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EXPRESSION OF HETROSIS IN SILKWORM HYBRIDS, *BOMBYX MORI* (LEPIDOPTERA: BOMBYCIDAE) TOLERANT TO HIGH TEMPERATURE AND HIGH AND LOW HUMIDITY CONDITIONS OF THE TROPICS

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ABSTRACT: In order to introduce bivoltine races in a tropical country like India, it is necessary to have stability in cocoon crop under high temperature environment. Considering the poor performance of productive bivoltine hybrids during summer season, emphasis was given to evolve bivoltine silkworm breeds suitable to tropical conditions for achieving the primary objective of establishing bivoltine sericulture with quality raw silk among sericulturists. One of the main aims of the breeders is to recommend silkworm breeds/hybrids to farmers that are stable under different environmental conditions and minimize the risk of falling below a certain yield level. Silkworm breeds that are reared over a series of environment exhibiting less variation are considered stable. Therefore, it becomes imperative or essential to develop bivoltine breeds/hybrids which can with stand high temperature stress conditions. Attempts in this direction has led to the development of single and double hybrids tolerant to high temperature

Key words : *Bombyx mori* **,** temperature tolerant**,** bivoltine hybrid, hybrid vigour

INTRODUCTION

The continued efforts for the improvement of cocoon characters of domesticated silkworm were aimed at increased quality silk production. The main objective of silkworm rearing is to produce qualitatively and quantitatively superior cocoons, which in turn will have a direct bearing on the raw silk production. Therefore, it becomes imperative or essential to develop silkworm breeds/hybrids which can with stand high temperature stress conditions. Sericulture, the viable agro-based industry aptly matches the socio-economic backdrop of rural India. One of the main aims of the breeders is to recommend silkworm breeds/hybrids to farmers that are stable under different environmental conditions and minimize the risk of falling below a certain yield level. Silkworm breeds that are reared over a series of environment exhibiting less variation are considered stable. The climatic conditions prevailing in the tropics are most unpredictable and the problems of tropical sericulture are occurrence of aggravated silkworm diseases, unsuitable mulberry leaf for bivoltine silkworms and lack of sustainable silkworm breeds for effective selection of desirable characters. In order to introduce bivoltine races in a tropical country like India, it is necessary to have stability in cocoon crop under high temperature environment. The pre-requisite of summer hybrid is healthiness and adaptability to adverse conditions of high temperature, low food quality, relatively higher economic traits, with potential for increased cocoon production.

Silkworm breeding aims to achieve superior performances in respect of egg yield, cocoon raw silk yield, cocoon stability and production followed by expansion to new areas besides others. Silkworm breeders continue to strive for an inherent gain in resistance by incorporating resistant genes into the genetic backgrounds of high yielding temperate bivoltines. Besides this, the cocoon crop stability also relies more on improving other production technologies which have to be explored. India enjoys the patronage of second position for the production of silk in the world next only to China. Sericulture in India is practiced predominantly in tropical environmental regions such as Karnataka, Tamil Nadu, Andhra Pradesh and West Bengal and to a limited extent in temperate environment of Jammu and Kashmir.

The existing tropical situation provides scope for exploiting multivoltine x bivoltine hybrid at commercial venture as they are hardy and have tremendous ability to survive and reproduce under varied or fluctuating environmental climatic conditions. But its quality is at low ebb when compared to the existing international standard.

Considering these drawbacks, adoption of bivoltine sericulture became imperative and imminent considering its potentiality even under Indian tropical conditions. Keeping this in view, breeding experiments were initiated at Central Sericultural Research and Training Institute, Mysore to evolve hardy bivoltine silkworm races suited to tropical conditions for achieving the primary objective of establishing bivoltine hybrids as a concept among sericulturists. Accordingly, many productive and qualitatively superior bivoltine hybrids have been developed by utilizing Japanese commercial hybrids as breeding resource material [4].However, the hot climatic conditions prevailing particularly in summer are not conducive to rear these high yielding bivoltine hybrids throughout the year. It is well established fact that under tropical condition, unlike polyvoltines, bivoltines are more vulnerable to various stresses i.e hot climatic conditions of tropics, poor leaf quality and improper management during summer which are not conducive for bivoltine rearing. In order to select efficiently the breeds with high temperature tolerance, it is important to analyse the impact of high temperature on many silk yielding attributes of silkworm races and their heritability.

The hot climatic conditions of tropics prevailing particularly in summer are contributing to the poor performance of the bivoltine breeds and the most important aspect is that many quantitative characters such as viability and cocoon traits decline sharply when temperature is higher than 28°C [30]. Therefore, it is very much essential to develop bivoltine breeds/hybrids which can withstand the high temperature stress conditions. Keeping these in view compatible bivoltine hybrids for rearing throughout the year were developed by utilizing Japanese thermo-tolerant hybrids as breeding resource material [7, 8, 9, 36, 38] and suggested that any study involving cocoon traits is a trend setter to provide basis to formulate appropriate selection policies for required environments. While studying the performance of robust and productive hybrids under two temperature conditions [35, 9] indicated that the deleterious effect of high temperature was more pronounced in productive hybrids than the robust hybrids. Keeping this in view, attempts to develop compatible hybrids has led to the development of single and double hybrids tolerant to high temperature and high and low humidity situations of the tropics. The present study deals with the expression of hybrid vigour of these hybrids under different temperature and humidity conditions.

MATERIALS AND METHODS

Twenty two silkworm breeds were drawn from the germplasm of Central Sericultural Research and Training Institute, Mysore and screened under high temperature and high humidity conditions (40+1˚C and high humidity i.e. 85+5%,) to select the breeding resource materials [14]. Silkworm rearing was conducted by following the standard method under recommended temperature and humidity till 2nd day of 5th instar. On the third day of 5th instar 10 replicates of 100 larvae/breed were subjected to temperature treatments for six hours daily i.e., from 10AM to 4PM till spinning. The remaining larvae served as control and were reared at 25+1˚C and 65+5% relative humidity. For thermal exposure, the larvae were kept in plastic trays and reared in SERICATRON (Environmental chamber with precise and automatic control facilities for uniform maintenance of temperature and humidity) at 40+1ºC and 85+5%, and were fed with fresh mulberry leaves twice a day. When the larvae started spinning, they were shifted to 25+1˚C and 65+5% relative humidity. Plastic collapsible mountages were used for mounting the ripened larvae. Cocoon harvested was carried out on the 7th day and assessment was carried out on the subsequent day. The pupation rate was calculated as the number of live pupae to the number of larvae reared at 25+1˚C and 65+5% relative humidity and 40+1˚C and high humidity i.e. 85+5% respectively. Three oval and three dumbbell breeds were developed by utilizing selected bivoltine breeds as breeding resource material and crosses were made as oval x oval and dumbbell x dumbbell. In this breeding programme, repeated back crossing was given in the earlier (F2 to F5) by the respective productive breeds to increase the productivity traits in the resultant breeds. Owing to thermal effect in successive generations, it was observed after 5th generation that both qualitative and quantitative characters have declined. So the normal rearing was conducted every alternate generation to regain the lost vitality. Mass rearings were conducted from F1 to F5, while cellular rearings were conducted from F6 onwards. Further directional selection was employed in the following 5 generations. To obtain stability based on pupation rate and cocoon shape as important selection criteria. During the process of breeding care was also taken to maintain the productivity traits in the resultant breeds [15].

The parentages of the selected breeding lines are as follows.

. Sl. No.	Breeding lines	Parentage	Breeding Plan
Oval			
1	HL1, HH1	CSR18, CSR46, CSR50.	(CSR46 ×CSR18) × CSR50
2	HL3, HH3	CSR18, CSR46, CSR50.	(CSR50 × CSR46)) × CSR50
3	HL5	CSR18, CSR46, CSR50	(CSR50 × CSR18) × CSR50
4	HH6	CSR18, CSR46, CSR50	(CSR18 × CSR50) × CSR50
Dumbbell			
1	HH7	CSR19, CSR47, CSR51	(CSR19 × CSR47) × CSR51
2	HL8	CSR19, CSR47, CSR51.	(CSR47 × CSR19) × CSR51
3	HL10, HH10	CSR19, CSR47, CSR51	(CSR51 × CSR19) × CSR51
4	HL12 ,HH12	CSR19, CSR47, CSR51	(CSR51 × CSR47) × CSR51

The breeding lines were subjected for high temperature (40 ±1°C) and high humidity (85± 5 % RH) as well as at room temperature (25 ±1°C and 65±5% RH) treatments. Based on high pupation rate at high temperature and high humidity conditions, three oval lines were continued. Though, the resultant lines were more robust and relatively tolerant to silkworm diseases, the productivity traits were inferior to that of the already developed productive CSR breeds. Therefore, resorted to repeated out crossing with productive breeds to improve the productivity traits. Accordingly, all the dumbbell lines were out crossed with CSR51 to improve the quantitative traits. Similarly, all the oval lines were out crossed with CSR50 to improve the quantitative traits Mass rearing with directional selection was resorted up to F5 generations. Based on high pupation rate a minimum of three bathes were selected and resorted to either inbreeding or inter batch crossing. Further, directional selection was employed in the following 5 generations based on pupation rate and cocoon shape as selection criteria. Single cocoon assessment was carried out to select the cocoons for continuation of the progeny by maintaining the qualitative and quantitative characters at high profile. Though, no positive selection response was noticed on survival rate when reared at high temperature followed by directional selection, progenetive lines performed remarkably superior in subsequent generations at room temperature conditions. The foundation crosses for each temperature treatment were prepared by utilizing new breeds developed at high temperature and low humidity and high temperature and high humidity and reared at both temperature treatments. Based on high pupation rate at treatment level, the foundation crosses were short-listed. By utilizing the short listed foundation crosses, double hybrids were prepared. The single hyhrids and double hybrids were reared at both high temperature and high & low humidity and also at room temperature and the data generated for different metric traits were analyzed statistically

RESULTS

Heterosis and Heterobeltiosis

Heterosis (hybrid vigour over mid parent value) and heterobeltiosis (hybrid vigour over better parent value) were estimated for both rearing and reeling characters for single hybrid as well as double hybrids at 40+1ºC and 50+5% RH, 40+1ºC and 85+5% RH and 25+1ºC and 60+5% RH.

Single hybrids developed under high temperature (40 ±1°C) and low humidity (50±5%).

At 40+1ºC and 50+5% RH, majority of the hybrid showed positive heterosis and heterobeltiosis for all the characters except renditta and filament size (d) where majority of the hybrids showed negative heterosis and heterobeltiosis. However only the hybrid HL1 x HL7 manifested maximum hybrid vigour over mid parent value as well as better parent value for all the characters including the negative traits viz., renditta and denier. (Table 1 and 2). Similarly, at 25+1ºC and 60+5% RH, heterosis and heterobeltiosis were estimated and it observed that HL1 x HL7 and HL1 x CSR4 manifested maximum hybrid vigor over mid parent value for all the characters including renditta and filament size (d). However, HL1 x HL7 manifested maximum hybrid vigour over better parent value for all the characters including renditta and filament size (d). (Table 3 and 4).

Table 1. Heterosis of rearing and reeling characters in hybrids at 40±1ºc and 50±5%RH

Hybrid	Pupation rate (%)	Yield/ 10000 larvae(kg)	Cocoon Wt.(g)	Shell Wt.(g)	Cocoon Shell%	Reelability %	Filament length(m)	Renditta	Raw silk %	Filament size(d)	Neatness (p)
HL1XHL7	10.23**	4.91**	0.96**	2.88**	1.85**	1.07**	4.66**	-3.27	3.76**	-0.26	0.71**
HL1XHL10	5.44**	2.66**	0.37*	1.59**	1.20*	0.15ns	1.77**	-2.46	2.75**	-2.28	0.14ns
HL1XHL12	8.20**	3.07**	1.65**	3.29**	1.55**	0.36**	1.84**	-2.96	3.37**	-2.64	0.33*
HL1XCSR4	32.33**	19.38**	4.62**	6.60**	1.76**	27.26**	29.51**	19.41**	31.35**	22.56**	25.94**
HL1XCSR51	6.58**	4.95**	2.68**	3.19**	0.46ns	0.51**	0.60ns	-2.21	2.42**	-1.40	0.38*
HL1XCSR47	4.30*	6.99**	3.48**	4.71**	1.15*	0.78**	3.13**	-2.27	2.54**	-2.53	0.28ns
HL3XHL7	7.33**	1.08*	1.65**	1.97**	0.31ns	0.15ns	0.20ns	-1.96	2.13**	-1.27	0.19ns
HL3XHL10	10.76**	3.07**	1.17**	2.33**	1.13*	0.87**	4.30**	-2.44	2.75**	-0.46	0.66**
HL3XHL12	6.71**	2.01**	2.13**	2.24**	0.11ns	0.26*	0.93ns	-1.56	1.67**	-1.91	0.38*
HL3XCSR4	34.69**	19.02**	5.20**	5.07**	-0.04	26.23**	28.00**	22.42**	27.73**	23.52**	25.75**
HL3XCSR51	6.80**	5.68**	2.83**	2.63**	-0.16	0.00ns	0.46ns	-1.47	1.56**	-2.37	0.05ns
HL3XCSR47	9.41**	7.31**	4.58**	5.68**	0.99ns	1.09**	0.97ns	-2.26	2.56**	-2.99	0.23ns
HL5XHL7	4.59**	2.41**	1.47**	2.21**	0.70ns	0.05ns	-0.85	-1.96	2.16**	-2.08	0.19ns
HL5XHL10	2.80ns	3.06**	2.56**	3.52**	0.87ns	0.05ns	-0.32	-1.90	2.06**	-2.16	0.19ns
HL5XHL12	5.60**	1.92**	4.00**	4.49**	0.43ns	0.87**	2.95**	-1.81	1.95**	-2.70	0.57**
HL5XCSR4	23.13**	19.74**	5.26**	6.58**	1.13*	25.21**	21.82**	21.25**	29.17**	19.32**	25.38ns
HL5XCSR51	2.19ns	5.02**	2.83**	2.74**	-0.08	0.31ns	-0.71	-1.32	1.40**	-3.02	0.14ns
HL5XCSR47	9.89**	7.68**	3.84**	4.47**	0.57ns	2.11**	0.19ns	-1.75	1.89**	-1.87	0.51**
CSR2XHL7	14.94**	13.47**	5.30**	5.66**	0.28ns	25.41**	22.76**	21.10**	29.26**	20.71**	25.75**
CSR2XHL10	16.81**	14.88**	4.89**	5.90**	0.81ns	27.24**	28.70**	20.68**	29.75**	24.08**	26.32**
CSR2XHL12	17.61**	15.82**	4.45**	4.90**	0.37ns	26.02**	28.92**	20.90**	29.50**	19.75**	25.95**
CSR50XHL7	5.84**	3.70**	2.13**	2.45**	0.30ns	1.12**	-0.09	-2.22	2.45**	-0.40	0.33ns
CSR50XHL10	6.83**	4.69**	3.03**	2.88**	-0.15	0.41**	1.08ns	-1.49	1.59**	-2.07	0.33ns
CSR50XHL12	6.91**	4.71**	3.16**	3.49**	0.28ns	1.02**	2.40**	-2.11	2.31**	-2.40	0.42ns
CSR46XHL7	7.21**	6.95**	3.40**	3.85**	0.38ns	0.36**	1.02*	-2.12	2.32**	-2.02	0.19ns
CSR46XHL10	5.79**	6.65**	3.43**	4.01**	0.49ns	0.56**	2.51**	-2.04	2.24**	-2.25	0.09ns
CSR46XHL12	7.06**	7.10**	3.91**	4.20**	0.24ns	0.46**	2.92**	-1.99	2.17**	-2.03	0.28ns

* and ** Denote significant difference at 5% and 1%
ns Denote non significant

Table 2. Heterobeltiosis of rearing and reeling characters in hybrids at 40±1ºc and 50±5%RH

Hybrid	Pupation rate (%)	Yield/ 10000 larvae(kg)	Cocoon Wt.(g)	Shell Wt.(g)	Cocoon Shell%	Reelability %	Filament length(m)	Renditta	Raw silk %	Filament size(d)	Neatness (p)
HL1XHL7	34.98**	18.50**	3.17*	10.29**	6.16**	3.66**	11.48**	-14.44	13.25**	-1.37	2.63**
HL1XHL10	16.95*	8.47**	0.93ns	5.47**	3.71ns	0.00ns	4.17ns	-10.30	10.44**	-9.85	0.01ns
HL1XHL12	27.29**	11.33**	6.18**	11.74**	5.14*	1.23**	6.75**	-12.66	12.47**	-12.18	1.13*
HL1XCSR4	38.91**	7.91**	7.54**	12.67**	4.50ns	4.53**	9.02**	-11.19	12.69**	-4.88	1.89**
HL1XCSR51	17.39*	8.01**	7.36**	9.22**	0.55ns	2.06**	-1.79	-10.11	8.18**	-6.07	1.13*
HL1XCSR47	8.66ns	5.68*	6.91**	9.35**	2.40*	2.47**	9.73**	-10.40	8.60**	-12.73	0.37ns
HL3XHL7	18.28ns	2.64ns	5.94**	6.15**	-0.10	0.00ns	-3.83	-8.96	7.19**	-5.45	0.75ns
HL3XHL10	31.38**	9.40**	3.92*	7.30**	3.29*	2.85**	15.85**	-10.25	10.36**	-2.46	1.87**
HL3XHL12	15.69*	6.26*	7.06**	6.37**	-0.65	0.82ns	2.54ns	-7.16	5.65*	-8.92	1.13*
HL3XCSR4	47.33**	6.81**	8.59**	6.13**	-2.26	2.47**	6.01**	-5.15	5.46*	-2.96	1.51**
HL3XCSR51	20.19*	9.78**	6.76**	5.84**	-1.02	0.00ns	-0.90	-7.21	4.74	-9.76	-0.37ns
HL3XCSR47	28.70**	6.02*	9.95**	11.72**	1.67ns	3.70**	2.90ns	-9.65	9.54**	-14.15	0.37ns
HL5XHL7	13.68ns	8.29**	5.37**	8.42**	2.43ns	0.00ns	-4.41	-9.21	6.99**	-8.64	0.75ns
HL5XHL10	6.48ns	11.41**	9.84**	13.48**	2.93ns	0.00ns	-5.71	-8.56	7.14**	-8.85	0.00ns
HL5XHL12	16.03*	6.85**	15.41**	16.86**	1.00ns	3.27**	4.52ns	-8.58	6.26*	-11.82	1.88**
HL5XCSR4	14.20ns	9.11**	9.63**	12.89**	2.49ns	0.41ns	-6.36	-7.50	8.34**	-11.35	0.76ns
HL5XCSR51	-0.22	9.26**	7.65**	7.80**	-1.16	0.82ns	-5.78	-6.61	4.14ns	-12.23	0.00ns
HL5XCSR47	23.89**	8.88**	8.04**	8.75**	0.68ns	7.35**	-3.97	-7.65	6.81**	-9.54	1.49**
CSR2XHL7	-5.37	1.90ns	8.89**	11.46**	-0.11	0.81ns	-4.48	-7.80	8.53**	-8.58	1.51**
CSR2XHL10	-0.38	6.33*	7.52**	12.55**	1.87ns	4.47ns	7.40**	-8.64	9.49**	-1.85	2.64**
CSR2XHL12	0.85ns	8.60**	6.51**	9.45**	0.22ns	2.05**	7.85**	-8.21	9.00**	-10.49	1.89**
CSR50XHL7	16.99*	6.35*	4.31**	7.30**	-0.51	4.07**	-4.53	-9.39	9.19**	-1.86	1.13ns
CSR50XHL10	20.53**	11.10**	7.87**	9.25**	-2.39	1.22*	3.03ns	-6.73	5.48*	-8.74	0.37ns
CSR50XHL12	20.26**	11.16**	9.02**	12.24**	-0.62	3.67**	7.97**	-8.91	8.71**	-10.98	1.14ns
CSR46XHL7	22.27**	9.49**	8.39**	11.43**	-0.28	0.81ns	0.24ns	-9.61	7.93**	-8.58	0.37ns
CSR46XHL10	17.40*	9.42**	8.63**	12.33**	0.54ns	1.63**	8.54**	-8.71	8.35**	-9.97	-0.37
CSR46XHL12	21.51**	11.03**	11.12**	13.64**	-0.35	1.64**	9.51**	-8.74	7.77**	-10.01	0.37ns

* and ** Denote significant difference at 5% and 1%
ns Denote non significant

Table 3. Heterosis of rearing and reeling characters in hybrids at 25±1ºc and 65±5%RH

Hybrid	Pupation rate (%)	Yield/ 10000 larvae(kg)	Cocoon Wt.(g)	Shell Wt.(g)	Cocoon Shell%	Reelability %	Filament length(m)	Renditta	Raw silk %	Filament size(d)	Neatness (p)
HL1XHL7	0.88ns	3.05**	1.96**	3.18**	1.14**	0.54**	2.76**	-1.20	1.27**	-0.26	0.92**
HL1XHL10	0.50ns	2.08**	0.45ns	0.97*	0.50ns	-0.15	2.38**	-0.89	0.93**	-0.03	0.23ns
HL1XHL12	0.03ns	2.48**	0.76*	2.27**	1.49**	-0.05	1.62**	-1.63	1.78**	-0.58	0.60**
HL1XCSR4	0.43ns	3.88**	1.35**	2.38**	0.99**	0.49**	1.08**	-1.46	1.56**	-0.11	0.74**
HL1XCSR51	-4.92	3.77**	2.38**	3.31**	0.86**	0.10ns	1.59**	-1.31	1.39**	-2.39	0.41**
HL1XCSR47	0.56ns	3.80**	1.76**	2.96**	1.14**	-0.10	0.69ns	-1.43	1.53**	-1.77	0.41**
HL3XHL7	0.88ns	1.50**	1.53**	2.12**	0.56ns	-0.24	0.58ns	-1.02	1.06**	-0.36	0.37**
HL3XHL10	0.35ns	1.44**	0.23ns	0.88*	0.64*	0.34**	1.29**	-1.33	1.41**	0.10	0.60**
HL3XHL12	0.83ns	1.58**	1.28**	1.75**	0.45ns	0.44**	0.92ns	-1.44	1.53**	-0.60	0.69**
HL3XCSR4	0.72ns	3.35**	1.85**	2.93**	1.01**	0.49**	0.71ns	-1.59	1.69**	-1.56	0.55**
HL3XCSR51	0.22ns	3.29**	2.84**	3.70**	0.78**	0.00ns	0.64ns	-1.44	1.53**	-0.40	0.32*
HL3XCSR47	0.65ns	3.12**	2.42**	2.88**	0.43ns	0.29*	1.48**	-1.04	1.08**	16.48**	0.41**
HL5XHL7	0.70ns	2.19**	2.10**	3.02**	0.86**	-0.10	0.90ns	-1.49	1.58**	-0.96	0.42**
HL5XHL10	0.64ns	1.95**	1.27**	2.04**	0.72*	-0.20	0.32ns	-1.45	1.54**	-0.93	0.37**
HL5XHL12	0.64ns	1.33**	1.24**	2.11**	0.82**	0.49**	1.86**	-1.64	1.75**	0.61	0.74**
HL5XCSR4	0.40ns	3.06**	1.81**	2.80**	0.93**	-0.24	0.85ns	-1.39	1.48**	-0.23	-0.14
HL5XCSR51	0.84ns	3.55**	2.26**	3.06**	0.74*	0.15ns	0.90ns	-1.72	1.85**	-0.13	0.18ns
HL5XCSR47	0.61ns	3.75**	1.97**	2.98**	0.95**	0.24ns	1.93**	-1.09	1.15**	1.34	0.46**
CSR2XHL7	0.57ns	1.80**	1.30**	1.68**	0.36ns	-0.19	0.83ns	-0.98	1.03**	-0.06	0.14ns
CSR2XHL10	0.12ns	2.06**	0.47ns	1.05*	0.56ns	-0.29	0.77ns	-1.26	1.34**	-0.64	0.00ns
CSR2XHL12	0.54ns	1.28**	0.95*	1.54**	0.56ns	0.00ns	1.52**	-1.41	1.49**	0.57	0.00ns
CSR50XHL7	0.73ns	2.35**	2.00**	3.20**	1.11**	0.05ns	0.91ns	-1.03	1.10**	-1.85	0.23ns
CSR50XHL10	0.85ns	2.99**	1.56**	2.69**	1.07**	0.15ns	1.02ns	-0.85	0.88*	-1.70	-0.09
CSR50XHL12	0.68ns	3.54**	1.14**	2.27**	1.08**	0.05ns	1.15*	-1.09	1.13**	-2.18	0.00ns
CSR46XHL7	0.56ns	2.12**	2.27**	3.33**	0.99**	0.29*	1.71**	-0.73	0.76*	-1.19	0.55**
CSR46XHL10	0.51ns	2.29**	1.03**	1.37**	0.31ns	0.29*	1.34**	-0.66	0.68*	-0.81	0.18ns
CSR46XHL12	0.65ns	2.54**	-0.14	0.66ns	0.81**	0.10ns	2.50**	-0.73	0.74*	-1.61	0.28*

* and ** Denote significant difference at 5% and 1%
ns Denote non significant

Single hybrids developed under high temperature (40 ±1°C) and high humidity (85± 5%).

At 40+1ºC and 85 + 5% RH, majority of the hybrid showed positive heterosis and heterobeltiosis for all the characters except renditta and filament size (d) where majority of the hybrids showed negative heterosis and heterobeltiosis. Three hybrids namely HH1 x HH12, HH3 x HH8 and HH6 x HH12 were found maximum hybrid vigour over mid parent value for all the characters including renditta and filament size (d).

Table 4. Heterobeltiosis of rearing and reeling characters in hybrids at 25±1ºc and 65±5%RH

Hybrid	Pupation rate (%)	Yield/ 10000 larvae(kg)	Cocoon Wt.(g)	Shell Wt.(g)	Cocoon Shell%	Reelability %	Filament length(m)	Renditta	Raw silk %	Filament size(d)	Neatness (p)
HL1XHL7	2.78ns	9.74**	4.16*	8.23**	3.07*	1.55*	10.57**	-4.97	4.88**	-3.55	3.31**
HL1XHL10	1.76ns	5.48**	-0.31	2.62ns	1.09ns	-0.78	8.66**	-3.87	3.42*	-2.34	0.38ns
HL1XHL12	-0.50	7.48**	0.90ns	7.23**	4.63**	-0.38	5.75**	-7.46	6.05**	-3.54	2.21**
HL1XCSR4	1.32ns	9.49**	3.04ns	5.02*	1.92ns	1.56*	3.01ns	-6.15	5.88**	-0.88	2.57**
HL1XCSR51	-20.28	9.50**	5.25**	7.95**	2.54ns	0.00	4.77*	-6.04	4.66**	-10.30	1.11ns
HL1XCSR47	1.84ns	9.73**	3.67*	6.59**	2.81*	-0.39	1.85ns	-6.05	5.75**	-8.01	1.09ns
HL3XHL7	2.92ns	4.02*	3.24ns	5.55*	0.99ns	-1.55	1.61ns	-5.39	2.78ns	-2.75	1.11ns
HL3XHL10	1.34ns	4.76*	-1.19	2.08ns	1.84ns	1.17ns	4.26*	-6.33	4.49**	-0.58	2.21**
HL3XHL12	2.51ns	3.75ns	2.94ns	5.90**	0.72ns	1.56*	2.70ns	-6.57	5.24**	-2.84	2.21**
HL3XCSR4	2.32ns	5.41**	5.00**	7.29**	2.19ns	1.56*	1.30ns	-7.61	5.34**	-7.85	1.84**
HL3XCSR51	0.18ns	5.61**	7.01**	9.57**	2.41ns	-0.39	0.78ns	-7.25	4.49**	-2.79	0.74ns
HL3XCSR47	2.19ns	5.05*	6.22**	6.44**	0.20ns	1.17ns	4.88*	-5.75	2.54ns	64.84	1.10ns
HL5XHL7	2.26ns	6.97**	4.82**	8.55**	1.99ns	-0.38	2.88ns	-6.90	5.23**	-6.12	1.48*
HL5XHL10	1.84ns	6.37**	1.81ns	5.69*	1.96ns	-1.17	0.40ns	-6.62	5.22**	-6.32	1.48*
HL5XHL12	1.81ns	2.34ns	1.70ns	6.35**	1.99ns	1.56*	6.65**	-7.08	6.39**	-1.24	2.58**
HL5XCSR4	0.61ns	6.04**	5.96**	7.75**	1.68ns	-1.17	2.22ns	-6.56	4.81**	-6.07	-1.09
HL5XCSR51	3.01ns	8.27**	5.88**	8.07**	2.06ns	0.39ns	2.12ns	-8.16	5.91**	-5.26	0.37ns
HL5XCSR47	1.89	9.13**	5.59**	7.75**	2.08ns	0.39ns	7.06**	-5.60	3.24*	1.15	1.47*
CSR2XHL7	0.99	4.74*	2.43ns	3.18ns	-0.07	-1.15	2.51ns	-4.64	3.32*	-1.03	0.00ns
CSR2XHL10	-0.87	6.44**	-0.72	2.31ns	1.48ns	-1.92	2.41ns	-5.44	4.94**	-3.34	-0.36
CSR2XHL12	0.99	3.13ns	1.14ns	4.62*	1.12ns	-0.77	5.49*	-6.00	5.56**	1.74	-0.72
CSR50XHL7	2.20	3.79ns	5.26**	9.21**	2.79*	-0.38	2.48ns	-5.94	2.47ns	-9.82	0.00ns
CSR50XHL10	2.88	6.14**	1.84ns	6.00**	3.49**	0.00ns	3.04ns	-5.28	1.54ns	-8.93	-1.08
CSR50XHL12	1.98	9.10**	0.28ns	4.78*	3.17*	-0.39	3.66ns	-6.72	2.01ns	-9.93	-0.72
CSR46XHL7	1.41	4.63*	5.32**	8.73**	2.64ns	0.78ns	6.51**	-3.84	2.10ns	-7.16	1.84ns
CSR46XHL10	1.40	5.07*	-0.10	1.86ns	0.57ns	0.78ns	4.87*	-3.90	1.39ns	-5.37	0.00ns
CSR46XHL12	1.90	6.93**	-4.60	-0.49	2.22ns	0.00ns	9.41**	-4.83	0.95ns	-7.61	0.37ns

* and ** Denote significant difference at 5% and 1%

ns Denote non significant

On the other hand for heterobeltiosis two hybrids namely HH1 x HH12 and HH3xHH8 manifested maximum hybrids vigour for all the characters including renditta and filament size (d). (Table 5 and 6). Similarly, at 25+1ºC and 60+5% RH, it observed that HH1 x HH12 and HH3 x CSR51 were found maximum hybrid vigour over mid parent value for all the characters including renditta and filament size (d). On the other hand HH1 x CSR47, HH3 x HH8 and HH3 x CSR51 were found maximum hybrid vigour over better parent value for ten characters including renditta and filament size (d). (Table 7 and 8).

Table 5. Heterosis of rearing and reeling characters in hybrids at 40±1ºc and 85±5%RH

Hybrid	Pupation rate (%)	Yield/ 10000 larvae(kg)	Cocoon Wt.(g)	Shell Wt.(g)	Cocoon Shell%	Reelability %	Filament length(m)	Renditta	Raw silk %	Filament size(d)	Neatness (p)
HH1 XHH8	15.07**	15.54**	4.29**	6.35*	2.00ns	3.95ns	4.22**	-2.75	2.88ns	-5.28	2.27**
HH1XHH10	-6.64	16.78**	0.46ns	8.83**	8.31**	3.33ns	2.59ns	-8.74	9.57**	-5.48	1.89*
HH1XHH12	21.59**	13.21**	5.68**	15.20**	9.00**	4.98ns	9.23**	-9.79	10.87**	-2.74	4.67**
HH1XCSR4	90.04**	79.13**	20.26**	34.41**	12.21**	109.17**	109.79**	80.60**	121.52**	99.75**	104.55**
HH1XCSR51	23.20**	23.61**	7.41**	11.36**	3.78ns	4.58ns	5.54**	-4.79	5.09**	-1.30	1.89*
HH1XCSR47	36.28**	31.28**	11.58**	15.40**	3.48ns	4.17ns	6.20**	-4.13	4.38*	12.33**	1.89*
HH3XHH8	25.12**	19.74**	9.64**	25.24**	14.21**	5.20ns	5.90**	-12.64	14.50**	-3.51	1.88*
HH3XHH10	17.10**	13.31**	7.47**	10.30**	2.65ns	5.83ns	4.14**	-2.54	2.80ns	4.33**	2.64**
HH3XHH12	21.50**	12.52**	6.07**	12.01**	5.59**	4.98ns	9.08**	-4.68	5.00*	8.36**	3.91**
HH3XCSR4	94.31**	75.83**	22.16**	25.06**	2.72ns	109.17**	103.53**	99.94**	100.0**	82.91**	103.03**
HH3XCSR51	19.04**	21.35**	14.13**	13.69**	-0.39ns	3.75ns	3.86**	-0.21	0.41ns	-6.29	1.51*
HH3XCSR47	17.89**	30.41**	14.71**	16.65**	1.75ns	5.00ns	8.28**	-1.59	1.66ns	13.07**	1.51*
HH6XHH8	-1.05	13.64**	12.85**	17.36**	3.94ns	3.54ns	0.98	-1.85	1.97ns	-9.33	1.89*
HH6XHH10	5.69ns	14.45**	7.28**	9.02**	1.59ns	3.33ns	4.15**	-1.12	1.13ns	-8.89	1.89*
HH6XHH12	9.93*	11.62**	11.24**	17.64**	5.70**	3.33ns	6.86**	-4.98	5.33**	-9.85	3.52**
HH6XCSR	74.98**	78.81**	23.78**	32.16**	7.03**	106.67**	108.17**	97.32**	102.84**	85.96**	103.03**
HH6XCSR51	30.44**	23.75**	12.28**	15.41**	2.73ns	2.50ns	7.36**	-2.50	2.70ns	-7.14	1.13ns
HH6XCSR47	11.70*	31.69**	12.70**	14.06**	1.26ns	-15.00	3.24*	-0.27	0.29ns	8.66**	1.89*
CSR2XHH8	82.41**	87.94**	18.15**	26.17**	7.11**	106.65**	94.06**	97.75**	102.29**	83.26**	103.03**
CSR2XHH10	65.72**	86.53**	20.19**	28.18**	7.00**	110.00**	101.22**	95.19*	105.14**	107.28**	104.55**
CSR2XHH12	87.22**	80.82**	21.28**	30.91**	8.32**	106.63**	107.36**	90.77*	109.73**	96.22**	110.61**
CSR50XHH8	14.20**	13.94**	15.88**	16.34**	0.38ns	3.54ns	0.24ns	1.92	-1.77	-5.52	1.89*
CSR50XHH10	14.65**	12.50**	13.82**	17.79**	3.47ns	3.33ns	4.03**	-2.32	2.40ns	-8.29	2.27**
CSR50XHH12	10.48*	12.67**	14.69**	15.76**	0.89ns	4.16ns	8.27**	-1.12	1.13ns	16.77**	3.52**
CSR546XHH8	9.17ns	27.67**	14.90**	17.76**	2.40ns	4.37ns	4.82**	-3.02	3.10ns	7.90**	1.89*
CSR46XHH10	13.81**	29.16**	14.79**	13.82**	-0.94	2.92ns	4.54**	-0.79	0.82ns	-4.63	1.89*
CSR46XHH12	16.43**	26.43**	17.25**	12.30**	-4.29	3.32ns	3.23*	3.33ns	-3.22	0.01ns	3.90**

* and ** Denote significant difference at 5% and 1%

ns Denote non significant

Table 6. Heterobeltiosis of rearing and reeling characters in hybrids at 40±1ºc and 85±5%RH

Hybrid	Pupation rate (%)	Yield/ 10000 larvae(kg)	Cocoon Wt.(g)	Shell Wt.(g)	Cocoon Shell%	Reelability %	Filament length(m)	Renditta	Raw silk %	Filament size(d)	Neatness (p)
HH1 XHH8	11.83*	13.47**	3.64*	5.44ns	1.06ns	3.74	0.70ns	-3.83	1.74ns	-9.24	1.89*
HH1XHH10	-10.09	15.08**	-0.40	7.95**	6.93**	3.33	-0.87	-9.65	8.47**	-9.38	1.89*
HH1XHH12	19.16**	9.09**	5.47**	13.78**	7.51**	4.56	8.69**	-10.30	10.24**	-3.53	3.03**
HH1XCSR4	9.43ns	17.04**	9.12**	17.98**	8.13**	4.58	4.89**	-9.70	10.76**	-0.13	2.27**
HH1XCSR51	5.25ns	15.70**	4.22*	8.53**	2.76ns	4.58	4.49**	-6.00	3.71ns	-2.03	1.52ns
HH1XCSR47	17.04**	15.63**	6.78**	9.13**	0.88ns	4.17	5.40**	-5.14	3.29ns	11.72**	1.52ns
HH3XHH8	21.00**	19.05**	8.84**	24.83**	13.25**	4.98	3.47*	-13.54	13.30**	-3.86	1.13ns
HH3XHH10	13.29**	13.03**	6.42**	9.76**	2.07ns	5.83	1.74ns	-3.30	1.99ns	3.87**	2.26**
HH3XHH12	19.58**	9.31**	5.76**	11.58**	4.91*	4.56	7.83**	-4.96	4.70*	3.52**	1.89*
HH3XCSR4	11.74*	14.48**	10.97**	10.29**	-0.61	4.58	1.76ns	-0.03	0.03ns	-8.54	1.52ns
HH3XCSR51	1.37ns	12.81**	10.88**	11.37**	-1.45	3.75	2.54ns	-1.27	-0.71	-10.18	0.76ns
HH3XCSR47	0.34ns	14.09**	9.92**	10.84**	-0.05	5.00	6.26**	-2.34	0.89ns	8.17**	0.76ns
HH6XHH8	-4.31	13.20**	12.10**	16.80**	2.88ns	3.32	-1.34	-2.38	1.41ns	-9.95	1.52ns
HH6XHH10	2.72ns	13.63**	6.23**	8.31**	0.92ns	3.33	1.76ns	-2.04	0.19ns	-9.01	1.89*
HH6XHH12	8.72ns	9.49**	10.94**	17.14**	4.96*	2.92	5.63**	-5.79	4.43ns	-13.92	1.89*
HH6XCSR	0.53ns	15.87**	12.43**	16.44**	3.42ns	3.33	4.08*	-1.34	1.42ns	-7.02	1.52ns
HH6XCSR51	10.75*	13.99**	9.08**	12.86**	1.55ns	2.50	5.99**	-3.77	1.37ns	-11.04	0.76ns
HH6XCSR47	-5.06	14.25**	7.99**	8.20**	-0.61	-15.00	1.29ns	-1.61	-1.04	3.89**	1.52ns
CSR2XHH8	2.57ns	16.88**	6.15**	10.59**	4.19ns	3.32	-2.97	-1.12	1.14ns	-8.37	1.52ns
CSR2XHH10	-6.83	16.18**	7.17**	11.58**	4.14ns	5.00	0.61ns	-2.41	2.57ns	3.64**	2.27**
CSR2XHH12	5.58ns	11.39**	8.83**	14.47**	5.19*	3.31	3.68*	-4.61	4.87*	-1.89	5.30**
CSR50XHH8	-0.85	9.89**	10.10**	11.37**	-0.92	3.32	-3.30	1.56	-2.11	-7.99	1.52ns
CSR50XHH10	-1.96	8.34**	7.24**	11.70**	1.26ns	3.33	0.34ns	-3.06	1.63ns	-10.64	2.27**
CSR50XHH12	-3.93	9.85**	8.85**	10.41**	-1.35	3.74	7.54**	-2.54	-0.33	14.23**	1.89*
CSR546XHH8	-10.54	14.83**	9.24**	13.67**	0.81ns	4.15	1.26ns	-4.13	1.91ns	4.87**	1.52ns
CSR46XHH10	-7.85	16.64**	8.31**	8.99**	-2.49	2.92	0.98ns	-1.68	-0.06	-7.25	1.89*
CSR46XHH12	-4.39	11.32**	11.34**	8.11**	-5.61	2.91	2.74ns	2.85	-3.67	-1.99	2.27**

* and ** Denote significant difference at 5% and 1%
ns Denote non significant

Table 7. Heterosis of rearing and reeling characters in hybrids at 25±1ºc and 65±5%RH

Hybrid	Pupation rate (%)	Yield/ 10000 larvae(kg)	Cocoon Wt.(g)	Shell Wt.(g)	Cocoon Shell%	Reelability %	Filament length(m)	Renditta	Raw silk %	Filament size(d)	Neatness (p)
HH1 XHH8	2.59**	11.65**	5.53**	9.41**	3.69**	-1.35	1.05ns	-5.22	5.56**	2.21**	0.55ns
HH1XHH10	2.07**	9.78**	3.69**	8.87**	4.99**	-1.74	2.40ns	-7.15	7.68**	-6.04	0.74ns
HH1XHH12	3.11**	9.53**	4.81**	8.60**	3.65**	0.97*	8.31**	-6.30	6.92**	-6.72	2.19**
HH1XCSR4	2.35**	17.71**	7.55**	12.64**	4.77**	0.58ns	6.27*	-5.89	6.26**	-5.02	0.73ns
HH1XCSR51	3.55**	16.66**	8.41**	10.85**	2.29*	-1.36	1.39ns	-4.74	4.99**	-4.88	0.92ns
HH1XCSR47	3.44**	17.01**	7.97**	12.76**	4.49**	1.36**	4.34ns	-4.90	5.12**	-4.75	2.01**
HH3XHH8	3.29**	13.00**	7.44**	13.94**	6.04**	0.19ns	8.48**	-8.87	9.68**	0.07ns	2.00**
HH3XHH10	0.94ns	7.09**	5.42**	10.36**	4.65**	0.97*	5.55*	-8.33	9.02**	0.41ns	2.93**
HH3XHH12	1.47ns	8.92**	6.31**	10.08**	3.53**	0.19ns	7.48**	-7.40	7.96**	-3.23	1.10*
HH3XCSR4	0.76ns	15.75**	7.14**	9.43**	2.16*	-0.19	-1.59	-5.17	5.42**	-0.39	1.09*
HH3XCSR51	2.65**	18.51**	10.65**	14.91**	3.87**	0.97*	9.63**	-7.05	7.49**	-6.41	2.02**
HH3XCSR47	2.12**	17.49**	8.17**	10.38**	2.07*	-0.19	7.57**	-5.90	6.21**	-2.36	1.28**
HH6XHH8	1.62*	8.93**	4.86**	7.25**	2.30*	0.39ns	3.14ns	-4.20	4.44**	-5.60	1.65**
HH6XHH10	2.13**	7.88**	3.12**	7.83**	4.58**	-0.38	4.08ns	-6.08	6.51**	-3.68	1.47**
HH6XHH12	0.99ns	7.12**	2.89**	6.58**	3.60**	0.00ns	8.29**	-5.90	6.28**	-1.24	1.11*
HH6XCSR	2.33**	16.16**	5.67**	10.36**	4.48**	0.39ns	8.48**	-5.54	5.86**	-4.92	0.73ns
HH6XCSR51	2.03*	15.26**	8.42**	11.70**	3.04**	-1.55	4.77ns	-4.92	5.16**	-8.79	0.56ns
HH6XCSR47	2.51**	15.37**	6.16**	8.44**	2.21*	0.78ns	5.26*	-2.97	3.07*	-2.07	2.38**
CSR2XHH8	1.16ns	6.94**	4.71**	8.74**	3.86**	-0.97	13.90**	-5.18	5.48**	2.91**	2.55**
CSR2XHH10	0.57ns	7.45**	4.32**	9.83**	5.28**	-1.35	6.97**	-4.58	4.80**	2.67**	0.18ns
CSR2XHH12	0.66ns	5.82**	7.03**	11.33**	4.02**	0.19ns	7.48**	-6.63	7.10**	0.87	1.29**
CSR50XHH8	2.02*	12.49**	5.32**	10.18**	4.63**	0.78ns	9.65**	-4.30	4.58**	-1.53	0.36ns
CSR50XHH10	2.24**	10.16**	6.37**	12.28**	5.49**	1.17ns	11.88**	-4.10	4.25**	-1.65	1.29**
CSR50XHH12	1.04ns	10.27**	6.63**	12.40**	5.39**	0.00ns	13.08**	-4.69	4.82**	-0.67	0.55ns
CSR546XHH8	1.72*	9.54**	6.77**	9.14**	2.20*	0.19ns	11.79**	-1.94	1.96ns	-1.42	1.28**
CSR46XHH10	1.85*	10.13**	7.13**	12.55**	5.03**	0.19ns	4.04ns	-3.74	3.92**	-1.42	1.29**
CSR46XHH12	1.27ns	7.90**	6.81**	9.65**	2.61**	-0.19	5.47*	-3.67	3.77**	-1.35	0.55ns

* and ** Denote significant difference at 5% and 1%
ns Denote non significant

Double hybrids developed under high temperature (40 ±1°C) and low humidity (50±5%)

At 40+1ºC and 50+5% RH, (HL1 x HL3) x (HL10 x HL12) manifested maximum hybrid vigour over mid parent value as well as better parent value for all the characters including renditta and filament size (d). (Table 9 and 10). Similarly, at 25+1ºC and 60+5% RH, (HL1 x HL5) x (HL10 x HL12) was found maximum hybrid vigour over mid parent value for all the characters including renditta and filament size (d). However, for heterobeltiosis (HL1 x HL3) x (HL10 x HL12) was found maximum hybrid vigour for all the characters including renditta and filament size (d). (Table 11 and 12).

Table 8. Heterobeltiosis of rearing and reeling characters in hybrids at 25±1ºc and 65±5%RH

Hybrid	Pupation rate (%)	Yield/ 10000 larvae(kg)	Cocoon Wt.(g)	Shell Wt.(g)	Cocoon Shell%	Reelability %	Filament length(m)	Renditta	Raw silk %	Filament size(d)	Neatness (p)
HH1 XHH8	1.88*	6.78**	4.17**	7.25**	2.08*	-1.54	-0.61	-6.41	4.21**	-0.43	0.00ns
HH1XHH10	1.15ns	3.99**	2.17*	6.94**	2.86**	-1.93	0.77ns	-8.56	6.06**	-8.47	0.00ns
HH1XHH12	1.68ns	3.52**	4.30**	7.00**	2.62*	0.78ns	7.04*	-7.17	5.88**	-8.25	1.82**
HH1XCSR4	1.11ns	15.08**	5.32**	8.44**	2.97**	0.00ns	5.23ns	-7.02	4.92**	-5.38	0.00ns
HH1XCSR51	3.03**	14.51**	4.34**	6.06**	1.66ns	-1.55	-0.20	-6.20	3.35*	-5.61	0.37ns
HH1XCSR47	2.82**	14.95**	4.74**	7.89**	3.01**	1.16*	2.83ns	-6.37	3.46*	-6.27	1.83**
HH3XHH8	2.96**	9.46**	6.08**	12.47**	4.44**	0.00ns	7.35*	-10.94	7.13**	-0.34	1.45*
HH3XHH10	0.68ns	2.71*	3.92**	9.14**	2.58*	0.78ns	4.46ns	-10.22	6.74**	0.00	2.19**
HH3XHH12	0.82ns	4.26**	5.86**	9.43**	2.57*	0.00ns	5.59ns	-8.61	6.50**	-4.55	0.73ns
HH3XCSR4	0.29ns	11.65**	5.86**	6.33**	0.45ns	-0.78	-3.00	-7.31	2.93ns	-3.09	0.36ns
HH3XCSR51	2.27*	14.79**	7.43**	10.97**	3.19**	0.78ns	7.64*	-9.45	4.67**	-8.50	1.46*
HH3XCSR47	1.88*	13.91**	5.85**	6.58**	0.69ns	-0.39	5.83ns	-8.37	3.35*	-3.75	1.10ns
HH6XHH8	1.12ns	6.47**	3.38*	3.99**	0.58ns	0.39ns	1.89ns	-5.13	3.43*	-7.85	0.72ns
HH6XHH10	1.38ns	4.41**	2.36*	4.76**	2.34*	-0.38	2.83ns	-6.94	5.51**	-5.97	0.74ns
HH6XHH12	-0.24	3.46*	1.39ns	3.88**	2.46*	0.00ns	6.53ns	-6.36	5.77**	-2.65	0.74ns
HH6XCSR	1.25ns	11.05**	2.48**	5.12**	2.57*	-0.38	6.10ns	-6.40	4.88**	-5.29	-0.36
HH6XCSR51	1.68ns	10.67**	3.36**	5.74**	2.30*	-1.92	2.67ns	-6.09	3.85*	-9.29	0.38ns
HH6XCSR47	2.06*	10.86**	2.00*	2.66ns	0.64ns	0.39ns	1.95ns	-3.84	2.11ns	-3.43	1.82**
CSR2XHH8	0.17ns	5.11**	4.22**	6.79**	2.11*	-1.16	12.47**	-5.47	5.17**	2.07*	1.81**
CSR2XHH10	-0.28	4.57**	3.65**	8.08**	3.01**	-1.54	5.64	-5.24	4.07**	1.84*	-0.72
CSR2XHH12	0.34ns	2.77*	6.52**	9.92**	2.87**	0.00ns	6.10*	-7.47	6.14**	0.00	0.73ns
CSR50XHH8	1.44ns	6.33**	3.69**	8.67**	3.22**	-0.38	7.58*	-6.03	2.77ns	-3.46	0.00ns
CSR50XHH10	2.12*	3.14*	4.01**	10.96**	4.19**	0.00ns	9.82**	-6.32	1.85ns	-3.57	0.73ns
CSR50XHH12	0.43ns	3.05*	5.05**	10.63**	4.25**	-1.16	11.17**	-7.48	1.79ns	-1.67	0.37ns
CSR546XHH8	1.26ns	5.18**	5.22**	7.85**	0.57ns	0.00ns	10.14**	-3.47	0.37ns	-3.24	0.73ns
CSR46XHH10	1.62ns	4.71**	4.85**	10.99**	2.86**	0.00ns	2.52ns	-4.94	2.62ns	-3.24	0.73ns
CSR46XHH12	0.79ns	2.40ns	5.29**	8.75**	1.58ns	-0.38	3.95ns	-5.60	1.69ns	-2.24	0.37ns

* and ** Denote significant difference at 5% and 1%
ns Denote non significant

Table 9. Heterosis of rearing and reeling characters in hybrids at 40±1ºc and 50±5%RH

Hybrid	Fecundity (No.)	Pupation rate (%)	Yield/ 10000 larvae(kg)	Cocoon Wt.(g)	Shell Wt.(g)	Cocoon Shell%	Reelability %	Filament length(m)	Renditta	Raw silk %	Filament size(d)	Neatness (p)
(HL1XHL3) X (HL10XHL12)	3.81**	4.10**	3.03**	1.19**	2.96**	1.70**	1.43**	2.07**	-2.36	2.61**	0.03	0.47**
(HL1XHL5) X (HL10XHL12)	3.74**	1.03ns	1.86**	0.52ns	1.57*	1.03ns	0.26ns	1.33**	-2.05	2.20**	-1.35	0.14ns
(HL3XHL5) X (HL10XHL12)	3.92**	0.65ns	2.29**	1.31**	1.97**	0.63ns	0.61**	1.26**	-1.72	1.88*	-0.43	0.14ns

Table 10. Heterobeltiosis of rearing and reeling characters in hybrids at 40±1ºc and 50±5%RH

Hybrid	Fecundity (No.)	Pupation rate (%)	Yield/ 10000 larvae(kg)	Cocoon Wt.(g)	Shell Wt.(g)	Cocoon Shell%	Reelability %	Filament length(m)	Renditta	Raw silk %	Filament size(d)	Neatness (p)
(HL1XHL3) X (HL10XHL12)	13.40**	8.62**	8.22**	4.51**	10.73**	5.63*	5.31**	5.72**	-11.22	8.34*	-1.55	1.87**
(HL1XHL5) X (HL10XHL12)	14.26**	1.83ns	5.25*	1.86ns	5.60ns	3.29ns	0.82ns	4.031	-11.22	5.22ns	-6.00	0.37ns
(HL3XHL5) X (HL10XHL12)	14.24**	1.42ns	6.28**	5.08**	6.50*	1.16ns	2.46**	3.57ns	-9.69	4.31ns	-3.36	0.37ns

* and ** Denote significant difference at 5% and 1%
ns Denote non significant

Table 11. Heterosis of rearing and reeling characters in hybrids at 25±1ºc and 50±5%RH

Hybrid	Pupation rate (%)	Yield/ 10000 larvae(kg)	Cocoon Wt.(g)	Shell Wt.(g)	Cocoon Shell%	Reelability %	Filament length(m)	Renditta	Raw silk %	Filament size(d)	Neatness (p)
(HL1XHL3) X (HL10XHL12)	0.34ns	0.91**	1.16**	2.71**	1.49**	0.24ns	2.20**	-1.29	1.37**	0.66**	0.36**
(HL1XHL5) X (HL10XHL12)	0.66**	1.00**	0.38*	1.40**	1.01**	-0.10ns	0.64ns	-1.42	1.53**	-0.22	-0.04
(HL3XHL5) X (HL10XHL12)	0.05ns	1.06**	0.69**	1.00**	0.31ns	0.05ns	0.68ns	-0.09	0.08ns	0.28	0.00ns

Table 12. Heterobeltiosis of rearing and reeling characters in hybrids at 25±1ºc and 65±5%RH

Hybrid	Pupation rate (%)	Yield/ 10000 larvae(kg)	Cocoon Wt.(g)	Shell Wt.(g)	Cocoon Shell%	Reelability %	Filament length(m)	Renditta	Raw silk %	Filament size(d)	Neatness (p)
(HL1XHL3) X (HL10XHL12)	1.06ns	3.14ns	3.83**	8.53**	4.55**	0.38ns	8.16**	-6.73	3.76**	-1.55	1.44**
(HL1XHL5) X (HL10XHL12)	2.01ns	2.18ns	0.68ns	3.31**	2.62ns	-0.77	0.88ns	-6.68	4.99**	-4.16	-0.35
(HL3XHL5) X (HL10XHL12)	-0.38	1.78ns	2.05**	2.06ns	0.02ns	-0.38	1.61ns	-2.56	-1.89	-0.69	-0.35

* and ** Denote significant difference at 5% and 1%
ns Denote non significant

Double hybrids developed under high temperature (40 ±1°C) and high humidity (85±5%)

At 40+1ºC and 85+5% RH, (HH1 x HH3) x (HH8 x HH12) manifested maximum hybrid vigour over mid parent value as well as better parent value for all the characters including renditta and filament size (d). (Table 13 and 14). Similarly, at 25+1ºC and 60+5% RH, (HH1 x HH3) x (HH8 x HH12) was found maximum hybrid vigour over mid parent value for all the characters including renditta and filament size (d). On the other hand (HH1 x HH3) x (HH8 x HH12) was also found maximum hybrid vigour over better parent value for all the characters including renditta. (Table 15 and 16).

Table 13. Heterosis of rearing and reeling characters in hybrids at 40±1ºc and 85±5%RH

Hybrid	Fecundity (No.)	Pupation rate (%)	Yield/ 10000 larvae(kg)	Cocoon Wt.(g)	Shell Wt.(g)	Cocoon Shell%	Reelability %	Filament length(m)	Renditta	Raw silk %	Filament size(d)	Neatness (p)
(HH1XHH3) X (HH8XHH12)	4.87**	6.44**	2.20**	1.90**	3.83**	1.79**	0.76**	1.29*	-1.67	1.78**	-2.35	0.52ns
(HH1XHH3) X (HH10XHH12)	4.26**	1.60ns	2.02**	1.13**	1.88**	0.73ns	0.45**	0.98ns	-0.57	0.57ns	-3.65	0.33ns
(HH3XHH6) X (HH8XHH12)	2.76**	3.17ns	0.72ns	1.38**	2.34**	0.94*	0.41*	0.22ns	-1.21	1.28**	0.64**	0.72ns
(HH3XHH6) X (HH10XHH12)	3.50**	1.11ns	2.12**	0.54ns	2.41**	1.82**	0.20ns	0.25ns	-2.18	2.39**	-2.93	0.55ns

Table 14. Heterobeltiosis of rearing and reeling characters in hybrids at 40±1ºc and 85±5%RH

Hybrid	Fecundity	Pupation	Yield/	Cocoon	Shell	Cocoon	Reelability	Filament	Renditta	Raw silk	Filament	Neatness
	(No.)	rate (%)	10000	Wt.(g)	Wt.(g)	Shell%	%	length(m)		%	size(d)	(p)
			larvae(kg)									
(HH1XHH3) X (HH8XHH12)	18.03**	19.08**	8.16**	6.90ns	14.48**	5.86**	2.41**	3.64ns	-8.74	4.77**	-10.67	1.51ns
(HH1XHH3) X (HH10XHH12)	15.00**	1.56ns	6.19**	4.16ns	6.25**	1.41ns	1.61*	3.32ns	-4.69	-0.22	-17.50	0.37ns
(HH3XHH6) X (HH8XHH12)	9.76**	8.80ns	2.16ns	5.23ns	8.72**	3.31ns	1.22ns	-0.88ns	-5.50	4.38*	0.00	0.00ns
(HH3XHH6) X (HH10XHH12)	11.59**	-2.17	6.72**	1.97ns	8.96**	6.40**	0.00ns	-0.54ns	-9.56	8.56**	-11.70	0.39ns

* and ** Denote significant difference at 5% and 1%
ns Denote non significant

Table 15. Heterosis of rearing and reeling characters in hybrids at 25±1ºc and 65±5%RH

Hybrid	Pupation	Yield/	Cocoon	Shell	Cocoon	Reelability	Filament	Renditta	Raw silk	Filament	Neatness
	rate (%)	10000	Wt.(g)	Wt.(g)	Shell%	%	length(m)		%	size(d)	(p)
		larvae(kg)									
(HH1XHH3) X (HH8XHH12)	0.59*	1.50**	1.50**	2.28**	0.73**	0.19ns	1.92**	-0.97	1.02**	0.64**	0.36**
(HH1XHH3) X (HH10XHH12)	0.27ns	0.84*	0.74ns	1.65**	0.88**	0.10ns	0.42ns	-1.26	1.32**	0.64**	0.14ns
(HH3XHH6) X (HH8XHH12)	0.24ns	1.09**	1.03**	1.58**	0.52**	-0.14	0.62ns	-0.95	1.00**	-0.07	-0.05
(HH3XHH6) X (HH10XHH12)	0.74**	1.32**	0.52ns	1.14**	0.60**	0.05ns	1.06ns	-1.08	1.13**	0.10	0.09

Table 16. Heterobeltiosis of rearing and reeling characters in hybrids at 25±1ºc and 65±5%RH

Hybrid	Pupation	Yield/	Cocoon	Shell	Cocoon	Reelability	Filament	Renditta	Raw silk	Filament	Neatness
	rate (%)	10000	Wt.(g)	Wt.(g)	Shell%	%	length(m)		%	size(d)	(p)
		larvae(kg)									
(HH1XHH3) X (HH8XHH12)	1.28ns	5.63**	4.29*	6.95**	2.55**	0.39ns	5.76*	-4.32	3.59**	1.25	1.08*
(HH1XHH3) X (HH10XHH12)	0.24ns	2.85ns	1.93ns	4.86**	1.93*	0.00ns	0.22ns	-6.05	4.16**	1.61	0.36ns
(HH3XHH6) X (HH8XHH12)	0.07ns	3.78*	1.87ns	4.18*	1.67*	-0.77	-0.12	-4.79	2.93*	-1.71	-0.36
(HH3XHH6) X (HH10XHH12)	1.94ns	4.56**	-0.14	3.09ns	0.71ns	-0.38	2.74ns	-5.29	3.49**	-0.69	0.00ns

* and ** Denote significant difference at 5% and 1%
ns Denote non significant

DISCUSSION

Geneticists and breeders of all the sericultural countries have experienced the influence of environment during the process of breeding. [30] studied the silkworm viability and cocoon weight for 19 generations at two different temperature and humidity. He observed that the lines selected at high temperature and humidity perform better than the lines selected at normal temperature and humidity . The effect of high temperature more than 30 ° C on silkworm larvae was reported earlier by [39 and 26]. [16 and 17] used survival rate of silkworms as a main yardstick character for evaluating thermo-tolerance. [20] conducted a series of experiments and concluded that the resistance to high temperature is a heritable character and it may be possible to breed silkworm races tolerant high temperature. [16 and 23] while attempting to synthesise high temperature resistant silkworm races confirmed the genetically heritable nature of thermo-tolerance by selection based on pupation rate of silkworm reared under high temperature conditions during 5th instar. Recently, [7, 8, 9, 36] have evolved compatible robust hybrid CSR18 x CSR19 for rearing throughout the year by utilizing Japanese thermo-tolerant hybrids as breeding resource materials.

Though, the introduction of CSR18 × CSR19 in the field during summer months had considerable impact, the productivity level and returns realized does not match to that of other productive CSR hybrids. Therefore, the acceptance level of this hybrid with the farmers was not up to the expected level because of the low productivity traits. This has necessitated in the development of a temperature tolerant hybrid with better productivity traits than CSR18 × CSR19. Considering the gravity of the situation and also to cope up with the challenge, though, it was a difficult task to break the negative correlation associated with survival and productivity traits, attempts on this line had resulted in the development of CSR46 × CSR47 [39], a temperature tolerant bivoltine hybrid with better productivity traits than CSR18 × CSR19. It was also reported that any study involving temperature as one of the environmental factors and viability followed by cocoon traits is a trend setter to provide basis to formulate appropriate selection methods for required environments.

Silkworm breed which are reared over a series of environments exhibiting less variation are considered stable. One of the objectives of the breeder is to recommend stable breeds to the farmers for rearing under different environmental conditions. Effect of high temperature and low humidity in terms of cocoon crop depends on several factors that operate within and outside the body of the silkworm. In the present study, it was observed that apart from the temperature, humidity also influences the productivity pattern in the silkworm and is in agreement with [34]. [24] observed that the cocoon yield/10000 larvae, cocoon weight, cocoon shell weight and cocoon shell percentage were also low in the high temperature treated batches when compared to the batches reared under optimum rearing conditions which corroborates the findings of the present study. [37] reported the deleterious effect of high temperature and high humidity on quantitative traits of parents, foundation crosses, single and double hybrids of bivoltine silkworm breeds of *Bombyx mori* L.

Evaluation of hybrid vigour with reference to expression of economic characters in the crosses is an important task that enables to understand the manifestation of hybrid vigour independently for each character and in conjugation with others. Generally, hybrid vigour is manifested when two genetically distinct breeds are crossed. In the present study, in order to know the degree of manifestation of hybrid vigour in twenty seven hybrids, the heterosis values over mid and better parents were computed for each character to adjudicate the best hybrid. The results revealed that some hybrids expressed positive heterosis for various economic characters in different temperature conditions.

Among the 27 hybrids, higher pupation rate recorded in all hybrids contributing to increased viability indicate positive hybrid vigour for this trait. Further, the moderate hybrid vigour revealed by all the hybrids is attributed to expression of positive heterotic effects by the hybrids derived in the present study can be largely due to the result of recovery from inbreeding depression of the breeds contributing to the improvement of fitness traits. Total cocoon yield is an important trait from the productivity point of view. All the hybrids have recorded positive hybrid vigour and positive heterobeltiosis. The observations made in the present study indicating positive hybrid vigour for total yield for all the hybrids is in conformity to the findings of [25 and 18]. Positive heterosis observed for cocoon shell weight in all the hybrids contribute to the increase in cocoon shell weight in all the hybrids. Positive heterobeltiosis was recorded in majority of the hybrids. Majority of the hybrids manifested positive heterosis for cocoon shell percentage. The reelability was found to be mostly influenced by environmental factors rather than genetic background of the hybrids. However, the positive heterosis manifested in majority of hybrids establish their superiority of this trait over other hybrids. Positive heterosis found for filament length, raw silk percentage in majority of the hybrids can be correlated with increase filament length and raw silk percentage. Marginal hybrid vigour observed for neatness in majority of hybrids indicate their superiority for neatness.

Among the 27 hybrids derived and studied, no single hybrid expressed consistency in hybrid vigour for all the traits. Most of the hybrids manifested desired hybrid vigour for pupation rate, cocoon yield/10,000 larvae, Cocoon weight, Cocoon shell weight, cocoon shell percentage, filament length, raw silk percentage, neatness and over dominance for pupation rate, cocoon yield/10,000 larvae, Cocoon weight, Cocoon shell weight. The present results indicating variable magnitude of hybrid for different combinations clearly establish the superiority of hybrids and corroborate the observations of [12,13,43, 11, 3, 1, 43, 23, 42,and 2] for hybrid vigour, who attributed the manifestation of hybrid vigour to variable combinations of genes that are brought together in the hybrids, which in turn interact with another in relation to the prevailing environmental conditions to which the hybrids are exposed during the growth and development.

Expression of hybrid vigour for only certain traits in some hybrids can be related to the impact of the selection of particular gene complexes during the course of breeding of the particular breeds. The variable degree of manifestation of hybrid vigour and over dominance recorded in the hybrids under study form the basis to identify the promising hybrids. In addition, the uniformity in the expression of characters in the hybrids compared to parental breeds as evidenced by the present study for all major metric traits also form the basis for the identification of superior hybrids. The phenotypic consequences with reference to metric traits analysed in 27 hybrids are observed to be greatly dependent upon the genetic loci that are combined to gather by the parents. The manifestation of hybrid vigour was explained by over dominance hypothesis by [32,33] dominance hypothesis of [19, 22 , 10, 27 and epistasis theory by [28, 29]. As evidenced by the manifestation of hybrid vigour for various traits in the hybrids under study, it is possible that the theories put forwarded are not mutually exclusive as it could be due to cumulative effects of several factors responsible for the manifestation of hybrid vigour in varying proportions which support the views of [5]. Although, the genesis of hybrid vigour is debated for long, questioning it to be a result of the heterozygocity or its origination from other causes, the fact that the hybrids perform much better than the parental breeds implies that certain groups of favourable alleles combine together in the hybrid which interact with the environment and produce desirable levels of hybrid vigour and confer the superiority of hybrids over parental breeds.

Improvement of breeds necessarily means selection of desirable genes in appropriate combinations, which contribute to the overall genetic worth of the population. With respect to the economic value, the focus should be on all the genes affecting the traits thereby contributing to the viability and productivity. Therefore, selection of hybrid combinations emphasize the need to organize the genetic material in a way that help to improve the manifestation of commercially important traits [25]. This can be achieved precisely by adopting a strategy by setting up a common index giving adequate weightage to all the component traits manifested among an array of hybrids. The rationale for judging the utility of multiple trait evaluation index in the present study is based on major metric traits., which are considered to be economically important. However, asymmetry is found in most of the traits as evidenced by indices of the individual component traits that the index value obtained individually for each trait can fail but the overall index values help in adjudicating the performance of the hybrids derived. In view of this, all the major traits have been considered together to obtain the aggregate index value, since exclusion of any one trait can result in negative situation.

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