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Seasonal Effects on the Performance of Newly Evolved Bivoltine Hybrids of the Silkworm (*Bombyx mori* L.) Under Tropics

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Seasonal effects of the newly evolved bivoltine hybrids namely $CSR_2 \times SR_5$, $SR_1 \times SR_4$ and control hybrid KA $\times$ NB_4D_2 along with their parents SR_1, SR_4, SR_5, CSR_2 KA and NB_4D_2 were evaluated during different seasons of the year to understand genotype and environment interactions. Data were collected on five economic importance namely, pupation rate, cocoon yield, cocoon weight, cocoon shell ratio and filament length of the lines, hybrids and the control breeds/ hybrid in three different seasons *i.e.,* Pre-Monsoon, Monsoon and post-monsoon and subjected to relevant statistical methods. Seasonal performance of CSR_2, SR_1, SR_4 and SR_5 revealed superiority over control breeds KA and NB_4D_2. Both the hybrids *i.e.,* $CSR_2 \times SR_5$ and $SR_1 \times SR_4$ performed well under diversified environmental conditions of tropical climate in a year indicating overall stability. These hybrids revealed highly significant ($P < 0.01$) variations for majority of the traits studied over the control hybrid KA $\times$ NB_4D_2.

Key words: *Bombyx mori* L, Bivoltine hybrids, Seasonal effects and tropical climate

Introduction

Seasonal performance of silkworm breeds is of vital importance in understanding combined action of environment and genetic potentiality of its population under diversified environmental conditions. The cocoon crop stability and other yield attributes in silkworm (*Bombyx mori* L.) largely depend on a wide range of environmental conditions and attaining this objective is a challenge to a breeder particularly in tropical countries (Ren *et al.*, 1988). Consistency of a genotype or its population over wide range of environments indicates the high buffering ability. Genotype × environment interaction exists where the relative performance of a strain changes from environment to environment.

The concept of genotype and environment has been well documented in both plants and animals (Griffing and Zsiorios, 1971). Several studies were made earlier on silkworm to provide reliable estimates of phenotypic variability of different genotypes under diverse environmental conditions by adopting different methods (Harada, 1961; Krishanaswami and Narasimhanna, 1974; Das *et al.*, 1995; Kalpana and Reddy, 1998; Sudhakara Rao *et al.*, 2001, 2004; Mal Reddy *et al.*, 2003; Krishna Rao *et al.*, 2003). In the present investigation an attempt has been made to evaluate the genetic response of the newly evolved bivoltine breeds and their hybrids during three major seasons *i.e.,* pre-monsoon, monsoon and post-monsoon of the year prevailing in the tropics to provide reliable estimates of phenotypic stability of new genotypes.

Materials and Methods

The newly evolved bivoltine hybrids $SR_1 \times SR_4$ and $CSR_2 \times SR_5$ along with control hybrid KA $\times$ NB_4D_2 and their parents *i.e.,* SR_1, SR_4, SR_5, CSR_2, KA and NB_4D_2 form the study material. The rearing of the of all the above breeds and their hybrids were evaluated in three different seasons *i.e.,* pre-monsoon season (March-June) characterized by high temperature (35 ± 5°C) and low humidity (50 ± 5%) and no rainfall, in the monsoon (July - October)

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with moderate temperature (28 ± 5°C) and high humidity (80 ± 5%) and moderate to heavy rainfall; in the post monsoon (November - February) having low temperature (25 ± 5°C) and low humidity (60 ± 5%). The rearing was conducted in 3 replicates of each having 300 larvae twice in three different seasons (6 trials) and data were collected on six quantitative traits *i.e.,* pupation rate, cocoon yield/ 10,000 larvae, cocoon weight, cocoon shell ratio and filament length as per the standard rearing procedure (Datta, 1992). The results obtained were subjected to two-way classification (Kempthorne, 1952) to find out genotype-environment interaction.

Results

Seasonal variations

The data on seasonal performance pertaining to eight economic traits of the lines SR_1, CSR_2 (oval type), SR_4 and SR_5 (Dumbbell type) along with control breeds KA and NB_4D_2 are presented in Tables 1 and 2. Seasonal values of Pupation rate (%) in synthesized oval line SR_1 and productive breed CSR_2 during different seasons show a maximum of 92.6% recorded in SR_1 and CSR_2 during post-monsoon followed by lowest of 89.6 and 89.5% recorded for CSR_2 and SR_1 during pre-monsoon, respectively (Table 1). Maximum pupation rate of 93.9% was recorded in SR_4 and 92.8% in SR_5 in post-monsoon. During pre-monsoon, a lowest pupation rate of 89.9% recorded in SR_4 followed by 90.2% in SR_5 (Table 2). Cocoon yield in newly synthesized oval line SR_1 and productive breed CSR_2 during different seasons indicate a maximum of 17.8 kg in CSR_2 during post-monsoon followed by 17.8 kg/10,000 larvae in CSR_2 during monsoon. A mean cocoon yield of 14.8 kg in followed by 14.2 kg in CSR_2 and SR_1, respectively during pre-monsoon (Table 1). Maximum cocoon yield of 17.3 kg was recorded in SR_5 during post-monsoon followed by 16.9 kg in SR_4 during monsoon. Lowest cocoon yield of 14.7 kg/10,000 larvae recorded in SR_5 during pre-monsoon (Table 2). Cocoon weight in synthesized oval line SR_1 and productive breed CSR_2 during different seasons indicating a maximum of 1.9 g in CSR_2 during monsoon and lowest value of 1.58 g recorded for SR_1 in pre- monsoon (Table 1) while a maximum cocoon weight of 1.8 g recorded in SR_4 during monsoon and lowest value of 1.58 g was recorded in SR_5 during pre-monsoon (Table 2). Cocoon shell ratio synthesized oval line SR_1 and productive breed CSR_2 during different seasons are indicate a maximum of 23.2% in SR_1 and lowest value of 22.8% in CSR_2 during pre-monsoon. In both the newly evolved lines, a cocoon shell ratio of 23.00% was recorded during monsoon (Table 1). Maximum cocoon shell ratio of 23% was recorded in SR_4 during post-monsoon and a lowest value of 21.9% was recorded in SR_5 during pre-monsoon (Table 2). Filament length in synthesized oval line SR_1 and productive breed CSR_2 during different seasons indicate a maximum of 980 m in SR_1 during monsoon and lowest value of 937 m

Table 1. Seasonal performance of newly evolved oval breeds in the laboratory during different seasons

Pure breed (ovals)	Season	Pupation rate (%)	Cocoon yield (kg)	Cocoon weight (g)	Shell ratio (%)	Filament length (m)
CSR_2	Pre-Monsoon	89.6	14.8	1.6	22.8	952
SR_1	(35 ± 5°C, 50 ± 5)	89.5	14.2	1.5	23.2	956
KA*		82.6	12.4	1.4	20.4	839
CD at 5%		---	0.60	0.047	0.40	30.1
CSR_2	Monsoon	92.2	17.8	1.9	23.1	937
SR_1	(28 ± 5°C, 80 ± 5)	91.5	16.6	1.8	23.0	980
KA*		90.7	15.5	1.7	20.5	818
CD at 5%		---	0.66	0.051	0.51	26.8
CSR_2	Post-Monsoon	92.6	17.8	1.9	22.5	949
SR_1	(25 ± 5°C, 60 ± 5)	92.6	17.2	1.8	22.1	970
KA *		90.6	16.9	1.8	20.1	847
CD at 5%		--	0.34	0.040	0.62	22.2
(Season × Breed)						----
CD at 5%		0.58	0.053	0.11	---	---
C.V.%		2.35	4.07	3.60	2.34	3.28

*Control breed.

Table 2. Seasonal performance of newly evolved dumb bell breeds in the laboratory during different seasons

Pure breed (Dumbbells)	Season	Pupation rate (%)	Cocoon yield (kg)	Cocoon weight (g)	Shell ratio (%)	Filament length (m)
	Pre-Monsoon					
SR_4	(35 ± 5°C, 50 ± 5)	89.9	14.8	1.7	21.9	947
SR_5		90.2	14.7	1.6	21.9	967
NB_4D_2*		86.1	11.8	1.5	19.4	815
CD at 5%		---	0.86	0.062	0.52	25.1
	Monsoon					
SR_4	(28 ± 5°C, 80 ± 5)	92.1	16.9	1.8	22.4	942
SR_5		92.3	16.1	1.7	22.0	957
NB_4D_2*		91.1	14.4	1.6	20.4	792
CD at 5%		---	0.47	0.038	0.38	21.9
	Post-Monsoon					
SR_4	(25 ± 5°C, 60 ± 5)	93.9	16.5	1.8	23.1	934
SR_5		92.8	17.2	1.8	22.3	958
NB_4D_2*		92.0	16.0	1.7	20.7	825
CD at 5%		---	0.54	0.032	0.44	27.9
(Season × Breed)						
CD at 5%		---	0.57	0.043	0.44	---
C.V%		3.05	4.16	2.66	2.27	2.67

*Control breed.

Table 3. Seasonal performance of newly evolved hybrids in the laboratory during different seasons

Pure breed	Season	Pupation rate (%)	Cocoon yield (kg)	Cocoon weight (g)	Shell ratio (%)	Filament length (m)
$CSR_2 \times SR_5$	Pre-Monsoon	92.1	16.7	1.81	23.0	1049
$SR_1 \times SR_4$	(35 ± 5°C, 50 ± 5)	91.9	16.2	1.80	23.0	1042
$KA \times NB_4D_2$		83.1	12.4	1.80	20.3	953
CD at 5%		---	1.08	---	0.74	31.2
$CSR_2 \times SR_5$	Monsoon	95.6	18.5	1.96	23.2	1096
$SR_1 \times SR_4$	(28 ± 5°C, 80 ± 5)	95.1	18.8	1.99	23.1	1089
$KA \times NB_4D_2$		92.5	16.5	1.90	20.1	973
CD at 5%		---	0.65	0.06	0.56	37.2
$CSR_2 \times SR_5$	Post-Monsoon	94.7	20.2	2.0	22.5	1170
$SR_1 \times SR_4$	(25 ± 5°C, 60 ± 5)	93.3	19.7	2.0	23.0	1159
$KA \times NB_4D_2$		92.1	17.7	1.9	20.2	954
CD at 5%		--	1.00	0.077	0.69	40.7
(Season × Breed)						
CD at 5%		0.58	0.061	---	36	---
C.V.%		3.29	5.36	3.68	0.06	3.84

recorded in CSR_2 in monsoon (Table 1). Maximum filament length of 967 m recorded in SR_5 during pre-monsoon and lowest value of 934 m recorded in SR_4 during post-monsoon (Table 2).

The data on seasonal performance pertaining to six economic traits of the newly evolved hybrids along with control hybrid $KA \times NB_4D_2$ is presented in Table 3. The mean values for pupation rate in the newly evolved hybrids

$SR_1 \times SR_4$ and $CSR_2 \times SR_5$ during different seasons indicate a maximum of 95.6 in $CSR_2 \times SR_5$ during monsoon followed by 95.1% in $SR_1 \times SR_4$. During pre- monsoon a lowest value of 92.1% and 91.9% recorded for the hybrid $CSR_2 \times SR_5$ and $SR_1 \times SR_4$ respectively. Cocoon yield in the newly evolved hybrids $SR_1 \times SR_4$ and $CSR_2 \times SR_5$ during different seasons indicating a maximum of 20.2 kg/10,000 larvae in $CSR_2 \times SR_5$ during post-monsoon and lowest value of 16.3 kg/10,000 larvae were recorded for the hybrid $SR_1 \times SR_4$ during pre- monsoon. Cocoon weight in newly evolved hybrids $SR_1 \times SR_4$ and $CSR_2 \times SR_5$ during different seasons indicating a maximum of 2.05 g in $CSR_2 \times SR_5$, followed by 2.02 g in the hybrid $SR_1 \times SR_4$ during post-monsoon. The lowest value of 1.80 g cocoon weight recorded in $SR_1 \times SR_4$ hybrid during pre-monsoon. The mean values of cocoon shell ratio in the newly evolved hybrids $SR_1 \times SR_4$ and $CSR_2 \times SR_5$ during different seasons indicated a maximum cocoon shell ratio of 23.3 and 23.1% in $CSR_2 \times SR_5$ and $SR_1 \times SR_4$ hybrids, respectively. Lowest value of 22.5% recorded in $CSR_2 \times SR_5$ during post-monsoon. Filament length in newly evolved hybrids $SR_1 \times SR_4$ and $CSR_2 \times SR_5$ during different seasons indicating a maximum of 1,170 m in $CSR_2 \times SR_5$ during post-monsoon and lowest value of filament length of 1,042 m is recorded in $SR_1 \times SR_4$ during pre-monsoon.

Analysis of variance

Data on analysis of variance pertaining to pure lines are depicted in Tables 4 and 5. Anova results indicating significant ($P < 0.01$) values between races, seasons and race × season for pupation rate, cocoon yield, and cocoon shell ratio while significant ($P < 0.01$) for cocoon weight between seasons and race × season. Filament length shown significant ($P < 0.01$) differences between races and seasons (Table 4).

In dumb bell breeds, results indicated significant differences ($P < 0.01$) between races and seasons while non-significant for race × season for pupation rate and filament length. Significant differences ($P < 0.01$) were also observed for the traits cocoon yield and cocoon shell ratio between races, seasons and race × season while non-significant for filament length between race × season (Table 5).

The results of hybrids were presented in Table 6 indicating significant differences ($P < 0.01$) between races for pupation rate, cocoon yield, cocoon weight, cocoon shell ratio and filament length. Pupation rate, cocoon yield, cocoon weight and filament length indicating significant differences between seasons and race × season. Non-significant values are observed between seasons for cocoon shell ratio.

Table 4. Analysis of variance values for newly evolved oval breeds

Source of Variation	df	Pupation rate	Cocoon yield	Cocoon weight	Cocoon shell ratio	Filament length
Race	2	168.4620	104.0201	0.7992	3.8390	818.0092
Season	2	92.6150	25.9830	0.1779	59.4235	154047.495
Race × Season	4	20.5725	2.3991	0.0201	0.6473	1710.7626
Error .	81	2.8832	0.4219	0.0035	0.2648	907.1395
CD at 5% (R)		0.8737**	0.3342**	0.0307	0.2648**	15.4988**
CD at 5% (S)		0.8737**	0.3342**	0.0308**	0.2648**	15.4988**
CD at 5% (R × S)		1.5134**	0.5789**	0.0532**	0.4587**	26.8447

**Significant at 1%, *Significant at 5% and NS: Non significant.

Table 5. Analysis of variance values for newly evolved dumbbell breeds

Source of Variation	df	Pupation rate	Cocoon yield	Cocoon weight	Cocoon shell ratio	Filament length
Race	2	140.8763	62.5022	0.3040	7.0686	1309.2333
Season	2	46.3283	38.9115	0.2940	45.2026	199611.300
Race × Season	4	6.8271	5.6222	0.0176	0.9312	1134.2833
Error.	81	4.9644	0.4114	0.0023	0.2407	592.9716
CD at 5% (R)		1.1455**	0.3300**	0.0248	0.2524**	12.5307NS
CD at 5% (S)		1.1460**	0.3302**	0.0249**	0.2525**	12.5308**
CD at 5% (R × S)		1.9858NS	0.5716**	0.0429**	0.4373**	21.7039NS

**Significant at 1%, *Significant at 5% and NS: Non significant.

Table 6. Analysis of variance values for newly evolved hybrids

Source of Variation	df	Pupation rate	Cocoon yield	Cocoon weight	Cocoon shell ratio	Filament length
Race	2	262.1827	85.4713	0.2938	0.7913	47937.81111
Season	2	220.6486	41.7753	0.0343	74.4442	199912.54
Race × Season	4	30.8796	0.5853	0.0121	0.5318	12696.6277
Error.	81	5.9691	0.8963	0.0047	0.4568	1636.2950
CD at 5% (R)		1.2572**	0.4872**	0.0353**	0.34783**	20.8157**
CD at 5% (S)		1.2542**	0.4802**	0.0350**	0.34763**	15.4989**
CD at 5% (R × S)		2.8899**	0.8433**	0.0613**	0.6024NS	36.0539**

**Significant at 1%, *Significant at 5% and NS: Non significant.

Discussion

The data analysed in the present investigation on the performance of the lines and their hybrids in different seasons of the year revealed maximum expression of economic traits during the favourable post-monsoon season followed by monsoon and pre-monsoon season and corroborates with the earlier findings (Narasimhanna, 1976; Subramanya, 1985; Maribashetty, 1991; Basavaraja, 1996; Kalpana and Reddy, 1998; Sudhakara Rao *et al.*, 2001). Comparative seasonal performance of the hybrids in the favourable post-monsoon and monsoon and un-favourable pre-monsoon seasons revealed marginal differences in the expression of economic traits. The lower pupation rate in pure lines during unfavourable pre-monsoon season when compared to hybrids particularly during summer months may be due to the prevailing inclement weather conditions and feed quality in the tropical areas (Pillai and Krishnaswami, 1987).

It is clear from the results that the pupation rate and cocoon characters of newly evolved hybrids and their parents were significantly superior to those of control breeds during different seasons of the year. Analysis of variance results indicated significant values for pupation even in parental breeds over control breeds is due to the genetic make up of newly synthesized breeds indicating their buffering capacity to tropical climates. The better pupation rate during summer months in the hybrids may be ascribed due to the presence of high magnitude of heterosis. Generally hybrids are strong, easy to rear and resistant to diseases as they are homozygotes (Gamo and Hirabayashi, 1983). On the other hand, the newly evolved hybrids and their parents (except CSR_2) are evolved under high temperature (36 ± 1°C) and low humidity (60 ± 5%) conditions by introducing polyvoltine blood to cope up with true tropical climate. This buffering ability may be due to increased thermo-tolerance over the generations. Once thermo-tolerance has been induced, it may persist for days (Mc Alister and Finkelstein, 1980; Carretero *et al.,* 1991). Surviving in a thermal stress depends on part of the individual organisms stress history and its genetic plasticity to buffer the changes in tropical conditions.

The significant values for cocoon weight which is positively related to cocoon yield in the newly evolved hybrids over control hybrid indicating more productivity under diversified environmental conditions showed their over all productivity and better post cocoon parameters. Thus, it is concluded that the newly evolved breeds and their hybrids are superior and suitable to rear through out the year for cocoon crop stability under tropical climates.

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