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Heterosis studies on thermotolerant hybrids of bivoltine silkworm (*Bombyx mori* L.)

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Abstract

The investigation was carried out to evaluate the twenty-eight silkworm bivoltine hybrids raised by involving half (8 × 8) diallel set of bivoltine breeds in order to identify the thermotolerant, adaptable, high yielding hybrids suited for sub-tropical climate. The evaluation of hybrids was done on heterosis worked at mid parent value. Maximum heterosis was depicted by non-breakable filament length (37.75) followed by filament length (35.62), cocoon yield (by weight) (35.22), larval weight (28.21), single shell weight (24.46) and cocoon weight (17.10). On the basis of significant heterosis displayed for thirteen important commercial parameters, four hybrid combinations $ND_5 \times PO_1$ (Cumulative heterosis 362.83), $ND_5 \times PO_3$ (Cumulative heterosis 323.17), PO_1 × Udhey-6 (Cumulative heterosis 291.31) and PO_1 × Udhey-3 (Cumulative heterosis 250.42) were identified to be heterotic. The superiority of these hybrids was further confirmed by Evaluation Index (E.I.) method. Hybrid $ND_5 \times PO_3$ (E.I. 55.61) ranked 1st followed by $ND_5 \times PO_1$ (E.I. 54.40) and PO_1 × Udhey-6 (E.I. 51.97). The control hybrid ($SH_6 \times NB_4D_2$) scored the cumulative heterosis value of 155.36 and the average E.I. value of 39.17 only.

Keywords: Heterosis, Thermotolerant, Adaptable, High Yielding, Mid Parent Value, Evaluation Index (E.I.)

Introduction

Silk is adorned by rich and poor alike. It originates in the huts and cottages of poor Indian villages and finds a place in the wardrobes of rich people. The trend of sericulture development in India has shown a quantum jump in mulberry silk production with an annual production of 28,708 MT of raw silk (Anonymous, 2015) [1] during last three decades and it enjoys the comfortable second position in the world next only to China, in which silkworm breeding and development of bivoltine hybrids have played a vital role. The development of superior silkworm breeds and hybrids for commercial utilization has unequivocally contributed for increase in the production of high quality raw silk and stability of the sericulture industry. India being predominantly a tropical country with marginal sub-tropical and temperate sericulture zones, mostly multi × bivoltine hybrids is reared in tropical areas of the country which do not meet the international standards as the silk produced by multi × bivoltine hybrids is not so superior in comparison to bi × bivoltine hybrids and hence have no international market. Thus, there is great need and scope for improving the bivoltine sericulture of the country, therefore more emphasis needs to be given to bivoltine sericulture for producing international grade silk (Datta *et al*., 2002) [4]. Realizing the importance of bivoltine sericulture, efforts are being made by silkworm breeders of the country to evolve high yielding bivoltine silkworm breeds and hybrids for commercial exploitation which is slowly revolutionizing silk production in India (Moorthy *et al*., 2007) [21]. Most of the silkworm breeding programmes now-a-days are oriented towards boosting the bivoltine silk yield and fiber quality. Thus, there is a need to develop, evaluate and identify highly adaptive indigenous productive hybrids suitable for different rearing seasons (Kumari *et al*., 2011) [15]. Accordingly, the present investigation was carried out to evaluate and identify the newly developed bivoltine hybrids for commercialization.

Materials and Methods

The experimental research material for the proposed study comprised of eight bivoltine silkworm breeds evolved at Division of Sericulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu. Out of the eight parental breeds, Udhey-1, Udhey-3, Udhey-4 and Udhey-6 were developed as high temperature tolerant breeds specifically for autumn season where as PO_1, PO_3, ND_2 and ND_5 were evolved as hypersericigenous breeds for spring season. The salient features of the parent breeds are presented in Table 1. All the eight breeds were crossed in half diallel fashion and F1 seed of twenty eight hybrid combinations (Table 2) was prepared to develop, evaluate and identify new bi × bivoltine hybrids for achieving the primary objective of establishing bivoltine hybrids as a concept among sericulturists. The hybrids were reared in a Completely Randomized Block Design (CRD) as per the standard rearing techniques of Dandin *et al*. (2003) [3]. The observations were recorded replication-wise for different traits at egg, larval, cocoon and post-cocoon stage and subjected to the estimation of heterosis in relation to mid parent value (Shull, 1948) [33]. Further ranking of heterotic hybrids was done by Evaluation Index method (Mano *et al*., 1993) [18]. The popular commercial hybrid, $SH_6 \times NB_4D_2$ was also included in the study as control.

Table 1: Salient features of parental breeds developed by Division of Sericulture, SKUAST-J

Parent Breeds	Larval marking	Cocoon shape	Cocoon colour	Single cocoon weight (g)	Single shell weight (g)	Shell ratio (%)
Udhey – 1	Marked	Constricted	White	1.61	0.32	19.87
Udhey – 3	Marked	Constricted	White	1.62	0.33	20.37
Udhey – 4	Plain	Elongated	White	1.59	0.33	20.75
Udhey – 6	Plain	Elongated	White	1.60	0.32	20.00
PO_1	Plain	Oval	White	1.08	0.18	16.72
PO_3	Plain	Oval	White	1.18	0.20	17.51
ND_2	Marked	Constricted	White	1.33	0.28	20.87
ND_5	Marked	Constricted	White	1.30	0.29	22.30

Table 2: Half diallel crosses of eight parental breeds

Breeds	Udhey-1	Udhey-3	Udhey-4	Udhey-6	PO_1	PO_3	ND_2	ND_5
Udhey-1	Udhey-1 × Udhey -1							
Udhey-3	Udhey -3 × Udhey -1	Udhey 3 × Udhey -3						
Udhey-4	Udhey -4 × Udhey -1	Udhey -4 × Udhey -3	Udhey -4 × Udhey -4					
Udhey-6	Udhey -6 × Udhey -1	Udhey -6 × Udhey -3	Udhey -6 × Udhey -4	Udhey-6 × Udhey-6				
PO_1	PO_1 × Udhey -1	PO_1 × Udhey -3	PO_1× Udhey -4	PO_1 × Udhey-6	PO_1 × PO_1			
PO_3	PO_3 × Udhey -1	PO_3 × Udhey -3	PO_3 × Udhey -4	PO_3 × Udhey-6	PO_3 × PO_1	PO_3 × PO_3		
ND_2	ND_2 × Udhey -1	ND_2 × Udhey -3	ND_2 × Udhey -4	ND_2 × Udhey-6	ND_2 × PO_1	ND_2 × PO_3	ND_2 × ND_2	
ND_5	ND_5 × Udhey -1	ND_5 × Udhey -3	ND_5 × Udhey -4	ND_5 × Udhey-6	ND_5 × PO_1	ND_5 × PO_3	ND_5 × ND_2	ND_5 × ND_5

No. of Parents = 8 (n)

Half diallel formula = n (n-1)/2
= 8(8-1)/2
= 8(7)/2
= 56/2
= 28

Mid Parent Value (Relative Heterosis)

It was measured as the F1 deviation from mid parental value. Mid Parental Value (Relative heterosis) was obtained by using following formula:

Relative Heterosis (MP) = (H–MP/MP) × 100

Where, H = Mean performance of F_1 hybrid

MP = Mid Parental Value (P1 + P2) / 2

Evaluation Index (E.I.)

The Evaluation Index (E.I.) was calculated as:

Evaluation Index = [(A–B/C) × 10] + 50

Where, A= Value of the particular hybrid combination

B= Mean value of all the hybrid combinations

C= Standard deviation of all the hybrid combination

10= Standard Unit

50= Fixed Value

The E.I. value fixed for the selection of hybrid is 50 or >50 for the characters. The hybrid, which scored above the limit, is considered to possess greater economic value.

Results

Nature and Extent of Heterosis in bi × bivoltine silkworm hybrids

The perusal of Table 3 depicts average heterosis percentage of the hybrids over the parental values in respect of thirteen traits and it revealed that maximum heterosis was observed for non-breakable filament length (37.75%) closely followed by filament length (35.62%) which is almost near to double than the control, cocoon yield by weight (35.22%), larval weight (28.21%), single shell weight (24.46%) and single cocoon weight (17.10%) which constitute important commercial parameters. The magnitude of heterosis for fecundity was to a tune of 14.49 per cent. A negative but desirable heterosis was observed in case of total larval duration (-7.59 %).

Table 3: Overall heterosis percentages of fifteen parameters in bi × bivoltine silkworm hybrids

Traits→	Heterosis percentage	Rank	Control ($SH_6 \times NB_4D_2$)
Fecundity	14.49	8	9.96
Hatching percentage	1.34	13	1.27
Total larval duration	-7.59	10	-3.59

Larval weight		28.21	4	25.99
Cocoon yield/ 10,000 larvae	By number	6.58	11	5.29
	By weight	35.22	3	30.03
Pupation percentage		16.13	7	9.21
Single cocoon weight		17.10	6	5.29
Single shell weight		24.46	5	7.45
Shell ratio percentage		5.86	12	2.05
Total filament length		35.62	2	19.24
Non-breakable filament length		37.75	1	23.06
Filament size		7.64	9	16.52

Egg stage

Only nine hybrid combinations were found to be heterotic for egg traits (Table 4) which recorded above average values and as compared to the check hybrid. Fecundity is one of the most important commercial parameter of quality seed for maximum crop harvest and survival of the silk industry. It scored an average heterosis value of 14.49 per cent, which was higher as compared to control hybrid (9.96%). The highest heterosis was displayed by hybrid $ND_2 \times PO_1$ (25.54) closely followed by $PO_3 \times PO_1$ (25.00), $ND_2 \times PO_3$ (24.06), $ND_5 \times PO_1$ (23.55) and PO_1 × Udhey-6 (22.36) whereas lowest but above average heterosis was found in hybrid $ND_5 \times ND_2$ (15.30). Maximum heterosis for fecundity was observed in the hybrids of hypersericigenous breeds. Hatching percentage is an important parameter with regard to quality of seed. The maximum heterosis was found in hybrid PO_1 × Udhey-1 (6.47) followed by $ND_5 \times PO_3$ (2.75) and $ND_5 \times PO_1$ (2.19) whereas, minimum but above average value was recorded in hybrid PO_1 × Udhey-3 (1.42). Among the traits studied, minimum heterosis was observed for this parameter only.

Table 4: Heterosis percentages of bi × bivoltine silkworm hybrids for egg traits

Traits→ Hybrids↓	Fecundity	Hatching percentage
$SH_6 \times NB_4D_2$	9.96	1.27
PO_1 × Udhey - 1	17.72	6.47
PO_1 × Udhey - 3	18.16	1.42
PO_1 × Udhey - 6	22.36	1.83
$PO_3 \times PO_1$	25.00	1.83
$ND_2 \times PO_1$	25.54	1.54
$ND_2 \times PO_3$	24.06	1.60
$ND_5 \times PO_1$	23.55	2.19
$ND_5 \times PO_3$	21.69	2.75
$ND_5 \times ND_2$	15.30	1.43
Mean	14.49	1.34

Larval stage

At larval stage, out of twenty eight hybrid combinations only ten hybrids were found to be heterotic that displayed a significant and desirable heterosis as compared to the average value and control (Table 5). Larval duration depicted negative but above average and better values than control, maximum value of heterosis was recorded in hybrid PO_1 × Udhey-1 (-11.38) followed by hybrid ND_5 × Udhey-1 (-8.12), ND_5 × Udhey-4 (-8.11), Udhey-4 × Udhey-1(-8.06), whereas, minimum heterosis was found in PO_1 × Udhey-3 (-4.42). The magnitude of heterosis was almost same in five hybrids viz. PO_3 × Udhey-1 (-7.97), $ND_5 \times PO_1$ (-7.92), ND_2 × Udhey-4 (-7.91), $ND_5 \times PO_3$ (-7.79) and PO_1 × Udhey-6 (-7.59) respectively. Larval weight is a cocoon and shell contributing parameter. The maximum heterosis was recorded in hybrid Udhey-4 × Udhey-1 (38.93) closely followed by PO_1 × Udhey-1 (36.89), $ND_5 \times PO_3$ (34.22) and PO_3 × Udhey-1 (33.86) whereas minimum value was recorded in hybrid $ND_5 \times PO_1$ (28.29).

Table 5: Heterosis percentages of bi × bivoltine silkworm hybrids for larval traits

Traits→ Hybrids↓	Larval duration	Larval weight
$SH_6 \times NB_4D_2$	-3.59	25.99
Udhey-4 × Udhey-1	-8.06	38.93
PO_1 × Udhey-1	-11.38	32.93
PO_1 × Udhey-3	-4.42	36.89
PO_1 × Udhey-6	-7.59	28.88
PO_3 × Udhey-1	-7.97	33.86
ND_2 × Udhey-4	-7.91	32.40
ND_5 × Udhey-1	-8.12	30.99
ND_5 × Udhey-4	-8.11	30.79
$ND_5 \times PO_1$	-7.92	28.29
$ND_5 \times PO_3$	-7.79	34.22
Mean	-7.59	28.21

Cocoon stage

Out of all the twenty eight cross combinations, only seven hybrids were found to be heterotic for different parameters at cocoon stage (Table 6) which were above average as compared to control hybrid. Hybrids exhibited positive and significant heterosis over mid parent value as compared to the average value of control hybrid for cocoon yield/10,000 larvae (by weight). The maximum value was observed in hybrid $ND_5 \times PO_1$ (68.04) closely followed by $ND_5 \times PO_3$ (64.11), PO_1 × Udhey-6 (54.99) and PO_1 × Udhey-3 (44.37) whereas, minimum value was recorded in case of hybrid PO_1 × Udhey-1 (39.53). The cocoon yield/10,000 larvae, by number ranged from 5.69 per cent ($ND_5 \times PO_3$) to 9.28 per cent (PO_1 × Udhey-1). The heterosis value for this parameter was low than the cocoon yield by weight. The maximum value of heterosis for yield by number was found in hybrid PO_1 × Udhey-1 (9.28) closely followed by PO_3 × Udhey-1 (9.26), PO_1 × Udhey-3 (8.38) and ND_2 × Udhey-6 (8.27). However, minimum heterosis was recorded in hybrid $ND_5 \times PO_3$ (5.69). Heterosis over mid parent value for pupation percentage was maximum in hybrid PO_1 × Udhey-6 (25.53) followed by PO_1 × Udhey-3 (22.55) and PO_1 × Udhey-1 (21.83), whereas, minimum value for this trait was recorded in hybrid $ND_5 \times PO_3$ (8.13). Single cocoon weight is an important commercial parameter for the production of both quality and quantity of cocoon crop. The maximum value was recorded in hybrid $ND_5 \times PO_1$ (43.24) followed by $ND_5 \times PO_3$ (29.72) and PO_1 × Udhey-6 (23.12), whereas, almost same values (21.84 and 21.98) was recorded in hybrids PO_1 × Udhey-1 and PO_1 × Udhey-3 respectively. However, minimum heterosis for single cocoon weight was recorded in hybrid ND_2 × Udhey-6 (15.21). Single shell weight is the silk contributing parameter. The maximum heterosis value for this parameter was found in hybrid $ND_5 \times PO_1$ (57.94) closely followed by $ND_5 \times PO_3$ (44.71), PO_1 × Udhey-6 (38.40) and PO_1 × Udhey-1 (28.40), whereas, it was minimum in hybrid

ND_2 × Udhey-6 (22.41). The other heterotic hybrids were PO_3 × Udhey-1 (26.23) and PO_1 × Udhey-3 (25.88), respectively. Shell ratio percentage is an important parameter of quality depicting actual silk content of a cocoon. The maximum heterosis value was recorded in hybrid PO_1 × Udhey-6 (12.41) closely followed by ND_5 × PO_3 (11.55) and ND_5 × PO_1 (10.26). The other heterotic hybrids found for this parameter were ND_2 × Udhey-6 (6.25), PO_3 × Udhey-1 (6.06), PO_1 × Udhey-1 (5.38) and PO_1 × Udhey-3 (3.20), respectively.

Table 6: Heterosis percentages of bi × bivoltine silkworm hybrids for cocoon traits

Traits→ Hybrids↓	Cocoon yield/ 10,000 larvae		Pupation percentage	Single cocoon weight	Single shell weight	Shell ratio percentage
	By weight	By number				
SH_6 × NB_4D_2	30.03	5.29	9.21	5.29	7.45	2.05
PO_1 × Udhey-1	39.26	9.28	21.83	21.84	28.40	5.38
PO_1 × Udhey-3	44.37	8.38	22.55	21.98	25.88	3.20
PO_1 × Udhey-6	54.99	7.02	25.53	23.12	38.40	12.41
PO_3 × Udhey-1	39.72	9.26	17.23	19.02	26.23	6.06
ND_2 × Udhey-6	42.12	8.27	18.58	15.21	22.41	6.25
ND_5 × PO_1	68.04	-0.05	8.59	43.24	57.94	10.26
ND_5 × PO_3	64.11	5.69	8.13	29.72	44.71	11.55
Mean	35.22	6.58	16.13	17.10	24.46	5.86

Post-cocoon stage

At post cocoon stage, out of twenty eight hybrid combinations studied only eight hybrid combinations were found to be heterotic (Table 7). Their F1 deviations from corresponding mid parent value was significant and above average. The maximum heterosis for total filament length was displayed by hybrid ND_5 × PO_3 (61.02) followed by ND_5 × PO_1 (53.08), PO_3 × PO_1 (49.45) and ND_5 × Udhey-4 (46.64), whereas, minimum and below average value was found in hybrid PO_1 × Udhey-3 (21.63). The other heterotic hybrids found for this parameter were ND_5 × Udhey-3 (37.48), ND_2 × Udhey-4 (36.86) and PO_1 × Udhey-6 (34.61) respectively. The heterosis value for non-breakable filament length parameter ranged from 25.25 (PO_1 × Udhey-3) to 67.65 (ND_5 × PO_1) per cent. The maximum heterosis was displayed by hybrid ND_5 × PO_1 (67.65) followed by PO_3 × PO_1 (54.30) and ND_2 × Udhey-4 (50.88). Same heterotic value was recorded in two hybrids ND_5 × Udhey-4 (45.72) and ND_5 × Udhey-3 (45.50) respectively. Whereas, other hybrids recorded as heterotic were ND_5 × PO_3 (34.84) and PO_1 × Udhey-3 (25.25), respectively. The heterosis per cent for filament size ranged from -0.86 (ND_5 × PO_1) to 20.71 (PO_1 × Udhey-3). The positive value represented the thick denier whereas; the negative value represented the fine denier. The fine denier was displayed by hybrid ND_5 × PO_1 (-0.86) followed by PO_1 × Udhey-6 (-2.45) whereas, thick denier was recorded in hybrid PO_1 × Udhey-3 (20.71) followed by ND_5 × Udhey-4 (20.17), ND_5 × Udhey-3 (16.25) and PO_3 × PO_1 (16.11).

Table 7: Heterosis percentages of bi × bivoltine silkworm hybrids for post cocoon traits

Traits→ Hybrids↓	Total filament length	Non-breakable filament length	Filament size
SH_6 × NB_4D_2	19.24	23.06	16.52
PO_1 × Udhey-3	21.63	25.25	20.71
PO_1 × Udhey-6	34.61	41.89	-2.45
PO_3 × PO_1	49.45	54.30	16.11
ND_2 × Udhey-4	36.86	50.88	13.82
ND_5 × Udhey-3	37.48	45.50	16.25
ND_5 × Udhey-4	46.64	45.72	20.17
ND_5 × PO_1	53.08	67.65	-0.86
ND_5 × PO_3	61.02	34.84	4.74
Mean	35.62	37.75	7.64

Identification and Evaluation of superior crosses

The estimates for heterosis worked out for twenty eight hybrids for commercial parameters for different stages of silkworm life cycle were pooled in groups. Among these groups, only four hybrids excelled in heterosis value for thirteen commercial parameters which displayed superiority over other hybrids (Table 8). The perusal of data on the basis of cumulative positive heterosis value of different traits revealed that, hybrid ND_5 × PO_1 (362.83) ranked at 1st position closely followed by ND_5 × PO_3 (323.17). Other superior crosses identified on the basis of evaluation include PO_1 × Udhey-6 (291.31) and PO_1 × Udhey-3 (250.42). The control hybrid (SH_6 × NB_4D_2) scored the cumulative heterosis value of 155.36 only.

The superiority of breeds was further confirmed by using Evaluation Index (E.I) method (Table 9). Among these four hybrids only three cross combinations crossed over all rank of >50 with maximum average E.I. value of 55.61 in hybrid ND_5 × PO_3 closely followed by hybrid ND_5 × PO_1 (54.40) and hybrid PO_1 × Udhey-6 (51.97) whereas, a marginal average E.I. value (49.86) was depicted by hybrid PO_1 × Udhey-3. Further it was found that in hybrid ND_5 × PO_3, the individual parameter Evaluation Index (E.I) value in most of the parameters exceeded the bench mark of >50 such as fecundity (53.80), hatching percentage (65.64), larval weight (59.55), cocoon yield/10,000 larvae by number (55.78), single shell weight (60.00), shell ratio percentage (63.44), average filament length (64.33) and non-breakable filament length (59.93). All these parameters contribute for the production of quality cocoon crop that establishes the superiority of the hybrid. In case of the control hybrid (SH_6 × NB_4D_2) the average E.I. value stood at 39.17.

Table 8: Heterosis over mid parent value for thirteen commercial traits among superior cross combinations or heterotic hybrids

Hybrids → **Traits ↓**		**Crosses**					**S.E**	**C.D at 5%**	**C.D at 1%**
		SH_6 × NB_4D_2	**PO_1 × Udhey-3**	**PO_1 × Udhey-6**	**ND_5 × PO_3**	**ND_5 × PO_1**			
Fecundity		9.96	18.16	22.63	21.69	23.55	2.63	6.20	9.17
Hatching percentage		1.27	1.42	1.83	2.75	2.19	0.07	0.16	0.24
Larval duration		-3.59	-2.42	-7.59	-7.79	-7.92	1.19	2.80	4.15
Larval weight		25.99	36.89	28.88	34.22	28.29	2.02	4.76	7.05
Cocoon yield / 10,000 larvae	By weight	30.03	44.37	54.99	64.11	68.04	6.90	16.28	24.08
	By number	5.29	8.38	7.02	5.69	-0.05	1.43	3.37	4.99
Pupation percentage		9.21	22.55	25.53	8.13	8.59	3.80	8.96	13.26
Single cocoon weight		5.29	21.98	23.12	29.72	43.24	6.14	14.49	21.42
Single shell weight		7.45	25.88	38.40	44.71	57.94	8.58	20.24	29.94
Shell ratio percentage		2.05	3.20	12.41	11.55	10.26	2.18	5.14	7.60
Total filament length		19.24	21.63	34.61	61.02	53.08	8.33	19.65	29.07
Non-breakable filament length		23.06	25.25	41.89	34.84	67.65	8.02	18.92	27.98
Filament Size		16.52	20.71	-2.45	4.74	-0.86	6.06	14.30	21.14
Cumulative heterosis		155.36	250.42	291.31	323.17	362.83	-	-	-

Table: 9 Evaluation Index (E.I.) values of superior cross combinations or heterotic hybrids for commercial traits

Hybrids → **Traits ↓**		**Crosses**				
		SH_6 × NB_4D_2	**PO_1 × Udhey-3**	**PO_1 × Udhey-6**	**ND_5 × PO_1**	**ND_5 × PO_3**
Fecundity		31.37	54.94	60.65	49.24	53.80
Hatching percentage		36.06	47.76	48.51	52.45	65.64
Larval duration		68.97	44.73	41.57	43.68	51.05
Larval weight		31.34	56.75	48.02	53.58	59.55
Cocoon yield / 10,000 larvae	By weight	31.28	59.14	56.58	54.36	48.97
	By number	30.94	56.64	57.63	49.00	55.78
Pupation percentage		32.21	58.85	60.14	48.62	50.22
Single cocoon weight		37.50	52.50	52.50	67.50	42.50
Single shell weight		40.00	40.00	55.00	65.00	60.00
Shell ratio percentage		41.01	36.46	51.14	57.57	63.64
Total filament length		38.50	40.87	47.70	58.59	64.33
Non-breakable filament length		37.67	40.61	49.12	62.66	59.93
Filament Size		52.31	59.04	46.73	45.00	47.50
Av. E.I.		39.17	49.86	51.97	54.40	55.61

Discussion

The mulberry silkworm (*Bombyx mori* L.) is one among the few completely domesticated insects that has attracted breeders from time immemorial due to its economic importance. Attempts have been made to exploit the heritable genetic component. It has been reported that most of the economically important characters are quantitative and polygenic in nature (Kobari and Fujimoto, 1966) [13]. The ultimate goal of breeding efforts is the achievement of genetic improvement or the genetic gain. The existing gene pool provides raw materials for combining genes into recombinants from which individuals with the desirable gene combination are selected for multiplication and exploitation. A gene may affect many characters at the same time, linked genes on the chromosome tend to segregate simultaneously and group of genes may work together and interact to express a given character exhibiting a correlated change between interacting traits. It is on the basis of these genetic properties that one can predict possible alteration of one trait, while working to improve the other trait.

In order to improve the yield and quality of silk, it is pertinent to characterize the potential of available genetic resources for transferring the desirable components in hybrids. Selection of parents on the basis of per se performance does not always lead to fruitful results. More diverse the parents more are the chances of heterosis (Gamo, 1976) [7]. Almost all the economic traits of silkworm are reported to exhibit heterosis (Gautam *et al*., 1998) [8]. Systematic procedures developed for the estimation and exploitation of hybrids through hybridization in silkworm for economic traits on the basis of mid parent value (Relative heterosis) has brought a revolutionary change in overall qualitative and quantitative silk output (Malik *et al*., 2002) [17]. Any effort to improve the yield potential requires consideration of cumulative effect of the major characters that influence the silk yield. Evaluation Index method (Mano *et al*., 1993) [18] was found to be a useful tool for judging the superiority of the silkworm hybrids impartially.

In the present study, the estimates for heterosis of all the twenty eight hybrids at different stages of life cycle of silkworm exhibited a significant and desirable heterosis in groups over stages. Some hybrids performed well at one stage but exhibited a poor performance at other stage and vice versa as in silkworm selection for one character produce a correlated change in other characters (Kobari and Fujimoto, 1966) [13].

At egg stage, amongst twenty nine hybrid combinations studied including control, nine hybrids exhibited above average, significant and desirable heterosis for fecundity and hatching percentage. It indicates genetic superiority due to the heterotic effect of inter crossing as reported by Kamble (1998) [12]. According to Tazima (1957) [36], fecundity mainly depends upon genotype of mother moth and environmental conditions at the time of oviposition. Lakshmanan and Kumar (2012) [16] suggested that when parental breed are utilized for the production of hybrid combination it not only helps in high egg recovery but heterosis manifestation in hybrids also gets exploited for commercial purpose. In the present study, maximum heterosis value for fecundity observed in hybrid combination may be due to more accumulation of pupal weight. Similar observations were made by Narayanaswamy *et al*. (2002) [23]. Hatching percentage being an important seed parameter, commercially show direct co-relation to number of worms hatched and larval population reared that ultimately contribute for cocoon yield. In the present study, it may be due to physiological status of embryonic development and environmental factors like temperature, light and humidity during incubation of eggs (Tazima, 1957) [36]. Similar trend was observed by Ram *et al*. (2010) [27] in bivoltine hybrids. High hatching percentage observed in bivoltine breeds also reflects the high value for number of eggs hatched, number of worms brushed and brushing percentage which are important characters of quality silkworm seed and breed. The observations are in concordance with the findings of Reddy *et al*. (2012) [31].

The observations made on the larval duration and larval weight depicted significant variation. Larval duration being one of the important characters that influence the rearing duration, labour input and leaf consumption that are directly related to the cost of production and silk productivity. At the larval stage, a group of ten hybrids displayed above average and significant heterosis for larval duration and larval weight. Maximum negative heterosis expressed for larval duration indicates shorter larval life as well as less intake of mulberry leaf during larval period thus saving more man days, which is a desirable character. Hybrids scoring negative heterosis value for larval duration are considered to possess greater economic value (Rayar, 2007) [30]. Mustafaev (1975) [22] has suggested reduction in larval duration to better nutritional value of mulberry variety especially triploids. However, hybrids depicting longer larval duration express slow growth with reduced rate of metabolism due to the associated environmental conditions (Mirhosieni *et al*., 2004) [20]. Fluctuations observed in larval duration in various breeds and hybrids can be interpreted to the variable level of heterozygosity attained at some loci as observed by Soliman, 1982 [34]. Similar observations were also suggested by Rao *et al*. (2006) [29]. Silkworms are voracious eaters of mulberry during its larval stages and around 80 percent of leaf is consumed in last two instars (Fukuda, 1960) [6]. Highlighting the importance of food intake, Horie *et al*. (1978) [10] reported that for the production of 1 g larval dry weight, requirement of ingestion and digestion of food is 4.2 mg and 1.8 mg respectively. The intake of food during total larval life is also reflected by the weight of 10 mature larvae. The significant heterosis values observed in ten hybrids indicates their superiority and thus parallels the observations of Rayar (2007 [30].

Minagava and Otsuka (1975) [19] has reported interrelationship between multiple characters in silkworm. It therefore becomes essential to evaluate the breeds and their hybrids to understand the magnitude of potential and heterosis towards improvement in cocoon and silk productivity as suggested by Bandopadyay (1990) [2]. Malik *et al*. (2002) [17] suggested that cocoon yield/10,000 larvae by weight and by number, pupation percentage, single cocoon weight, shell weight and shell ration percentage are important parameter for quality cocoon crop as well as potential hybrid. At cocoon stage, the heterosis estimates of seven hybrids exhibited desirable and significant result when compared to average value of control hybrid. The higher yield by weight and number in bivoltine hybrids may be due to the higher hatching and brushing percentage, larval survival percentage and their adaptability for autumn season. Positive correlation for cocoon yield, single cocoon weight with fecundity and hatching parentage has been reported by Jayaswal *et al*. (1990) [11]. Similar results were also recorded by Kumar *et al*. (2011) [14]. Pupation rate is one of the important economic characters to determine the variability of a breed/hybrid. It is though an independent character but is greatly dependent on rearing environment, food quality and other abiotic factors and is a positive sign for cocoon reeling performance as well as seed production. The genetic and environment factor gets more reflected in this character. The higher pupation rate in the hybrids can be attributed to the fact that they were more adaptable to autumn season and can with stand the higher temperature and humidity. Pupation rate is a low heritable character and is prone to large variations in different environmental conditions and management. The observations are in accordance with the findings of Gowda *et al*. (2013) [9]. The cocoon weight, shell weight and shell ratio are the important commercial parameters. The cocoon weight has a negative correlation with shell ratio but positive correlation with shell weight whereas shell weight has a positive correlation with shell ratio. Higher heterosis values for cocoon and shell weight may be due to the superiority of hybrids thus indicating the phenomenon that heterosis could be either due to additive gene action or due to dominance. The results are in accordance with the findings of Ramesha *et al*. (2010) [28]. Higher shell ratio percentage is an important parameter contributing to productivity and silk filament. The high heterosis values obtained for bivoltine hybrids compared to other can be ascribed to its genetic constitution. The results are in close conformity with the observations of Subba Rao and Sahai (1989) [35] who reported the additive gene action for this trait. Cocoon yield, pupation rate, single cocoon weight, single shell weight and shell ratio combinedly constitute major qualitative and quantitative traits of silk. Saratchandra *et al*. (1992) [32] has reported superior mulberry variety particularly triploids responsible for higher cocooning characters. Similar findings were also recorded by Rao *et al*. (2006) [29].

Post cocoon characters have greater significance not only from reeler's point of view but also from industrial point of view. Three post-cocoon parameter viz. total filament length, non-breakable filament length and filament size mainly contribute for silk, the end product. In this study, eight hybrids exhibited above average and better values than control hybrid. Higher filament length had significant correlation with cocoon weight, shell weight and shell ratio percentage (Qadri *et al*., 2013) [25]. Filament length and denier are considered as important characters from economic point of view and have direct bearing on the merit of a breed/hybrid. Increase or decrease in filament length is dependent on increase or decrease in the thickness of silk filament and cocoon shell weight of breeds and hybrids. Results of the present study revealed fluctuations in filament length in different hybrids studied. Rajalakshmi *et al*. (2000) [26] opines that quality of the good hybrid is to have minimum or no breaks during reeling. The high degree of heterosis in heterotic hybrids for post-cocoon parameters may be due to additive gene effects, especially higher heterosis obtained for filament length and shell weight reveals the magnitude of genetic diversity of the parental material. The results are in accordance with the findings of Dayanada *et al*. (2011) [5].

Thiagarajan *et al*. (1993) [37] reported that silk yield is the main contributing factor among major characters usually considered by breeders. In the present study, three hybrids were found to be having significant values for silk yield. Premalatha *et al*. (2000) [24] suggested that low magnitude of heterosis in hybrids for a particular trait indicates the presence of partial dominance. Ram *et al*. (2010) [27] suggested that the superiority and potential of a breed and hybrid mainly depends on the ranking and considering all the major cocoon yield and silk contributing parameters.

Thus, based on these facts it can be concluded that for the cumulative heterosis and evaluation index values for qualitative and quantitative traits, three hybrid combinations viz. $ND_5 \times PO_3$, $ND_5 \times PO_1$ and PO_1 × Udhey-6 were short listed and found promising among twenty eight hybrids studied and hence, can be exploited in the field at farmer's level for better prospects of bivoltine sericulture in the country..

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