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Analysis of the boil-off loss in parental and different crosses of bivoltine silkworm, *Bombyx mori* L.

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ABSTRACT: The process of removal of gummy proteinous material (sericin) from the silk is commonly referred to as degumming loss or boil-off loss and is considered as one of the important economic traits during the course of silkworm breeding. Loss of sericin varies with breeds / hybrids, it is essential to analyze the ratio with reference to cocoon shell, as it is the basic raw material for the raw silk to estimate silk productivity of a breed / hybrid. In the present study, boil-off loss ratio in the cocoon shells of twelve bivoltine parental breeds (6 oval and 6 dumb-bell) and newly developed 21 each of different crosses (single, three-way and four-way crosses) of bivoltine hybrids along with control hybrids CSR2xCSR4 and [(CSR2xCSR27)x(CSR6xCSR26)] was analyzed to identify promising hybrids with desired boil-off loss ratio. Heterosis for boil-off loss ratio, shell ratio and raw silk percentage both in parents and all the hybrid crosses was also estimated and discussed. Among the parents, the least value of 21.50% was registered in JPN8 (oval), 22.01 % (S9) amongst dumb-bells and in the hybrids, single-cross hybrid CSR27xCSR26 (23.25%), three-way cross hybrid, (JPN8xCSR17)xCSR26 (22.51%) and four-way cross hybrid [(JPN8xCSR17)x(D13xCSR26)] (22.33%) was recorded. It was observed that some of the different crosses of the hybrids have also recorded desirable heterosis values for boil-off loss trait.

KEYWORDS: Bivoltine silkworm, *Bombyx mori* L., Sericin, Boil-off loss, economic trait, heterosis, single, three-way and four-way cross.

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INTRODUCTION

To meet the requirement of the consumers across the world, sericulture industry requires superior quality of silk to produce internationally gradable silk fabric and increased foreign exchange. To face the global competitiveness in silk production there is a need to improve the quality of the raw silk. At the end of larval period, the silkworm spins a shell by extruding silk bave for protection during its pupation from adverse environment.

The silk bave composed of two protein substances viz., fibroin and sericin also contains a small quantity of fatty, waxy, coloring and mineral matters. Fibroin, axis of silk thread, represents 70-80% of its weight, whereas, sericin, encloses fibroin in a common sheet, accounts for 20-30% of the weight. The fatty, waxy, coloring and mineral matter forms very meager part (2-3%) of the silk bave.

Degumming is the process of removal of sericin in boiling soap solution and the cocoon shell has more boil-ff loss ratio when compared to the raw silk (Kannan, 1986). The main silk substance, fibroin is insoluble in alkaline hot water, whereas, sericin (silk gum) is easily soluble in boiling alkaline soap solution (Sadov et al., 1978). Boil-off loss ratio, one of the important qualitative traits during breeding, for bivoltine race is found to be 24% (optimum) and it is genetically different among silkworm strains (Sinha et al., 1992). The boil-off loss ratio is comparatively higher in polyvoltines than bivoltines because of more floss (Sidhu and Sonwalker, 1969, Naseema Begum et al., 2010). Low boil-off loss ratio improves cocoon reeling qualities (Gamo and Hirabayashi, 1984). The boil-off loss varies according to the seasons and is influenced by environment (Sonwalker, 1969).

As the loss of sericin and its effect on weaving and other post weaving processes due to degumming, varies with different breeds, it is necessary to study in detail the boil-off loss with reference to cocoon shell itself, as it is the basic raw material for the raw silk. In light of the above, the present study was undertaken to analyze the boil-off loss in bivoltine parental breeds and their different cross hybrids to identify and select the promising hybrids.

MATERIALS AND METHOD

Six each of oval and dumb-bell bivoltine silkworm breeds viz., CSR17, CSR27, JPN8, JPN7, S5, BBE226 (oval) and CSR16, CSR26, D13, S9, BBE247, BBE247 (dumb-bell) were utilized for preparation of single, three-way (oval x oval) x dumb-bell and four-way cross (oval x oval) x (dumb-bell x dumb-bell) hybrids by employing partial diallel-cross technique. The parental breeds and hybrids were brushed together and reared in three replications by the standard rearing technique (Datta, 1992) during different seasons of the year viz., summer, rainy and winter.

After the sex-separation and assessment, sixty cocoon shells (thirty each of female and male) were taken at random and were replicated into three, with ten each of male and female, for conducting the experiment. Degumming was carried out by boiling the cocoon shells in standard soap solution (Basavaraja et al., 2000).

The method followed for degumming of the cocoon shells is by using neutral liquid soap for boiling. Degumming of raw silk was carried out by using the material to liquor ratio of 1: 40 prepared by dissolving a quantity of 5g / liter neutral soap with 1g / liter sodium carbonate (soda) and was boiled in a copper vessel at a temperature of 90 to 95ºC for 45 minutes. After a shorter time gap, the sample material was rinsed in hot water for 30 minutes and then in cold water before being hydro extracted. The degummed cocoon shells were then transferred to perforated paper envelops and dried in oven maintaining temperature of 105ºC for 5 hours. The initial dry weight and final dry weight of the degummed silk were considered for calculation of boil-off loss by following the formula,

$$\text{Boil-off Loss Ratio (\%)} = \frac{\text{Initial dry weight} - \text{final dry weight after degumming}}{\text{Initial dry weight}} \times 100$$

The hybrid vigour of different crosses was estimated by using the following formula,

$$\text{Heterosis (\%)} = \frac{\text{Hybrid value} - \text{Mid parent value (MPV)}}{\text{Mid parent value (MPV)}} \times 100$$

Multiple trait evaluation index (Mano et al., 1993) was estimated by using the following formula:

$$\text{Evaluation Index (E. I.)} = \frac{(A - B)}{C} \times 10 + 50$$

Where, A = Value of a particular breed for particular trait,

B = Mean value for a particular trait of all the breeds,

C = Standard Deviation of a particular trait for all the breeds,

10 = Standard unit,

50 = Fixed value.

Minimum/average E.I. value fixed for selection of a breed is >50.

Cocoons selected randomly were cut, sex separated at pupal stage and weighed for the cocoon weight and shell weight. The average weight of 20 (10 male and 10 female) shells was taken as cocoon weight and shell weight. Shell ratio was estimated by following the formula,

$$\text{Shell ratio (\%)} = \frac{\text{Weight of cocoon shell}}{\text{Weight of cocoon}} \times 100$$

Raw silk percentage, defined as the quantity of raw silk obtained after reeling 100 kg of cocoons, was calculated by using the following formula,

$$\text{Raw silk (\%)} = \frac{\text{Weight of raw silk reeled + converted silk weight of carry over cocoons}}{\text{Weight of cocoons taken for reeling}} \times 100$$

RESULTS

The mean values of performance showing shell ratio, raw silk percentage and boil-off loss in oval and dumb-bell bivoltine parental breeds, exhibiting variations for these traits, is detailed in Table-1. Among oval breeds, shell ratio ranged from 23.33% (BBE226) to 25.01% (CSR27), raw silk percentage from 17.09% (BBE226) to 18.40% in CSR27 and in boil-off loss, JPN8 (21.50%) and JPN7 (21.90%) lines registered lower values against the average of 22.78%. Whereas, in dumb-bell breeds shell ratio ranged from 18.15% (BBE267) to 22.18% (CSR16), raw silk percentage from 16.30% (BBE267) to 19.22% (S9) and highest boil-off loss value of

Table 1. Mean values of performance in parental breeds

Sl.No.	Breeds	Shell ratio(%)	Raw silk (%)	Boil-off loss (%)
Ovals				
1	CSR17	23.61	18.37	22.66
2	CSR27	25.01	18.40	22.33
3	JPN8	23.81	18.26	21.50
4	JPN7	23.65	18.15	21.90
5	S5	23.50	18.30	23.22
6	BBE226	23.33	17.09	25.04
	CD at 5%			**0.603**
Dumb-bells				
1	CSR16	22.18	18.12	23.09
2	CSR26	21.95	18.32	22.66
3	S9	21.72	19.22	22.01
4	D13	21.35	17.80	22.87
5	BBE247	22.04	16.35	25.05
6	BBE267	18.15	16.30	25.06
	CD at 5%			**0.923**

25.06% was recorded by BBE267 with values ranging from 22.01 to 25.26%. The least boil-off loss was registered by S9 (22.01%) followed by CSR26 (22.66%) and the maximum of 25.06% was recorded by BBE267 against the average of 23.61%.

Comparison of the mean values of shell ratio, raw silk percentage and boil-off loss exhibiting variations among the bivoltine single cross hybrids with a maximum shell ratio of 24.30% in CSR27xCSR26 and a minimum of 22.52% (JPN8xS9) and 21.29% in the control. The raw silk percentage ranged from 17.16% (CSR17xD13) to 19.08% in CSR27xCSR26. In boil-off loss trait, maximum of 24.89% in CSR17xBBE247 and a minimum of 23.25% in CSR27xCSR26 as against the 23.89% in the control hybrid, CSR2xCSR4, was recorded (Table 2).

Variation in shell ratio, raw silk percentage and boil-off loss among the bivoltine three-way cross (oval x oval) x dumb-bell hybrids (Table 3) (CSR27xCSR17)xBBE267 recorded lowest cocoon shell ratio of 19.87% and highest value of 22.31% by (JPN8xCSR17)xCSR26 was recorded. Raw silk percentage ranged from 16.54% (CSR27xCSR17)xBBE267 to 19.58% in

Table 2. Mean values of performance and heterosis in single cross hybrids

Sl .No	Hybrid	Performance			Heterosis (%)		
		Shell Ratio (%)	Raw Silk (%)	Boil-off loss (%)	Shell Ratio	Raw silk	Boil-off loss
1	CSR17xCSR16	23.14	17.38	24.31	0.72	2.26	6.82
2	CSR17xCSR26	23.22	19.01	24.00	-10.87	2.04	4.55
3	CSR17xS9	23.18	17.66	24.25	4.24	3.01	6.82
4	CSR17xD13	22.68	17.16	24.87	7.89	7.03	4.35
5	CSR17xBBE247	22.82	17.18	24.89	2.93	-0.08	4.73
6	CSR17xBBE267	22.77	18.75	24.03	-1.02	5.73	5.45
7	CSR27xCSR26	24.30	19.08	23.25	2.11	11.55	-1.43
8	CSR27xS9	23.56	18.75	24.03	2.09	2.18	0.01
9	CSR27xD13	23.51	18.39	23.83	1.41	4.13	-1.02
10	CSR27xBBE247	23.37	18.59	24.65	6.13	2.25	4.34
11	CSR27xBBE267	23.73	18.84	24.58	2.81	7.18	4.54
12	JPN8xS9	22.52	18.20	23.83	3.55	0.81	6.98
13	JPN8xD13	23.02	18.79	24.13	2.80	9.86	6.97
14	JPN8xBBE247	23.12	18.19	24.65	9.02	4.74	2.22
15	JPN8xBBE267	23.02	17.39	24.50	1.85	0.35	6.51
16	JPN7xD13	22.74	17.71	24.53	-3.41	10.57	1.15
17	JPN7xBBE247	23.05	17.33	24.50	6.86	-0.137	1.09
18	JPN7xBBE267	23.59	17.47	24.83	6.93	4.77	-0.36
19	S5xBBE247	23.35	17.63	24.27	4.63	3.94	4.26
20	S5xBBE267	22.88	17.34	24.07	2.20	0.46	2.17
21	BBE226xBBE267	22.59	17.47	24.68	10.83	7.91	-5.48
22	CSR2xCSR4 **(C)**	21.29	18.23	23.89	-2.04	3.34	-2.13

Table 3. Mean values of performance and heterosis in three-way cross hybrids

Sl. No	Hybrid	Performance			Heterosis (%)		
		Shell Ratio(%)	Raw silk (%)	Boil-off loss (%)	Shell Ratio	Raw silk	Boil-off loss
1	(CSR27xCSR17)xBBE267	19.87	16.54	24.51	-2.88	1.59	2.84
2	(CSR27xCSR17)xD13	20.23	16.87	24.17	-6.76	-1.91	4.73
3	(CSR27xCSR17)xS9	21.36	18.36	23.38	-8.43	-2.71	5.50
4	(CSR27xCSR17)xBBE247	21.50	17.22	24.31	-10.89	1.91	4.95
5	(CSR27xCSR17)xCSR16	21.17	18.89	23.72	-9.02	-0.75	3.75
6	(CSR27xCSR17)xCSR26	21.24	18.54	23.89	-2.92	1.90	4.10
7	(JPN8xCSR27)xD13	21.52	19.88	24.52	-4.93	-1.15	7.54
8	(JPN8xCSR27)xS9	21.87	18.59	24.08	0.47	1.06	6.64
9	(JPN8xCSR27)xBBE247	20.43	17.46	24.51	-6.20	-1.53	5.63
10	(JPN8xCSR27)xCSR16	20.78	17.52	24.25	-8.15	-4.97	6.50
11	(JPN8xCSR27)xCSR26	20.57	17.10	24.26	-7.95	-2.56	10.36
12	(JPN8xCSR17)xD13	21.58	18.24	23.83	-3.03	0.33	3.73
13	(JPN8xCSR17)xBBE247	20.33	16.62	24.54	-7.52	-4.62	7.27
14	(JPN8xCSR17)xCSR16	20.72	16.94	24.52	-4.52	-2.42	5.84
15	(JPN8xCSR17)xCSR26	22.31	19.58	22.51	0.28	0.49	1.09
16	(JPN8xJPN7)xBBE247	20.84	18.44	23.86	-6.01	-2.92	2.97
17	(JPN8xJPN7)xCSR16	21.32	19.23	23.81	-5.11	-2.58	2.95
18	(JPN8xJPN7)xCSR26	21.52	17.57	24.17	-9.07	-4.51	8.87
19	(S5xCSR27)xCSR16	20.60	19.30	23.97	-11.14	-1.70	6.63
20	(S5xCSR27)xCSR26	20.48	17.23	24.55	-7.06	-2.12	7.44
21	(S5xJPN8)xCSR26	21.41	18.53	24.19	0.28	1.68	7.47
22	CSR2xCSR4 **(C)**	20.91	17.47	23.22	0.88	1.07	2.04

(JPN8xCSR17)xCSR26. The least boil-off loss of 22.51% in (JPN8xCSR17)xCSR26 and highest of 24.55% in (S5xCSR27)xCSR26 was recorded. Some other hybrids have also shown lower deviation (<24.00%) against the highest of 24.55% recorded by (S5xCSR27)xCSR26 and control hybrid, CSR2 x CSR4 with 23.22%.

Mean values of performance in respect of shell ratio, raw silk percentage and boil-off loss in respect of bivoltine four-way cross hybrids is presented in Table 4. [(CSR27xCSR17)x(CSR16xCSR26)] exhibited least shell ratio (19.97%), raw silk percentage was less (16.49%) in [(JPN8xCSR17)x(D13xCSR16)] and minimum boil-off loss of 22.33% was recorded by [(JPN8xCSR17)x(D13xCSR26)]. The shell ratio of four-way cross hybrids ranged from 19.97% [(CSR27xCSR17)x(CSR16xCSR26)] to 28.89% [(JPN8xCSR17)x(D13xCSR26)]. Similarly, raw silk percentage ranged from 16.49% [(JPN8xCSR17)x(D13xCSR16)] to 19.52% [(JPN8xCSR17)x(D13xCSR26)]. Most of the four-way cross hybrids have shown less variation in boil-off loss with the average ratio of 23.36% and ranged from 22.33 to 24.75%. The hybrid [(JPN8xCSR17)x(D13xCSR26)] has recorded lowest boil-off loss (22.33%) as compared to [(CSR27xCSR17)x(S9xCSR16)] with 23.75% and the control hybrid [(CSR2xCSR27)x(CSR6xCSR26)] with the ratio of 24.04%.

Table 4. Mean values of performance and heterosis in four-way cross hybrids

Sl. No	Hybrid	Performance			Heterosis (%)		
		Shell Ratio(%)	Raw silk (%)	Boil-off loss (%)	Shell Ratio	Raw silk	Boil-off loss
1	(CSR27xCSR17)x (CSR16xCSR26)	19.97	18.62	24.43	-2.88	1.59	6.22
2	(CSR27xCSR17)x (S9xCSR16)	20.14	18.87	23.75	-6.76	-1.91	4.40
3	(CSR27xCSR17)x (S9xCSR26)	21.60	18.10	23.69	-2.43	-2.71	4.13
4	(CSR27xCSR17)x (D13xCSR26)	21.51	19.34	23.51	4.22	4.48	2.17
5	(CSR27xCSR17)x(D13xS9)	19.40	18.89	23.47	-3.14	-0.75	3.16
6	(CSR27xCSR17)x(D13x CSR16)	19.93	17.12	23.52	-2.92	1.89	2.17
7	(JPN8xCSR27)x(S9xCSR16)	20.77	17.06	23.55	-5.46	-0.24	5.01
8	(JPN8xCSR27)x(S9xCSR26)	21.46	19.45	23.52	-0.96	2.69	5.36
9	(JPN8xCSR27)x(D13x CSR26)	21.56	19.18	23.50	-0.92	3.62	3.84
10	(JPN8xCSR27)x(D13xS9)	21.43	19.40	23.57	1.05	-4.97	5.00
11	(JPN8xCSR27)x(D13x CSR16)	20.55	19.12	23.65	-3.60	-2.56	3.84
12	(JPN8xCSR17)x(S9xCSR26)	22.01	19.05	22.45	-3.03	0.33	5.02
13	(JPN8xCSR17)x(D13x CSR26)	22.89	19.52	22.33	2.27	3.99	3.84
14	(JPN8xCSR17)x(D13xS9)	21.88	16.94	22.35	-4.52	-2.42	5.05
15	(JPN8xCSR17)x(D13x CSR16)	20.03	16.49	23.15	0.28	0.49	3.84
16	(JPN8xJPN7)x(D13xCSR26)	20.15	19.43	23.30	-6.10	-2.93	5.68
17	(JPN8xJPN7)x(D13xS9)	20.23	19.23	23.51	-5.11	-2.58	6.82
18	(JPN8xJPN7)x(D13xCSR16)	19.80	18.57	23.56	0.67	-4.49	5.62
19	(S5xCSR27)x(D13xS9)	21.73	19.18	23.49	-0.87	-1.70	3.30
20	(S5xCSR27)x(D13xCSR16)	21.16	17.85	23.52	-7.06	-2.12	2.21
21	(S5xJPN8)x(D13xCSR16)	19.87	18.87	23.50	0.40	2.17	3.84
22	(CSR2xCSR27)x (CSR6xCSR26) (C)	20.17	18.91	24.04	-8.50	2.09	4.75

Table 5. Rearing and reeling performance of bivoltine single cross hybrids
(Mean values of 3 seasons)

Sl. No.	Hybrid	Yield / 10000 larvae (No.)	Cocoon weight (g)	Shell weight (g)	Shell ratio (%)	Raw silk (%)	Filament length (m)	Reelability (%)	Neatness (p)	Boil-off loss ratio (%)	E. I. (%)
1	CSR17xCSR16	9555	1.984	0.459	23.14	17.38	978	84.14	92.50	24.31	53.81
2	CSR17xCSR26	9029	1.929	0.448	23.22	19.01	972	79.96	92.17	24.00	50.83
3	CSR17xS9	9183	1.989	0.461	23.18	17.66	1007	83.55	91.80	24.25	53.69
4	CSR17xD13	9458	1.904	0.432	22.68	17.16	936	79.85	91.98	24.87	49.43
5	CSR17xBBE247	9048	1.916	0.437	22.82	17.18	996	80.15	90.90	24.89	51.86
6	CSR17xBBE267	9612	1.915	0.436	22.77	18.75	977	81.75	91.72	24.03	49.21
7	CSR27xCSR26 *	9608	2.074	0.504	24.30	19.08	1098	88.05	93.75	23.25	59.16
8	CSR27xS9	9511	1.982	0.466	23.56	18.75	949	85.10	92.81	24.03	55.15
9	CSR27xD13	9661	1.948	0.458	23.51	18.39	1076	86.12	93.10	23.83	55.10
10	CSR27xBBE247	9141	1.823	0.426	23.37	18.59	882	80.10	91.33	24.65	48.71
11	CSR27xBBE267	9240	1.850	0.439	23.73	18.84	970	80.50	91.86	24.58	45.93
12	JPN8xS9	9204	1.922	0.433	22.52	18.20	1046	82.60	92.33	23.83	52.52
13	JPN8xD13	9286	1.876	0.432	23.02	18.79	1040	82.50	92.50	24.13	52.15
14	JPN8xBBE247	9498	1.881	0.435	23.12	18.19	882	80.50	90.96	24.65	45.72
15	JPN8xBBE267	9517	1.877	0.432	23.02	17.39	1062	81.80	92.10	24.50	50.26
16	JPN7xD13	9505	1.957	0.445	22.74	17.71	965	80.50	92.03	24.53	51.59
17	JPN7xBBE247	9378	1.879	0.433	23.05	17.33	900	80.10	91.80	24.50	49.22
18	JPN7xBBE267	9538	1.823	0.430	23.59	17.47	897	80.55	91.05	24.83	45.77
19	S5xBBE247	9256	1.812	0.423	23.35	17.63	924	80.50	92.10	24.27	48.01
20	S5xBBE267	9356	1.876	0.429	22.88	17.34	1025	82.00	92.06	24.07	52.27
21	BBE226xBBE267	9170	1.806	0.408	22.59	17.47	919	80.50	90.10	24.68	45.74
22	CSR2xCSR4 **(C)**	9065	1.855	0.395	21.29	18.23	943	80.00	92.00	23.89	45.97

* Selected hybrid.

Table 6. Rearing and reeling performance of bivoltine three-way cross hybrids

(Mean values of 3 seasons)

Sl. No.	Hybrid	Yield / 10000 larvae (No.)	Cocoon weight (g)	Shell weight (g)	Shell ratio (%)	Raw silk (%)	Filament length (m)	Reelability (%)	Neatness (p)	Boil-off loss ratio (%)	E. I. (%)
1	(CSR27xCSR17)xBBE267	8955	1.988	0.395	19.87	16.54	906	81.10	91.40	24.51	43.09
2	(CSR27xCSR17)xD13	8930	1.928	0.390	20.23	16.87	910	80.70	92.20	24.17	44.05
3	(CSR27xCSR17)xS9	9445	1.994	0.426	21.36	18.36	1001	86.05	93.00	23.38	50.08
4	(CSR27xCSR17)xBBE247	8893	1.786	0.384	21.50	17.22	899	79.55	91.20	24.31	44.38
5	(CSR27xCSR17)xCSR16	8944	1.866	0.395	21.17	18.89	952	83.20	91.50	23.72	43.95
6	(CSR27xCSR17)xCSR26	9445	1.996	0.424	21.24	18.54	1008	86.20	92.00	23.89	49.80
7	(JPN8xCSR27)xD13	8877	1.863	0.401	21.52	19.88	1021	86.12	92.10	24.52	50.10
8	(JPN8xCSR27)xS9	9423	1.948	0.426	21.87	18.59	1090	87.10	93.35	24.08	51.99
9	(JPN8xCSR27)xBBE247	8801	1.943	0.397	20.43	17.46	927	84.10	91.50	24.51	46.88
10	(JPN8xCSR27)xCSR16	8859	1.934	0.402	20.78	17.52	991	80.40	91.20	24.25	44.58
11	(JPN8xCSR27)xCSR26	8795	1.974	0.406	20.57	17.10	1005	84.80	91.50	24.26	48.27
12	(JPN8xCSR17)xD13	9448	1.867	0.403	21.58	18.24	1007	83.10	92.00	23.83	48.95
13	(JPN8xCSR17)xBBE247	8916	1.860	0.378	20.33	16.62	903	82.10	91.50	24.54	46.94
14	(JPN8xCSR17)xCSR16	8782	1.897	0.393	20.72	16.94	947	79.95	91.60	24.52	42.87
15	(JPN8xCSR17)xCSR26*	9466	1.901	0.424	22.31	19.58	1098	87.50	93.50	22.51	52.96
16	(JPN8xJPN7)xBBE247	8952	1.867	0.389	20.84	18.44	922	80.50	91.50	23.86	43.17
17	(JPN8xJPN7)xCSR16	8898	1.857	0.396	21.32	19.23	953	80.90	91.60	23.81	43.79
18	(JPN8xJPN7)xCSR26	8834	1.873	0.403	21.52	17.57	947	80.50	91.50	24.17	44.14
19	(S5xCSR27)xCSR16	8892	1.927	0.397	20.60	19.30	927	80.40	91.00	23.97	43.69
20	(S5xCSR27)xCSR26	8807	1.943	0.398	20.48	17.23	936	80.10	92.10	24.55	43.84
21	(S5xJPN8)xCSR26	9032	1.948	0.417	21.41	18.53	990	85.50	92.20	24.19	49.53
22	CSR2xCSR4 (C)	9065	1.889	0.395	20.91	17.47	943	84.50	93.80	23.22	49.81

* Selected hybrid.

Table 7. Rearing and reeling performance of bivoltine four-way cross hybrids
(Mean values of 3 seasons)

Sl. No.	Hybrid	Yield / 10000 larvae (No.)	Cocoon weight (g)	Shell weight (g)	Shell ratio (%)	Raw silk (%)	Filament length (m)	Reelability (%)	Neatness (p)	Boil-off loss ratio (%)	E. I. (%)
1	(CSR27xCSR17)x (CSR16xCSR26)	9178	2.093	0.418	19.97	18.62	993	80.10	91.89	23.43	43.83
2	(CSR27xCSR17)x (S9xCSR16)	9274	2.120	0.427	20.14	18.87	1073	83.30	91.67	23.75	45.76
3	(CSR27xCSR17)x (S9xCSR26)	9341	2.162	0.467	21.60	18.10	1108	85.20	92.33	23.69	48.54
4	(CSR27xCSR17)x (D13xCSR26)	9324	2.143	0.461	21.51	19.34	1112	86.00	92.44	23.51	49.22
5	(CSR27xCSR17)x (D13xS9)	9356	2.170	0.421	19.40	18.89	1120	86.20	92.40	23.47	49.09
6	(CSR27xCSR17)x (D13xCSR16)	9460	2.072	0.413	19.93	17.12	1102	84.00	91.67	23.52	47.14
7	(JPN8xCSR27)x (S9xCSR16)	9230	2.176	0.452	20.77	17.06	1049	85.50	92.22	23.55	49.69
8	(JPN8xCSR27)x (S9xCSR26)	9381	2.143	0.460	21.46	19.45	1092	86.00	92.30	23.52	50.60
9	(JPN8xCSR27)x (D13xCSR26)	9330	2.180	0.470	21.56	19.18	1118	86.40	92.70	23.50	49.88
10	(JPN8xCSR27)x(D13xS9)	9536	2.156	0.462	21.43	19.40	1066	79.55	92.34	23.57	47.73
11	(JPN8xCSR27)x (D13xCSR16)	9157	2.034	0.418	20.55	19.12	1039	79.80	91.67	23.65	43.13
12	(JPN8xCSR17)x (S9xCSR26)	9381	2.144	0.472	22.01	19.05	1100	84.50	92.67	22.45	50.67
13	(JPN8xCSR17)x (D13xCSR26) *	9447	2.153	0.494	22.89	19.52	1168	88.55	93.40	22.33	56.47

Sl. No.	Hybrid	Yield / 10000 larvae (No.)	Cocoon weight (g)	Shell weight (g)	Shell ratio (%)	Raw silk (%)	Filament length (m)	Reelability (%)	Neatness (p)	Boil-off loss ratio (%)	E. I. (%)
14	(JPN8xCSR17)x(D13xS9)	9365	2.148	0.470	21.88	16.94	1105	86.00	92.33	22.35	50.58
15	(JPN8xCSR17)x (D13xCSR16)	9195	2.077	0.415	20.03	16.49	1021	80.40	91.67	23.15	45.08
16	(JPN8xJPN7)x (D13xCSR26)	9158	2.144	0.432	20.15	19.43	1026	80.00	92.44	23.30	44.88
17	(JPN8xJPN7)x(D13xS9)	9136	2.086	0.422	20.23	19.23	1033	80.10	91.87	23.51	44.30
18	(JPN8xJPN7)x (D13xCSR16)	9204	2.121	0.420	19.80	18.57	1012	81.20	91.60	23.56	47.88
19	(S5xCSR27)x(D13xS9)	9326	2.172	0.472	21.73	19.18	1099	83.50	92.20	23.49	48.76
20	(S5xCSR27)x(D13xCSR16)	9191	2.123	0.428	20.16	17.85	1040	80.50	91.80	23.52	45.92
21	(S5xJPN8)x(D13xCSR16)	9256	2.179	0.433	19.87	18.87	1020	84.00	91.40	23.50	49.32
22	(CSR2xCSR27)x (CSR6xCSR26) (C)	9155	2.043	0.412	20.17	18.91	996	86.20	92.10	24.04	49.15

* Selected hybrid.

The heterosis values of shell ratio, raw silk percentage and boil-off loss in single, three-way and four-way cross hybrids are presented in Table 2, 3 and 4. In respect of shell ratio and raw silk percentage, among single cross hybrids (Table 2) highest shell ratio heterosis value of 10.83% was registered by BBE226xBBE267, in raw silk percentage CSR27xCSR26 scored top heterosis of 11.55%. Among three-way cross hybrids, maximum shell ratio heterosis of 0.476% was recorded by (JPN8xCSR27)xS9, raw silk percentage 1.91% by (CSR27xCSR17)xBBE247. Four-way cross hybrid (CSR27xCSR17)x(D13xCSR26) recorded highest shell ratio (4.22%) and raw silk percentage (4.48%) heterosis values.

In respect of the boil-off loss ratio heterosis, it is observed that, four single cross hybrids and control hybrid have recorded negative heterosis, which is desirable for this trait (Table 2). Among the single cross hybrids, negative heterosis values ranged from -0.36% in JPN7xBBE267 followed by CSR27xD13 (-1.02%), CSR27xCSR26 (-1.43%) and BBE226xBBE267 (-5.48%).

Heterosis in respect of boil-off loss recorded in three-way and four-way cross hybrid combinations is as in Table 3 and 4. The three-way cross hybrids have recorded positive heterosis ranging from 1.09% (JPN8xCSR17)xCSR26 to 10.36% (JPN8xCSR27)xCSR26. Among the four-way cross hybrids, expressing positive boil-off loss heterosis, the resultant values ranged from 2.17% [(CSR27xCSR17)x(D13xCSR26)] to 6.82% (JPN8xJPN7)x(D13xS9).

The rearing and reeling performance of the single, three-way and four-way cross hybrids presented in Table 5, 6 and 7 indicate significant difference for all the economically important quantitative traits such as yield/10000 larvae, cocoon weight., shell weight., shell ratio, raw silk percentage, filament length, reelability, neatness and boil-off loss ratio. Multiple trait evaluation index (E.I.) estimated including all the said quantitative traits to select the promising hybrids specify that, from the commercial point of view, one hybrid combination of each with highest E.I. value are the best compared to the other hybrids in different cross hybrids.

DISCUSSION

The outcome of silkworm breeding is judged by the best desirable traits of the parental characters that appear in F1 hybrids. Similarly, from the reeling point of view, cocoon shell ratio, raw silk percentage, boil-off loss ratio and other quantitative traits that are directly linked to raw silk production are considered as the most important ones. In sericulturally advanced countries, the silkworm breeders have developed productive parental breeds and hybrids with low boil-off loss ratio and quality silk (Kurasawa, 1968, Gamo and Hirabayashi, 1983). During the course of breeding process, the boil-off loss with reference to cocoon shell has been given utmost importance along with other quantitative and qualitative traits (Harada et al., 1961, Gamo and Ichiba, 1971, Yokoyama, 1959, Mano et al., 1988). Analyzed data on the performance of parents and hybrids in expression of boil-off loss corroborate with the earlier findings of Sonwalker (1969), Sidhu and Sonwalker (1969), Sinha et al., (1992) and Raghavendra Rao et al., (2004).

In the present study, the oval breeds registered higher average of boil-off loss ratio (22.78%) as compared to dumb-bell breeds (23.61%). However, the hybrids have registered intermediate values (24.46%) in single cross, (24.01%) three-way cross and (23.36%) four-way cross hybrids as compared to their parents. Among the oval breeds, JPN8 (21.50%) and JPN7 (21.90%) recorded the lower values, single cross hybrid CSR27xCSR26 (23.25%), three-way cross hybrid (JPN8xCSR17)xCSR26 (22.51%) and four-way cross hybrid (JPN8xCSR17)x(D13xCSR26) (22.33%) have recorded boil-off loss less than 24%. These results are in conformity with findings of Gamo and Hirabayashi (1983), Sinha et al. (1992), Basavaraja et al., (2000) and Seetharamulu et al., (2013).

The phenomenon of heterosis in conjunction with the expression of boil-off loss ratio analyzed in the hybrids under present study facilitated procedures to identify the promising hybrids. Further, the more uniformity in the expression of this trait in hybrids than the parents is one of the desirable features to understand the genetic constitution of the hybrids for their commercial exploitation as evidenced by the mean values computed for this trait. For boil-off loss ratio trait, a negative heterosis value is desirable corroborate with the earlier findings of Basavaraja et al., (2000), Raghavendra Rao et al., (2004) and Seetharamulu et al., (2013). For instance, high magnitude of negative heterosis was recorded in the combinations of BBE226xBBE267 (-5.48%) and CSR27xCSR26 (-1.43%) which could be attributed to the higher mid parental value. The heterosis expressed is variable in different combinations / crosses of hybrids and the results are in accordance with the findings of Gamo and Hirabayashi (1983). In certain hybrids of different crosses, remarkably less heterosis was noticed and very often the hybrids were intermediate between parents for this trait. The manifestation of heterosis phenomenon was explained by over-dominance hypothesis by Jones (1917), Mather (1955) and Fisher (1965). The result of the present study indicated the manifestation of heterosis in different hybrid combinations for this trait. It is possible that, the theories put forward are not mutually extensive as it could be done to several factors like dominance, incomplete dominance, epistasis and maternal effect responsible for the expression of heterosis in varying degrees and support the views of Bowman (1959).

Positive correlation that existed between boil-off loss ratio and cocoon shell weight of parental breeds clearly confirms the findings of Gamo and Hirabayashi (1983). Improvement of boil-off loss ratio towards low value can be achieved through selection by choosing the crossing types exhibiting higher negative heterosis results for this trait which is in accord with the findings of Basavaraja et al., (2000) and Seetharamulu et al., (2013).

Improvement of boil-off loss ratio towards low value can be achieved through selection by choosing different crossing pattern showing higher negative heterosis for boil-off loss trait. On the basis of hybrids rearing and reeling performance with multiple trait evaluation index values and heterosis with particular reference to different quantitative traits including boil-off loss ratio, the hybrids viz., CSR27xCSR26 (single-cross), (JPN8xCSR17)xCSR26 (three-way cross) and (JPN8xCSR17)x(D13xCSR26) four-way cross hybrids were identified as promising ones deserving further commercial exploitation. Also, outcome results of the present study makes it clear that evaluation of boil-off loss ratio among the bivoltine breeds / hybrids identified will enhance qualitative merit of raw silk.

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