831	16.5	42.7
HTO3 x HTP1	462	72.9 (58.6)	12.9	1.766	0.345	19.55	839	17.1	40.6
HTO3 x HTP2	445	90.9 (72.4)	15.4	1.694	0.317	18.68	770	16.1	41.1
HTO3 x HTP3	505	93.9 (75.7)	18.7	1.993	0.427	21.45	1006	18.1	56.7
HTO3 x HTP4	457	85.3 (67.5)	16.5	1.936	0.338	17.45	895	16.7	42.4
HTO3 x HTP5	448	82.0 (64.9)	14.1	1.709	0.329	19.26	854	16.5	39.3
HTO4 x HTP1	513	93.1 (74.8)	18.9	2.029	0.437	21.56	1060	18.1	59.0
HTO4 x HTP2	465	76.7 (61.1)	14.2	1.858	0.374	20.12	822	16.9	44.9
HTO4 x HTP3	516	94.2 (76.1)	19.4	2.057	0.426	20.70	1057	17.6	58.4
HTO4 x HTP4	451	77.7 (61.8)	16.0	2.043	0.401	19.68	839	17.1	47.5
HTO4 x HTP5	451	69.9 (56.4)	14.0	2.000	0.383	19.16	822	16.1	43.1
HTO5 x HTP1	454	78.7 (62.5)	14.7	1.863	0.368	19.76	1006	18.1	48.2
HTO5 x HTP2	534	96.3 (78.9)	19.6	2.035	0.429	21.08	1075	18.9	61.7
HTO5 x HTP3	455	81.8 (64.8)	15.5	1.893	0.325	17.21	854	16.5	42.1
HTO5 x HTP4	468	93.5 (75.2)	19.2	2.057	0.442	21.53	1148	18.5	59.6
HTO5 x HTP5	541	95.6 (77.9)	20.1	2.103	0.461	21.93	1176	18.9	64.7
Average	481	87.2	16.7	1.910	0.386	20.21	936	17.5	
S.D	35.2	7.9	2.2	0.103	0.032	1.4	122	0.9	
CV%	7.3	9.0	13.1	6.7	11.4	6.7	13.0	5.4	

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

Combi-nation	Fecun-dity(No.)	Survival Rate(%)	Yield/10000 Larvae/Wt.(kg)	Cocoon weight(g)	Shell Weight(g)	Shell Ratio(%)	Filament Length(m)	Raw Silk(%)	EI value
HTP1 x HTO1	489	92.5 (74.1)	15.7.	1.656	0.358	21.60	897	16.5	48.2
HTP1x HTO2	451	91.1 72.6)	12.8	1.474	0.284	20.65	686	16.5	38.3
HTP1 x HTO3	545	90.8 72.3)	17.5	1.935	0.417	21.54	979	16.8	53.1
HTP1 x HTO4	456	90.4 71.9)	15.4	1.802	0.411	22.88	996	18.5	50.6
HTP1 x HTO5	477	93.2 74.9)	16.7	1.828	0.416	22.83	914	18.1	55.0
HTP2 x HTO1	495	90.7 72.2)	17.7	1.951	0.415	21.25	956	17.5	50.9
HTP2x HTO2	482	89.8 71.4)	15.4	1.681	0.366	21.80	888	17.3	47.2
HTP2 x HTO3	476	89.6(71.2)	11.0	1.371	0.277	20.20	752	15.8	33.5
HTP2 x HTO4	442	91.3 72.9)	16.3	1.841	0.420	22.90	811	17.9	48.4
HTP2 x HTO5	518	89.9 71.5)	17.6	2.010	0.440	21.90	1060	17.9	55.2
HTP3 x HTO1	532	89.2 70.7)	17.9	2.032	0.455	22.39	963	18.0	55.4
HTP3 x HTO2	532	90.5 72.1)	17.5	1.886	0.446	21.80	997	18.0	54.5
HTP3 x HTO3	530	88.9 70.5)	13.8	1.537	0.340	22.10	752	16.7	44.6
HTP3 x HTO4	583	88.9 70.5)	12.3	1.313	0.284	21.60	595	17.5	41.8
HTP3 x HTO5	448	88.0 69.7)	15.3	1.703	0.412	24.20	827	18.7	49.0
HTP4 x HTO1	505	87.3 69.1)	14.5	1.720	0.414	24.08	975	18.3	51.9
HTP4 x HTO2	450	90.1 71.7)	14.8	1.704	0.393	23.10	805	18.2	46.7
HTP4 x HTO3	560	88.2 69.9)	16.9	1.946	0.412	21.20	805	17.5	50.4
HTP4 x HTO4	501	92.2 73.8)	15.5	1.618	0.367	22.70	834	17.6	50.8
HTP4 x HTO5	535	92.2 73.8)	12.4	1.396	0.283	20.25	729	16.2	42.0
HTP5 x HTO1	603	88.7 70.4)	17.8	1.994	0.442	22.17	855	17.2	54.1
HTP5 x HTO2	540	91.8 73.4)	17.3	1.986	0.437	21.99	1122	16.1	54.9
HTP5 x HTO3	483	92.0 73.6)	17.1	1.803	0.428	23.75	945	18.2	54.3
HTP5 x HTO4	550	93.0 74.7)	17.3	1.890	0.436	23.10	1038	18.3	59.1
HTP5 x HTO5	595	94.7(76.7)	17.5	1.936	0.452	23.33	1123	18.7	60.3
Average	511	90.6	15.8	1.760	0.392	22.21	892	17.5	
S.D	46.7	1.783	1.956	0.21	0.06	1.08	134.0	0.85	
CV%	9.1	1.968	12.41	12.1	14.6	4.9	15.0	4.8	

*NOTE: Values indicated in the parenthesis are angularly transformed

Table 7. Percent improvement in economic characters of HTO5 x HTP5 over control hybrid

Combination	Fecun-dity(No.)	Survival Rate(%)	Yield/10000 Larvae/ weight(kg)	Cocoon weight(g)	Shell Weight (g)	Shell Ratio (%)	Filament Length (m)	Reel-ability (%)	Neat-ness (p)
HTO5 x HTP5	519	94.0 (75.8)	17.2	1.833	0.399	21.7	996	85.0	89
CSR18x CSR19	443	91.2 (72.7)	15.0	1.614	0.339	21.0	830	83.4	85
Percent improvement	17.2	3.07	14.7	13.6	17.7	3.33	20.0	1.92	4.7

Table 8. Hybrid vigour in HTO_5 x HTP_5

Breed/ Combination	Fecun-dity(No.)	Survival Rate(%)	Yield/10000 Larvae/ weight(kg)	Cocoon weight (g)	Shell Weight (g)	Shell Ratio (%)	Filament Length (m)	Reel-ability (%)
HTO5	501	92.2	16.1	1.745	0.377	21.9	906	84.1
HTP5	515	92.0	14.0	1.661	0.369	22.2	960	83.7
Average	508	92.1	15.1	1.678	0.373	22.1	933	83.9
HTO5 x HTP5	519	94.0	17.2	1.833	0.399	21.8	996	85.0
MPH	2.17	2.06	13.9	9.24	6.97	1.38	6.75	1.31

DISCUSSION

Widespread utilization of hybrids towards achieving sustainability and quality oriented increased production is well established in plants and animals. Silkworm is the best exemplified animal where hybrids are used compulsorily for commercial silk production (Yokoyama, 1976). Several workers across the sericulture countries including India have realized the significant impact of silkworm hybrids through exploitation of hybrid vigour for increased quantitative and qualitative silk productivity besides crop stability on commercial scale and succeeded in the development bivoltine silkworm hybrids (Harada, 1961; Mano *et al*., 1982; He *et al*., 1991; Chen *et al*., 1994; Basavaraja *et al*.,1995; Datta *et al*., 2000a, 2000b, 2001; Sudhakara Rao *et al*., 2001, Suresh Kumar *et al*., 2002, 2003, 2004 and 2006b; Chandrashekhariah and Ramesh Babu, 2003; Ramesh Babu *et al*., 2005c). The goal of breeding is to bring together the desirable genes in appropriate combinations and allow them to recombine so as to improve the genetic performance of maximizing the yield and productivity per unit population (Nirmal Kumar and Sreerama Reddy, 1994). Since the breeding is a continuous process, the goal is to improve the silk yield continuously suiting to the requirements of the industry. Accordingly, the breeding approaches are reoriented and many bivoltine silkworm breeds have been developed over years by many silkworm breeders in the country (Krishna Rao, 1998;; Datta *et al*., 2000a, 2000b and 2001; Naseema Begum *et al*., 2001, Ramesh Babu *et al*., 2001, Krishna Rao *et al*., 2003 and Guruswami, 2006) with qualitative and quantitative merit besides better adaptability to different environmental conditions. However, most of the bivoltine hybrids so developed have been identified for rearing during favourable months (August to February) in south India leaving out a few suitable to the hot climatic conditions of tropics prevailing particularly summer necessitating more efforts towards the development of temperature tolerant bivoltine hybrids in the country. The effect of temperature on silkworm was reported earlier by many scientists (Takeuchi *et al*., 1964; Ohi and Yamashita, 1977; Huang et al., 1979, He and Oshiki, 1984). The present study was carried out to develop suitable high temperature tolerant bivoltine breeds/hybrids to the target environment with high temperature (32±1°C) and low humidity conditions (50±5%) by following the Chinese method (exposure of larvae from brushing up to spinning stage) of developing high temperature tolerant bivoltine breeds as observed by Falconer (1990) that the performance of insect could be improved by selection in the environment in which it is subsequently exploited. However, Shirota (1992) and Tazima and Ohnuma (1995) confirmed the genetical heritability nature of themotolerance by selection based on pupation rate (survival) of silkworms reared under high temperature conditions in fifth instar. In the present study, both the newly evolved lines HTO_5 and HTP_5 showed superiority with higher survival than their respective control breeds under target environmental conditions. Further, the higher survival recorded for the new hybrid, HTO_5 x HTP_5 (94.0%) compared to the parents corroborate the observations of Suresh Kumar and Yamamoto (1995) who indicated higher tolerance (survival) in hybrids than pure breeds and operation of maternal effect as evident from the better performance of hybrid where the female parent used was more tolerant as pure breed. As suggested by Datta *et al*., (1997), appropriate selection procedure was followed in the present study involving temperature as one of the environmental factors for balancing the viability traits with cocoons traits. Since selection for one character found to result in correlated changes in other quantitative characters of economic importance (Kobari and Fujimoto, 1966), it is observed from the present study that there is considerable improvement in silk yield contributing traits such as fecundity, cocoon yield by weight, shell weight and filament length compared to the control hybrid, CSR_{18} x CSR_{19} and thus corroborate the earlier observations of Datta *et al*., 2000a, b and 2001, Sudhakara Rao, 2003, Ramesh Babu *et al*., 2005c, Chandrashekharaiah *et al*., 2006 and Lakshmi, 2008). It is also well established that the superiority of the hybrids is judged by their yield and yield attributes through hybrid vigour (Hirobe, 1967; Harada, 1961; Kobayashi *et al*., 1968; Subba Rao and Sahai, 1990; Mal Reddy *et al*., 2003 and Chandrashekharaiah *et al*., 2006, Lakshmi, 2008) as is for the new hybrid, HTO_5 x HTP_5. To establish the superiority of the hybrids several silkworm breeders (Ramesh Babu *et al*., 2005b Vidyunmala *et al*., 1998; Lakshmi, 2008) followed the Evaluation Index method wherein each character having a minimum value of more than 50 was considered for selection in order to give equal weightage to all the characters of economic importance.

Accordingly, the superiority of the new hybrid combination, HTO_5 x HTP_5 is established with highest average Evaluation Index value over multiple traits. Further, in contrast to multivoltine x bivoltine hybrids wherein the reciprocal combinations are not being used, the bivoltine hybrids have an advantage of using the reciprocal combination even though there exist minor differences in most of the combinations. In the present study also in agreement with Chandrashekharaiah *et al.,* (2006) for the hybrid combination, HTO_5 x HTP_5, in which the performance of its reciprocal combination is on par with the direct combination so that the reciprocal combination could conveniently be utilized for commercial exploitation and contribute to the effective utilization of seed cocoons of component races, significant increase in the egg production besides overall reduction in the cost of egg production. In light of the overall economic merit for the fitness, quantitative and qualitative traits and hybrid vigour, the new hybrid, HTO_5 x HTP_5 is adjudicated as most promising for commercial exploitation under high temperature and low humidity conditions.

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