PHENOTYPIC AND QUANTITATIVE CHARACTERIZATION OF BIVOLTINE SILKWORM BREEDS

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ABSTRACT

The fundamental aim of silkworm breeding is to get robust and sturdy silkworm larvae for easy rearing and production of best cocoons in quality and quantity for a high yielding cocoon crop. The morphological characterization among domesticated insects like silkworm (*Bombyx mori* L.) is an important aspect for selection of suitable parents for breeding programme. Sericulture in India is practiced under varied agro-climatic conditions adopting different package of practices to suit different regions and seasons, besides being conserved and utilized for evolving high yielding breeds/hybrids. Characterization is of immense importance for isolating duplicates and it also identifies the genetically potential parents for breeding programmes. Many numbers of geographical races of Silkworm, *Bombyx mori* are being reared in many geographical areas of world and inbred lines. Generally, cocoon commercial characters are used to identify silkworm verities and selection of parental strains. Keeping in view the objectives of the paper the available literature was reviewed for phenotypic and quantitative characterization.

KEYWORDS: Silkworm, morphological characterization, bivoltine breeds, Yield.

INTRODUCTION

Silkworm comprises of large number of geographical races and inbred lines that are distributed in temperate and tropical countries which show substantial variation in their qualitative and quantitative traits. Currently, it is the major economic resource for nearly 30 million families in countries such as China, India, Japan, Korea, Vietnam and Thailand (Rathore *et al.*, 2011; 2012).The tropical genotypes (non diapausing) are hardy and withstand adverse eco-climatic conditions but produce small quantum of poor quality silk whereas genotypes of temperate (dia-pausing) origin produce higher quantity of international quality silk. The conventional breeding approaches although have increased the silk productivity but it has not integrated the high yielding traits of temperate genotypes with the low yielding disease resistant tropical genotypes. The environmental factors specifically interact with the phenotypic and conventional breeding; and thereby limit the yield improvement of the strains of silkworm. The genetic resources are the basic material for crop improvement and the success of breeding programme depends on the initial selection of parents and their effective utilization in desirable combinations. Further it also depends on the ability of breeds to assemble and recombine the genetic variability, extract the potential gene combinations from the gene pool based on phenotypic expression; leading to genetic fixation of the traits over generations. Therefore, silkworm genetic resources need to be properly evaluated and screened for identifying the potential of promising parental lines. A rich diversity of *Bombyx mori* L. exists globally which is derived from Chinese, Japanese, European and Indian strains, which have distinct traits. A recent compilation of silkworm genetic stocks indicate that there are around 3000 genotypes of *Bombyx mori* L. at global level, which includes mutants, parthenoclones, polyploids, and geographical races (Nagaraju *et al.*, 2001). The genetic variation within species happens due to geographical distance and among individuals within a population due to evolutionary changes (Fisher, 1930). Decreasing genetic diversity increases the extinction risk of populations due to decline in fitness. Moreover, estimates of genetic diversity and relationship between various collections from diverse origin help in efficient management and utilization. Hence, maintenance of genetic diversity is a fundamental component in long-term management strategy for genetic improvement of silkworm. Sericigenous insect *Bombyx mori* L remains in the prime preview of researchers due to their economic potential. Silkworm holds the pride position amongst all types of insects due to its production of highly priced commodity i.e. silk. *Bombyx mori* is an important economic insect and also a tool to convert leaf protein into silk protein. Quantity and quality of end product is largely dependent on the quality and quantity of mulberry leaves. The

overall development of silkworm larvae depends on getting the required food which can be easily digested and assimilated in the body tissues properly for the silk synthesis. Different types of silkworm hybrids respond differently to numerous types of mulberry varieties evolved suitably for different agro climatic zones and topography. Anormous amount of work is available on feed dynamics in all sorts of conditions prevailing in silk producing areas of the world. In India, sizeable work has been done under different types of climates of tropical, sub-tropical and temperate conditions. Keeping in view the objectives of the paper the available literature was reviewed for phenotypic and quantitative characterization. In order to validate the current study appropriate review of literature has been cataloged as under.

- **Studies at Phenotypic and Quantitative Characterization of bivoltine silkworm breeds**

Tazima (1978) reported different types of larval marking in Zebra, speckled, quail and multistars as useful variables which help in preventing the mixing or contamination of larvae from different strains.

Jolly *et al*. (1986) reported that the bivoltine race CPP_1 could withstand high temperature and low management levels and gave steady yield even with poor leaf quality and recorded higher fecundity (610), cocoon weight (1.576 g), shell weight (0.285 g) and shell ratio (18.17 %). The relative performance of pure lines viz., NB_7, NB_{18} and Wai-1 indicated that larval survival was higher in Wai-1 (88.03 %) as against NB_7 (65.69 %) and NB_{18} (61.50 %). NB_{18} and NB_7 had shorter larval period of 26 and 25 days respectively, while as Wai-1 recorded 26.7 days of larval life.

Pillai *et al*. (1987) reported that the bivoltine hybrids (KA × NB_4D_2, NB_4D_2 × KA, KA × NB_{18}, NB_4D_2 × NB_7, NB_{18} × NB_7 and NB_{18} × KA) reared on rain-fed Mysore local mulberry, recorded an average cocoon yield of 45 to 50 kg/100 dfls during July to February as compared to 30 to 40 kg/100 dfls during March to June.

Rayar (1987) observed superior performance of bivoltine races compared to local multivoltine (PM). Among bivoltine races, KA was superior in cocoon weight (2.084 g), cocoon shell weight (0.410 g) and cocoon shell ratio (19.60 %) but cocoon filament was longer in NB_7 (1035.93 m) and denier was more in Saniish-18 (3.45).

Trag *et al*. (1992) evolved ten high yielding bivoltine silkworm genotypes from Japanese F1 hybrids (5 marked and 5 plain) designated as SKUAST lines. The evolved lines were reported as significantly superior to conventional race (J122) for mature larval weight, single cocoon shell weight, shell ratio, filament length and yield.

Thangavelu (1997) studied the economic characters of popular bivoltine races; NB_7, NB_{18}, NB_4D_2, KA, CC_1 and CA_2. Race CC_1 performed better in comparison to other races in respect of fecundity (500-600), survival (90-95 %), cocoon weight (1.70-2.00 g), shell weight (0.34-0.40 g) and filament length (900 to 1050 m).

Datta (1999) identified seven highly productive bivoltine hybrids *viz.*, CSR-2 × CSR-5, CSR-2 × CSR-4, CSR-3 × CSR-6, CSR-12 × CSR-6, CSR-13 × CSR-5, CSR-16 × CSR-17 and CSR-20 × CSR-29. The hybrids recorded pupation rate of 89.70 to 94.70 per cent; shell ratio of 23.00 to 24.40 per cent; raw silk recovery of 18.0 to 19.90 per cent; filament length of 1176 to 1328 m and renditta of 5.0 to 5.60.

Reddy *et al*. (1999) studied five diapausing (HU_{204}, KA, NB_1, NB_{18}, and NB_4D_2) and seven non-diapausing silkworm strains (C. *nichi*, Moria, Nistari, Pure Mysore, Daizo, Gungnong and Sarupat). The non-diapausing strains were mostly of tropical origin and were characterized for lower body weight, shorter silk fibre (inferior quality) and resistance to pathogens BmNPV. Among seven non-diapausing strains Pure Mysore was characterized for spinning small, spindle shaped, light greenish-yellow coloured cocoons. Moria and Sarupat strains for spinning small spindle shaped small, flossy, creamish-coloured cocoons. Daizo of Chinese origin, for having small, flossy, short, spindle-shaped, dark greenish-yellow cocoons depicting unstable voltinism, i.e., laying both diapausing and non-diapausing eggs depending on environmental factors prevailing during rearing. Nistari was characterized for spinning small, spindle-shaped, golden-yellow cocoons. *C. nichi*, of Chinese origin was of diapausing type when brought to India from Japan almost 80 years ago but at present it behaves as more of a non-diapausing type due to continuous breeding under tropical conditions. It spins small, white and peanut-shaped cocoons. However, it was reported that the diapausing strains being temperate in origin, undergo diapause and attain higher body weight and secretes longer silk fibre of superior quality and is susceptible to different pathogens particularly to BmNPV. The bivoltine races, KA, NB_1, and NB_7 were reported to spin white coloured oval shaped cocoons while as NB_{18}, NB_4D_2, and HU_{204} spins white coloured peanut shaped cocoons.

Rayar *et al.* (2000) utilized five popular traditional multivoltines races *viz.*, C. Nichi, Sarupat, Nistari (Normal), Nistari (Marked) and Tamil Nadu White with an objective of identifying a superior multi × bivoltine hybrid in place of existing Pure Mysore × NB_{18}. Among the hybrids studied, Sarupat × NB_{18} scored superiority in full grown larval weight (47.68 g), ten cocoon weight (22.68 g), shell weight (3.913 g), cocoon yield/25dfls (21.59 Kg) and number of cocoons/Kg (461.50) as compared to Pure Mysore × NB_{18}. Hybrid Nistari-(Marked) x NB_{18} was significantly good in filament length (1355.25m), ERR (90.75%) and at par with Sarupat × NB_{18} in cocoon and shell weight. Larval duration was significantly short in C. Nichi × NB_{18} (647.00 hr) and ranked third in overall performance among the hybrids studied.

Farooq *et al.* (2002) studied heterosis in twenty four strains of silkworm and found that fecundity, larval weight, single cocoon weight, cocoon shell weight and filament length contributed about 97 per cent of the total genetic divergence for realizing the optimum heterosis. The studies identified genotype KA, P_5, Jam_{10} and NB_4D_2 suitable for heterosis.

Kumar *et al*. (2002) evolved two thermo-tolerant bivoltine breeds viz. CSR_{18} and CSR_{19}. The breeds recorded 92.30 and 92.00 per cent pupation, 16.80 and 16.70 kg cocoon yield/10000 larvae having 1.82 g cocoon weight, 0.399 and 0.392 g shell weight, 21.90 and 21.60 per cent shell ratio, 17.20 and 17.00 per cent raw silk, 1112 and 964 m filament, 2.68 and 2.91 denier and 82.00 and 83.00 per cent reelability, respectively.

Maribashetty and Ahamed (2002) evolved hardy bivoltine line KSO_2 with Japanese racial features. The breed was found to be superior in viability traits like cocoon yield by number, pupation rate and fibre technological characters with slight decrease in cocoon weight, shell weight and shell percentage over evolved breeds CSR_2 and SP_2.

Malik *et al.* (2002) tested eighteen bivoltine silkworm genotypes along with two newly authorized breeds (SKAU-R-1 and SKAU-R-6). Ranking of the genotype was done by evaluation index method giving weightage to seven economically important metric traits. Five genotypes viz. SKAU-R-8, SKAU-R-23, SKAU-R-25, SKAU-R-13 and SKAU-R-7 performed better than check parent (SKAU-R-6).

Ravinder (2002) studied the rearing performance of CSR18 and CSR19 breeds during summer and pre rainy seasons under Dharwad condition. Both the breeds performed better than NB_4D_2 for most of the economic traits except for fifth instar larval duration.

Babu *et al*. (2003) studied the combining ability effects of eight bivoltine breeds and their fifty-six hybrid combinations including reciprocals in 8 x 8 diallel crosses for six characters viz., cocoon yield/ 10000 larvae by weight, pupation rate, cocoon weight, cocoon shell weight, shell ratio and filament length. All the characters were controlled by additive but predominantly by non-additive gene action as evidenced from high estimates of specific combining ability (SCA) variance compared to general combining ability (GCA) variance. The comparison of parents on the basis of general combining ability effects indicated the superiority of APS-11 and APS-5 breeds as good combiners. The hybrid combination *viz.*, APS_{13} × APS_6, APS-5 × APS-2 and APS-5 × APS-8 were considered as most promising hybrids as they recorded highly significant specific combining ability effects for five out of six traits studied. The reciprocal combination APS-6 × APS-1 showed positive reciprocal effect for five out of six traits.

Chakravorty *et al*. (2003) evaluated four bivoltine hybrids; CSR_2 × CSR_5, APS_5 × APS_4, APS_9 × APS_8 and KA × NB_4D_2 for their suitability to the agro-climatic conditions of Assam during spring and autumn seasons. Among hybrids, APS_5 × APS_4 was found superior with respect to effective rate of rearing by weight, single cocoon weight and yield per 100 dfls in spring season. During autumn season, KA × NB_4D_2 was superior.

Jaiswal and Goel (2003) evaluated bivoltine hybrids., SH_6 × NB_4D_2, CSR_{18} × CSR_{19}, SH_6 × KA and P_5 × NB_{18} in monsoon and spring season of Uttar Pradesh. SH_6 x NB_4D_2 was found to be superior in respect of major cocoon parameters in both the seasons.

Vijayakumari *et al*. (2003) studied the performance of CSR_3 × CSR_6, CSR_{12} × CSR_6 and CSR_{16} × CSR_{17} hybrids. CSR_{12} × CSR_6 and CSR_3 × CSR_6 hybrids performed well in cocoon yield and quality when provided with 10 per cent more feed and 20 per cent excess bed spacing (2460 kg by shoot and 700 sq. ft. bed space), while, CSR-16 x CSR-17 performed better with 23 per cent less feed and 10 per cent more spacing (1728 kg by shoot and 650 sq. ft. bed space). Shoot cocoon ratio was better in hybrid CSR_{16} × CSR_{17}.

Krishnaprasad *et al*. (2003) studied the rearing and grainage performance of bivoltine breeds CSR_2, CSR_4, CSR_5 and NB_4D_2. Breed CSR_4 recorded significantly higher effective rate of rearing (91.96%), cocoon weight (1.80 g), shell weight (0.380 g), shell ratio (21.24%), pupal weight (1.40 g), moth emergence

(98.00%) with egg trait characteristics of fecundity (608 eggs/ laying) and hatching (98.50%) over other breeds.

Chandrashekharaiah *et al*. (2004) developed a new productive bivoltine silkworm hybrid, APS_{77} × APS_{100}. The evolved hybrid showed better economic merit for the characters fecundity (500 to 535 eggs/laying), hatching (94.00 to 96.00 %), larval duration (22 to 23 days), survivability (92.0 to 94.00 %), cocoon yield per 10000 larvae (16.50 to 17.00 kg), cocoon weight (1.800 to 1.850 g), cocoon shell weight (38.00 to 39.00 cg), shell ratio (21.50 to 22.00 %), filament length (1050 to 1100 m), reelability (86.00 to 87.05), raw silk recovery (17.00 to 18.00 %) and neatness (91.00 to 93.00 %) over the control hybrid, APS-9 × APS-8.

Mirhosieni *et al.* (2004) studied six economical characteristics viz. number of surviving larvae and pupae, percentage of pupal survival, single cocoon weight, single cocoon shell weight and percentage of cocoon shell in seven lines of Chinese and Japanese origin along with their hybrids. The results showed that general combining ability (GCA) of Japanese lines were significant for all the characteristics. The GCA of Chinese lines for resistance character was insignificant and for productive characters was highly significant. Specific combining ability (SCA) for productive characteristics and number of surviving larvae was significant while as for the number of surviving pupae and its percentage was insignificant. SCA of the resistance character in the hybrid Xihang-1 × Koming-1 was higher than other crosses studied.

Rao *et al.* (2004 a) evolved SD_7 and SD_{12} breeds for shorter larval duration. The evolved breeds were reported to have 516 and 511 hr of total larval duration, 152 and 146 hr fifth instar larval duration, 91.00 and 90.93 per cent pupation with1.810 and 1.765 g cocoon weight, 0.427 and 0.411 g shell weight, 23.62 and 23.30 per cent shell ratio and 577 and 572 eggs per laying in comparison to CSR_2 and CSR_5 which recorded 548 and 538 h larval duration, 176 and 168 h fifth instar larval duration, 89.93 and 89.83 per cent pupation,1.814 and 1.808 g cocoon weight, 0.410 and 0.411 g cocoon shell weight, 22.64 and 22.74 per cent shell ratio and 562 and 540 eggs/laying respectively.

Rao *et al.* (2004 b) studied the seasonal performance of CSR_2, SR_1, SR_4 and SR_5 during pre-monsoon, monsoon and post-monsoon seasons. All the breeds were reported to perform better over KA and NB_4D_2 in respect of pupation rate, cocoon yield, cocoon weight, cocoon shell ratio and filament length.

Reddy *et al*. (2004) developed productive bivoltine breeds, CSR_{16} and CSR_{17}. Higher pupation of 93.00 per cent in CSR_{16} and 94.40 per cent in CSR_{17} over control breeds NB_4D_2, CSR-4, KA and CSR-2 was reported. Breed CSR-17 recorded highest cocoon yield of 19.00 kg/10000 larvae while as highest cocoon shell ratio of 22.50 and 24.80 per cent was reported in CSR-16 and CSR-17 respectively. Other characters viz. filament length, filament size, reelability and neatness were reported to have non-significant values.

Babu *et al*. (2005) evaluated 47 bivoltine breeds (22oval and 25dumbbell) at APSSR&DI, Hindupur for three seasons over two years. The oval breeds comprises of, APS_5, APS_9, APS_{11}, APS31 and APS47 while as dumbbell hybrids studied were APS_8, APS_{18}, APS_6, APS_{64}, APS_{22}, APS_{12} and APS_{60} and were identified as potential breeding resource materials for developing promising hybrids for tropical conditions.

Islam *et al.* (2005) utilized line × tester method for eight existing and four newly developed popular bivoltine races to estimate the combining ability with respect to effective rate or rearing by number and by weight, single cocoon weight, shell weight and shell ratio. Among the lines BSRTI-4, BSRTI-5 and BSRTI-7 were found to be the best general combiners. Hybrids BSRTI- 4 × $CH\text{-}BV_2$, BSRTI-5 × $CH\text{-}BV_2$ and BSRTI-7 × $CH\text{-}BV_2$ exhibited significant positive GCA effect for most of the economic character.

Kalpana *et al*. (2005) studied forty-two bivoltine hybrids for fine denier. Hybrids, CSR_{48} × CSR_5 was identified for its superiority over the existing bivoltine hybrids namely CSR_2 × CSR_4, CSR_2 × CSR_5 and CSR_{18} × CSR_{19} for majority of the qualitative traits. Post cocoon testing of large quantity of cocoons of CSR48 x CSR5 resulted in the production of high quality "3A" grade silk, with filament size 2.4 d, standard size deviation 0.983 maximum size deviation 1.322, neatness 96 p, reelability 85 per cent, tenacity 3.87 g/d, elongation 22.32 per cent and cohesion 110 strokes.

Rao *et al.* (2005) evaluated general and specific combining abilities among popular and newly evolved thermo-tolerant bivoltine breeds and their hybrids through diallel crossing system under high temperature (36 ± 1°c) and low humidity (50 ± 5% RH) conditions. The evaluation results for 8 quantitative traits revealed that among 12 breeds, breed SR_1, SR_3, SR_4, SR_5 and SR_6 exhibited positive GCA effects for majority of the traits studied. Among 66 hybrids studied, one hybrid SR_1 × SR_4 showed positive SCA effect for seven traits and three hybrids namely SR_3 x NB_4D_2, CSR_2 × SR_5 and SR_4 × CSR_4 exhibited highly

significant (P<0.01) SCA effects. The most promising hybrid $SR_1 \times SR_4$ was selected for laboratory evaluation.

Petkov *et al.* (2006) analyzed in detail the quantitative selection characters variability in sex-limited lines and F_1 hybrids. The pupation ratio, filament thickness and silk ratio characters comparatively showed low values of co-efficient of variability in pure lines when compared to F_1 hybrids whereas filament length and cocoon yield characters exhibited higher values.

Choudhary and Singh (2006) evaluated polyvoltine × bivoltine hybrids through evaluation index method. It was found that two hybrids $BL_{68} \times CSR_{12}$ and 96 H × CSR_{17} exhibited evaluation index value > 50 for seven characters during spring season, however hybrid $BL_{67} \times CSR_2$ scored E.I. value > 50 for all the characters studied during the same rearing. Among polyvoltine x bivoltine crosses, hybrids $BL_{67} \times CSR_2$, 96H × CRS_{17} and $BL_{68} \times CSR_{12}$ exhibited average evaluation index > 50 for seven economic characters.

Dandin *et al*. (2006) evolved two bivoltine breeds *viz.*, CSR_{50} and CSR_{51}. Breed CSR-5 exhibited higher productivity, while as CSR_{51} was found comparatively tolerant to high temperature and disease. The breeds are currently being utilized for bivoltine hybrid.

Rao *et al.* (2006) evaluated general and specific combining abilities among popular and newly evolved thermotolerent bivoltine breeds and their hybrids through diallel crossing system under high temperature (36 ± 1°C) and low humidity (50 ± 5%) conditions. The evaluation result for eight quantitative traits revealed that among 12 breeds, hybrid $SR_1 \times SR_4$ showed positive SCA (specific combining ability) effect for seven traits. Three hybrids, $SR_3 \times NB4D_2$, $CSR_2 \times SR_5$ and $SR_4 \times CSR_4$ exhibited high significance (P<0.01) SCA effects. Promising hybrid $SR_1 \times SR_4$ was selected for field evaluation.

Pallavi and Basavaraja (2007) selected a suitable foundation crosses for utilization in bivoltine double hybrid. Based on pupation and cocoon yield, oval and dumbbell type foundation crosses viz., $CSR_2 \times CSR_5$, $CSR_{17} \times CSR_{21}$, $CSR_{17} \times CSR_{46}$, $CSR_{27} \times CSR_{46}$, $CSR_{46} \times CSR_2$ and $CSR_{46} \times CSR_{21}$ (oval type) and $CSR_4 \times CSR_{26}$, $CSR_6 \times Gen_2$, $CSR_{26} \times CSR_{47}$, $CSR_{26} \times Gen_2$, $CSR_{47} \times CSR_{26}$ and $Gen_2 \times Gen_{26}$ (dumbbell type) were short listed for the preparation of double hybrids.

Moorthy *et al*. (2007) developed D6 (P) N bivoltine breed suitable for variable climatic conditions of tropics. The breed showed significantly higher survival as compared to receptor D6 (P) parent and control bivoltine breed (NB_4D_2).

Begum *et al.* (2008) tested twelve bivoltine breeds for twenty-one traits and their performance was statistically analyzed using analysis of variance. Silkworm breeds were short-listed by using multiple trait evaluation method for eleven characters. Two breeds, BV_{183} ($SMGS_1$) and BV_{262} ($SMGS_9$) recorded average E.I value> 50 for ten and nine traits respectively.

Lakshmi and Chandrashekharaiah (2008) studied forty seven bivoltine breeds under high temperature (30 - 36°C) and low humidity (50 - 55%) conditions for nine economic characters viz., fecundity, cocoon yield per 10000 larvae by weight (kg), pupation rate (%), cocoon weight (g), cocoon shell weight (g), cocoon shell ratio (%), filament length (m), reelability (%) and neatness (%). Out of 47 breeds, twenty breeds comprising of ten oval APS_5 (2.5764), APS_7 (3.3050), APS_{19} (3.6508), APS_{11} (4.0610), APS_9 (4.1034), APS_{31} (4.2272), APS_{27} (4.2939), APS_{45} (4.2956), APS_{39} (4.5588) and APS_{17} (4.7332) scored lower metric values while as ten peanut breeds, APS_4 (3.1863), APS_8 (3.2886), APS_{32} (3.4138), APS_{24} (3.5794), APS_{12} (3.8078), APS_{16} (3.9715) APS_{18} (4.1263), APS_{62} (4.2164), APS_6 (4.2656) and APS_{10} (4.3777) were adjudicated as potential breeding resource material.

Matei *et al.* (2009) analyzed phenotypic character variability within 72 genetic stock of *Bombyx mori* L. for different biological developmental stages. The phenotypical and quantitative parameters of the gene stock studied for different characters ranged between; prolificacy (230-710 eggs/laying), hatchability (80.6-100%), larval duration (26-32 days), larvae weight (4.2-5.7 g), pupation rate (80.8-96.6%), cocoon weight (1.445-2.361 g), cocoon shell weight (0.240-0.520 g), fibre length (746-1356 m) and filament size (2917-3764 m/g).

Hussain *et al.* (2010) studied genetic potential of eleven pure silkworm lines (PAK-1, PAK-2, PAK-3, PAK-4, M-101, M-103, M-104, M-107, S-1, PFI-1 and PFI-2). Among tested lines, fecundity was maximum in PFI-1 (506) and minimum in M-10 (448). In all the lines, pupation rate was above 80 per cent except in PAK-4 (79.84%). Single cocoon weight was highest in M-107 (1.573 g) and lowest in PAK-1 (1.37 g). Raw silk was maximum in PFI-1 (12.65%) and minimum in S-1(10.63%). Filament length was maximum in M-107 (982 m) and minimum in PAK-3 (735 m). Maximum mortality was reported in M-104 (7.16%) and minimum in M-107 (2.7%).

Vijayan (2010) studied the phenotypic traits of 13 silkworm genotypes and reported considerable variability in all economic parameters. The total larval duration was found ranging from 547 hours in Nistari (P) to 655 hours in Pure Mysore. The weight of ten full grown larvae ranged from 19.486 g (Pure Mysore) to 29.182 g (BL-23) while as shell ratio varied from 13.43 per cent in Nistari (D) to 16.67 per cent in BL-23. Among 13 genotypes, breeds Mysore Princess, BL-23 and Kollegal Jawan recorded better cocoon characteristics.

Dayananda *et al.* (2011) studied six new bivoltine hybrids along with control hybrid under simulated conditions of farmers on a large scale for various economic traits. The hybrids evaluated expressed varied degree for their economic traits over control hybrid, $CSR_2 \times CSR_4$. Among the hybrids evaluated, two hybrids viz., $CSR_{50} \times CSR_{51}$ (67.25) and $D_2 \times D_{13}$ (53.84) recorded average E.I. values more than fifty. New hybrids recorded improvement over control in respect of cocoon yield (28.17 and 10.81 %), single cocoon weight (18.59 and 4.75 %), cocoon shell weight (25.65 and 7.59 %), cocoon shell percent (6.00 and 2.66 %) and filament length (18.13 and 6.53 %) besides uniformity in cocoon size. Overall data indicated the superiority in the performance of $CSR_{50} \times CSR_{51}$ under field conditions in comparison to other hybrids studied.

Gangawar (2011) evaluated seasonal response of ten bivoltine silkworm hybrids developed at West Bengal- $P_5 \times KB$, $P_5 \times$ KPG-B, $NB4D_2 \times NB_{18}$, $P_5 \times NB_{18}$, KPG-B $\times NB_7$ for spring KPG-B $\times NB_{18}$, $NB_{18} \times P_5$, $NB_{18} \times NB_7$, $SH_6 \times NB_{18}$ and $KA \times NB_{18}$ for summer season on the basis of climatic factors and checked their economic traits under U.P climatic conditions. The selected breeds were reared and data collected for nine parameters viz. hatching percentage, yield / 10000 larvae by number, by weight, survival percentage, cocoon weight, shell weight, shell percentage, total larval duration, filament length and reelability percentage. On the basis of results, hybrid $P_5 \times NB_{18}$ and KA $\times NB_{18}$ were found to be better for spring and summer seasons of Uttar Pradesh.

Lakshmi *et al.* (2011) made an attempt in the development of thermo-tolerant bivoltine hybrid, $HTO_5 \times HTP_5$. Fifty hybrid combinations involving 10 parents (5 each of oval and peanut shape) were evaluated in complete diallel pattern and combination $HTO_5 \times HTP_5$ was identified as most promising. This hybrid showed economic merit for fecundity – 519 eggs/laying; cocoon yield per 10000 larvae by weight – 17.2 kg; survival rate – 94.0 per cent - single Cocoon weight – 1.833 g; single Shell weight – 0.399g; shell percentage – 21.7 per cent; filament length – 996 m; reelability – 85.0 per cent and neatness – 89 points.

Pal and Moorthy (2011) studied variability in larval and cocoon traits in 19 genotypes of bivoltine silkworm (*Bombyx mori* L.). Characters like; larval weight, silk gland weight, cocoon weight, shell weight and shell percentage depicted higher variability; and significant and positive correlation was reported between larval weight and silk gland weight and cocoon weight. Larval body length and cocoon length was reported to have positive correlation with shell weight. Silk gland weight also depicted positive correlation with larval weight, cocoon weight and shell weight.

Renuka *et al.* (2011) studied clustered high silk yielding silkworm races with low silk yielding races. All the races showed distinct phenotypic diversity in cocoon characters. Significant diversity in quantitative characters was reported where in the total larval duration varied from 555 hours (DD-1) to 641 (FCC2-(P), cocoon weight from 1.21g (I-15) to 1.95g (14 M), single shell weight from 0.19g (I-15) to 0.43 (14 M) and shell ratio per cent from 15.91 (I-15) to 23.97 per cent (CSR-2). Though race I-15 had lowest cocoon weight, shell weight and shell ratio; it behaved as hardy race and authors recommended the breed for commercial exploitation in rainfed areas and hotter regions of India under unfavorable climatic conditions. The authors grouped the races under two major groups wherein high shell ratio (19.88-23.97%) races were grouped in one cluster and low shell ratio (15.91-20.94%) in another cluster. In first group three sub groups were formed while as in low shell ratio group, two sub groups were reported.

Panday *et al.* (2012) attempted second silkworm rearing during September month of autumn season, in Kandi Belt of Jammu under sub-tropical climatic conditions by adopting package of improved bivoltine cocoon production technology and obtained average filament length of 924 meters in $RSJ_3 \times RSJ_1$against 832 meters of $SH_6 \times NB_4D_2$,denierwas 2.5, finer than $SH_6 \times NB_4D_2$, which recorded 2.87d. $RSJ_3 \times$ RSJ recorded a renditta of 4.03kg against 4.13 of $SH_6 \times NB_4D_2$. These results showed that RSJ_3x RSJ_1 performed better than SH_6 x NB_4D_2during autumn season under sub-tropical conditions of Jammu and Kashmir.

Gawade (2012) studied heterosis in four bivoltine hybrids: $CSR_3 \times CSR_6$, $CSR_{16} \times CSR_{17}$, PM $\times CSR_2$ and $CSR_2 \times CSR_4$. During the study it was observed that hatching and survival percentage were highest in $CSR_{16} \times CSR_{17}$. Minimum days of larval duration were recorded in PM $\times CSR_2$. Growth rate was best in $CSR_{16} \times CSR_1$. Weight of mature larva was highest in $CSR_{16} \times CSR_{17}$. Among four hybrids, $CSR_{16} \times$

CSR_{17} showed superiority in economic traits of cocoon weight and shell weight and in morphomatrix, it recorded highest length and width of cocoon.

Reddy *et al.* (2012) assessed the performance of bivoltine silkworm hybrids involving parental foundation crosses (FCs) of different generation. Four bivoltine breeds of dumb-bell, ($CSR_6$and CSR_{26}) and oval, (CSR_2 and CSR_{27}) were utilized for preparation of dumbbell, $CSR_6 \times CSR_{26}$ (FC1) and oval, $CSR_2 \times CSR_{27}$ (FC_2). The FCs was inbred over generations. By utilizing inbred FCs of different generation, possible hybrids / crosses between dumbbell × oval inbred FCs ($FC_1 \times FC_2$) were prepared by employing half diallel method. The results clearly showed that hybrids involving FCs up to F_3 generation were at par with the hybrids involving FCs of F_1 generation. However, reduction in majority of characters and more cocoon variability was recorded in hybrid combinations involving FCs at F_4 generation. Based on the results, it was inferred that the hybrids involving parental FCs up to F_3 can be utilized for commercial exploitation.

Tribhuwan Singh *et al.* (2012) found that systemic and planned hybridization with improved farming and rearing practices helped a great deal in increasing the productivity of silk. By utilizing the known and established breeding material, the objective of synthesizing new breeds were easily realized by the application of appropriate selection pressure for desirable combinations of genes. The reciprocal crossings of two breeds were observed to be good in some characters and poor for some other characters. The segregation of characters at indefinitely large number of loci in F2 generation enabled the breeder to select the desirable combination of characters and reject the individual with undesirable characters.

Ilyas *et al.* (2013) conducted an experiment to evaluate the performance of bivoltine mulberry silkworm hybrids under Marathwada conditions. The bi x bi hybrid $CSR_{16} \times CSR_{17}$ was found significantly superior in hatching (95.22%), larval weight (45.08 g), single cocoon weight (1.98 g), single shell weight (0.393 g) and cocoon yield/10000 larvae brushed (18.55 kg). Based on overall performance it was concluded that bivoltine hybrid $CSR_{16} \times CSR_{17}$ reared on mulberry variety V_1 is the most suitable for rearing under Marathwada conditions.

Ahmad *et al.* (2013) evaluated 50 F1 hybrids and short listed five hybrids *viz.*, $NB_4D_2 \times CSR_2$; CSR4 × Chaung Naung; Chaung Naung × APS_8; Pam_{106} × ChaungNaung and $NB_4D_2 \times APS_9$ based on the Evaluation Index Values for summer rearing season under temperate climatic conditions of Kashmir. The results indicated that silkworm races NB_4D_2, CSR_4 and Pam_{106} were found as best female parents while as races CSR_2, APS_8 and APS_9 acted as best male parents. Race Chaung Naung proved as best female as well as male parent.

Joshi and Sisodiya (2013) maintained multivoltine HM and bivoltine race NB_{18} for number of generations to improve their racial characters and developed a multivoltine hybrid HM × NB_{18}. Significant improvement in fecundity from (450 to 537), weight of ten mature larvae (from 35 g to 43 g), effective rate of rearing (from 57.8% to 80%) and percentage of good cocoons from (46.3% to 64.5%) was recorded. Single cocoon weight and shell percentage ratio also improved from 1.3701g to 1.936g, 22.1 to 27.3% respectively.

Pereira *et al.* (2013) carried out study on 14 *Bombyx mori* L. parental strains (AS_3, AS_{31}, C_{75}, C_{36}, C_{37}, E_8, F_6, JK, M_8, M11-2, M_{18}, M_{11}, B_{82}, B_{106}) at Brazilian Germplasm Bank for biological traits related to strain characterization and production performance. The authors found that strain ES varied due to its geographical origin and further reported that the Japanese strains had elliptical shaped eggs whereas Chinese strains had oval shaped eggs. Most of the eggs were small in size except for AS_3 and C_{75} strains. Further two patterns of larval marking viz. plain and multilunar were reported. The plain larvae did not possess any markings, whereas multilunar larvae had 2 different characteristic spots.

Reddy *et al.* (2014) evolved a series of productive bivoltine breeds with higher survival and cocoon shell percentage. By systematic evaluation of large number of crosses, productive hybrids namely $CSR_2 \times CSR_4$, CSR_2 × CSRS, and $CSR_{16} \times CSR_{17}$ with cocoon shell percentage of 23-24; raw silk recovery of 18-19 per cent and 2A- 3A grade silk were developed. Significant improvements was noticed in raw silk recovery, filament length and renditta in all hybrids and were authorized for rearing in favorable months on V1 mulberry variety with assured irrigation adopting recommended rearing technology package.

Gadgala and Singh (2015) analyzed the seasonal rearing performance of bivoltine hybrids viz., $SH_6 \times NB_4D_2$, $APS_{12} \times APS_{45}$, and $FC_1 \times FC_2$ at farmers' level under sub-tropical conditions of Jammu (J&K) and obtained that hybrids, $FC_1 \times FC_2$ and $APS_{12} \times APS_{45}$ showed better performance with respect to single cocoon, shell weight and shell percentage.

Maqbool *et al.* (2015) reared twenty eight bivoltine silkworm lines namely; New Race, $Pure_{81}$, $Pampore_5$, J_{122}, Meigitsu, JA_1, 14M, SPJ_2, J2M, B_{38}, $CSGRC_5$, Belkokona II, Sheiki II, Sannish, A, Jam $_{18}$, Jam $_{21}$, JD_6, YS_3, NJ_3, NCD, NB_{18}, NB_4D_2, CSR_2, CSR_4, SH_6, SRC and JBEL during spring and summer

rearing seasons. The results showed that the breeds J2M, A and NCD were superior for several traits during spring while as breeds $CSGRC_5$, New race, JA_1 and Jam $_{21}$ surpassed the check breeds (NB_4D_2 and SH_6) in number of metric traits during summer. The authors further reported that breeds, Sheiki II, $Pampore_5$, J_{122}, Meigitsu, 14M, NJ_3, NB_{18}, CSR_2 and CSR_4 were significantly superior to check breeds in several traits in both seasons.

Kumari *et al*. (2015) analyzed the biological parameters of eggs and reported colour of the eggs as granite grey in Pam 102 (nut brown) and steel grey in Pam 103, and the shape of the eggs recorded was ellipsoidal. The authors reported highest fecundity of 522 eggs in Jam-2 and lowest (355) in Jam-18, lowest hatching of 89.31 per cent in Pam-102 and highest (93.99 %) in Pam-101, respectively.

Patel *et al*. (2016) studied the morphological features for nutrionally efficient silkworm strains and recorded their phenotypic salient features, the polyvoltine non-hibernating parental strains; RMW-2 and RMG-4 of Madagascar origin. Race RMW-2 was reported to spin oval shaped cocoons, having white colour and race RMG-4 spun greenish yellow cocoons. The bivoltine parental breeds (RBO-2 and RBD-1) spun white coloured cocoons having oval shape (RBO2) while as breed spun RBD-1 dumbell shaped cocoons. The egg colour of breeds reported was grayish.

Bhat *et al.* (2017) evaluated eight newly evolved silkworm, *Bombyx mori* L. hybrids $SK_{28} \times SBNP_1$, $SK_{30} \times SBNP_1$, $SK_6 \times SBNP_1$, $SH_6 \times KA$, $SH_6 \times NB_7$, $NB_{18} \times KA$, $NB_4D_2 \times SH_6$ and SH6 × NB4D2for their performance in eight metric traits *viz.*, fecundity, hatching, larval weight, yield per 10,000 larvae by number and by weight, single cocoon weight, single shell weight and shell ratio (%). Four hybrids *viz.*, $SK_{28} \times SBNP_1$, $SK_6 \times SBNP_1$, $NB_4D_2 \times SH_6$ and $SK_{30} \times SBNP_1$, exhibited better performance during summer season based on higher Index Value (>50) and were suggested for field rearing.

Buhroo *et al.* (2017) evaluated eleven popular bivoltine silkworm breeds *viz.*, CSR_2, $NB4D_2$, SK_1, CSR_4, DUN_6, SH_6, SK_6, CSR_{19}, SK_{28}, DUN_{22} and SK_{31} for their performance during spring season. The data generated in respect of different traits during two years was recorded replication wise and pooled. Six breeds viz., $NB4D_2$, SK_1, SH_6, SK_6, SK_{28} and SK_{31} were short-listed on higher EI values (>50) and suggested that these breeds can be used for the preparation of season specific hybrids to push up bivoltine silk productivity under specified environmental conditions in the Kashmir valley.

Gowda *et al.* (2017) evaluated 113 bivoltine silkworm breeds for their performance during winter season based on 12 important quantitative traits. After preliminary screening, and on per se performance, top performing breeds were identified after evaluating many economic parameters. The selected bivoltine breeds were analyzed for their consistency in expression of the quantitative traits by adopting multiple trait evaluation index method. Among the identified bivoltine breeds, BBE_{0272} expressed better performance in 8 parameters whereas the remaining 5 accessions (BBE_{0197}, BBE_{0222}, BBE_{0187}, BBE_{0186} and BBI_{0235}) were found performing better in 7 economic parameters only.

CONCLUSION

The quantitative and qualitative characters of silkworm, *Bombyx mori* L. such as larval duration, cocoon weight, cocoon shell weight, survival rate etc., are of utmost importance in sericulture. Mulberry silkworm, *Bombyx mori* L. is the most important insect being used for commercial production of silk in sericulture industry. The success of selection is governed by the degree to which the desired trait is transmitted to the succeeding generation. The nature of selection is to be given due consideration at appropriate developmental stages for pursuing selection in desired direction while improving or evolving high productive breeds or hybrids of the silkworm. As such, the silkworm genetic resources need to be evaluated from rearing, grainage and reeling point of view for identifying the genotypes with character like longer filament length, resistance to silkworm diseases and tolerance to stress conditions.

REFERENCES

1. Ahmed, S.N., Darzi, G.M., Ramegowda, G.K., Dhar, A., Aslam, M., Rashid, H., Khan, M.A. and Sahaf, K.A. 2013. Spring Performance of Silkworm Hybrids in Kashmir Valley. *Research Journal of Agricultural Sciences*, **4** (3): 347-349.
2. Basavaraja, H. K., Suresh, K., Reddy, N. and Datta, R. K. 1998. New approaches to bivoltine silkworm breeding. *Oxford: IBH Publishing*, 131-140.
3. Basavaraja, H. K., Ashwath, S. K., Suresh Kumar, N., Mal Reddy, N. and Kalpana, G. V. 2005. Silkworm Breeding and genetics. *Central Silk Board Publication Bangalore*, 409-439.
4. Babu, M.R., Chandrashekharaiah, Lakshmi, H., Goel, A.K. and Prasad, J. 2003. Combining Ability of Diallel Crosses in Bivoltine Silkworm, *Bombyx mori* L. In: *Proc. Natl. Conf. Trop. Seric. Global Compt*., pp. 96-101.
5. Babu, M.R., Lakshmi, H., Prasad, J., Seetharamulu, J., Chandrashekharaiah and Goel, A. K. 2005. Evaluation and Selection of Potential Bivoltine Parents for Silkworm (*Bombyx mori* L.) Breeding. *Indian Journal of Sericulture*, **44**: 82-91.
6. Begum, N.A., Basavaraja, H.K., Joge, P.G. and Palit, A.K. 2008. Evaluation and identification of promising bivoltine breeds in the silkworm *Bombyx mori* L. *International Journal of Industrial Entomology*, **16** (1): 15-20.
7. Bhat Shabir A., Khan, M.F. and Sahaf, K.A. 2017. Studies on the performance of some silkworm, *Bombyx mori* L. hybrids during summer season in Kashmir. *Journal of Entomology and Zoology Studies*, **5** (5): 1346-1348.
8. Bojan, C., Marghitas, L. A., Dezmirean, D. and Orsolya, T. 2007. Qualitative characters study for silkworm hybrids. *Bulletin of University of agricultural sciences and veterinary medicine cluj-napoca Agriculture*, **64**: 219-223.
9. Buhroo, Z.I., Malik, M.A., Ganai, N.A., Kamili, A.S. and Mir, A.S. 2017. Rearing Performance of Some Popular Bivoltine Silkworm *Bombyx mori* L. Breeds during Spring Season. *Advances in Research*, **9**(1): 1-11.
10. Chandrakanth, N., Moorthy, S. M., Anusha, P., Dayananda., Ashwath, S. K. and Kumar, V. 2014. Evaluation of genetic diversity in silkworm (*Bombyx mori* L.) strains using microsatellite markers. *International Journal of Biotechnology Allied Fields*, **2**:73-83.
11. Chandrakanth, N., Moorthy, S. M., Rekha, M. and Sivaprasad, V. 2016. Stability and path analysis for yield and related traits in silkworm, (*Bombyx mori* L.) reared under stress conditions. *Genetika*, **48**(1):271-284.
12. Chakravorty, R., Das, R., Senapati, M., Suryanarayana, N. and Mahanta, J. C. 2003. Evaluation of Season Specific Silkworm Hybrids For Agro-Climatic Condition of Assam. *Proc. Natl. Conf. Trop. Seric. Global Compt.*, pp. 288-291.
13. Chandrashekharaiah, Ramesh Babu, M., Lakshmi, H., Prasad, J. and Goel, A.K. 2005. Combining ability of diallel crosses of bivoltine silkworm, *Bombyx mori* L. *Int. J. Indust. Entomol*., **10** (1): 61-64.
14. Chandrashekharaiah, Ramesh Babu, M., Lakshmi, H., Prasad, J. and Seetharamulu, J. 2004, Development of New Productive Bivoltine Silkworm (*Bombyx Mori* L.) Hybrid, Aps-77 X Aps-100. In: *Proc. Fourth China Int. Silk Conf*., pp. 225-272.
15. Choudhary, N. and Singh, R. 2006. Heterosis in relation to combing ability in hybrids between multivoltine and bivoltine breeds of silkworm, *Bombyx mori* L. *Uttar Pradesh Journal of Zoology*, **26** (1): 29-32.
16. Dandin, S. B., Jayant, J. and Giridhar, K. 2003. Handbook of Sericulture Technologies. Central Silk Board, Bangalore.
17. Dandin, S.B., Suresh Kumar, N. Basavaraja, H.K., Mal Reddy, N. Kalpana, G.V., Joge, P.G., Nataraju, B., Balavenkatasubbaiah, M. and Nanjegowda, B. 2006. Development of new bivoltine silkworm hybrid, Chamaraja (CSR-50 x CSR-51) of *Bombyx mori* L. for tropics. *Indian Journal of Sericulture*, **45**: 35-44.
18. Dayananda, Kulkarni, B.S., Rao, M.R.P., Gopinath, K.O. and Kumar, N.S. 2011. Evaluation and selection of superior bivoltine hybrids of the silkworm, *Bombyx mori* L. for tropics through large scale inhouse testing. In: *Proceedings of Golden Jubilee Conference - Sericulture Innovations: Before and Beyond*, 28-29th January, 2011, CSR&TI, Mysore, pp. 199-203.
19. Datta, R.K. 2002. *Guidelines for Bivoltine Rearing*, Central Silk Board, Bangalore, India, pp.18.
20. Datta, R.K. 1984. Improvement of silkworm races (*Bombyx mori* L.) in India. *Sericologia*, **24**: 5-8.

21. Datta, R.K., Basavaraja, H.K., Mal Reddy, N., Nirmal Kumar, S., Suresh Kumar, N., Ramesh Babu, M., Ahsan, M.M. and Jayaswal, K. P. 2001. Evaluation and identification of promising bivoltine hybrid, CSR-12 x CSR-6 of silkworm, *Bombyx mori* L. *International Journal of Industrial Entomology*, **3** (2): 127-133.
22. Farooq, M., Puttaraju, H. P., Dar, H. U. and Sofi, A. M. 2002. Heterosis in relation to genetic divergence in bivoltine silkworm, *Bombyx mori* L. *Indian Journal of Sericulture*, **41**(1): 10-18.
23. Fisher, R. A. 1930. The Genetic Theory of Natural Selection Book. Clarendon Press.
24. Furdui, E. M., Marghitas, L. A., Dezmirean, D., Mihai, C. M., Bobis, O. and Pasca, I. 2010. Comparative study of biological characters of larvae, crude and dried cocoon in 7 races of Silkworm *Bombyx mori* L. raised in Transylvania area. *Scientific Papers: Animal Science And Biotechnologies*, **43**(1): 490-493.
25. Furdui, E. M., Marghitas , L. A., Dezmirean, D. S., Ca, I. Pas., Pop, I. F., Erler, S. and Schluns, E. A. 2014. Genetic Characterization of *Bombyx mori* (Lepidoptera: Bombycidae) Breeding and Hybrid Lines with Different Geographic Origins. *Journal of Insect Science*, **211**(14): 1-6.
26. Gadgala, O.P. and Singh, A. 2015. Seasonal performance of silkworm bivoltine hybrids under subtropical climatic zone in Rajouri District of J&K State. *Bionano Frontier*, **9** (1): 1-2.
27. Gangwar, S.K. 2011. Screening of region and season specific bivoltine silkworm *Bombyx mori* L. hybrid breeds of West Bengal in spring and summer season of Uttar Pardesh climatic conditions. *International Journal of Plant, Animal and Environmental Sciences*, **1** (1): 74-87.
28. Gawade, A.N. 2012. *Relative performance of different hybrids of mulberry silkworm Bombyx mori, L. under Konkan condition.* M.Sc. thesis. Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, pp.118.
29. Gowda, V., Kalpana G.V. and Ashwath, S.K. 2013. Evaluation and identification of potential bivoltine silkworm hybrids of *Bombyx mori* L. *Journal of Entomology and Zoology*, **1** (6): 39-43.
30. Gowda, V., Muthulakshmi, M., Murthy, N.G. and Sahay, A. 2017. Identification of potential bivoltine breeds of silkworm *Bombyx mori* L. for utilizing in breeding studies. *International Journal on Research Innovations in Engineering Science and Technology*, **2** (1): 1-7.
31. Gurjar, T. S., Siddhapara, M. R. and Patel, A. H. 2018. Rearing performance of various races of mulberry silkworm, *Bombyx mori* L. *International Journal of Agriculture Sciences*, **10**(13): 6625-6627.
32. Hussain, M., khan, M. A. and Aslam, M. 2010. Evaluation of genetic potential of inbred pure lines of silkworm for breeding and cocoon production in Pakistan. *African Journal of Food Science*, **4**(5):300-302.
33. Ilyas, M., Vidhate, S.G., Ugale, T.B. and Kamate, S.G. 2013. Performance of different bivoltine silkworm hybrids suitable for Marathwada regions of India. *Agric. Sci. Digest*., **33** (3): 178 – 182.
34. Islam, M.I., Ali, I.A. and Haque, T. 2005. Combining ability estimation in popular bivoltine mulberry silkworm, *Bombyx mori* L. *Pakistan Journal of Biological Sciences*, **8** (1): 68-72.
35. Jaiswal, K. and Goel, R. 2003. Evaluation and Identification of Promising Bivoltine Hybrids of Silkworm, *Bombyx mori* L. for Monsoon and Spring Season of Uttar Pradesh. *International Journal of Industrial Entomology*, **6** (2): 183-190.
36. Jingade, A. H., Vijayan, K., Somasundaram, P., Srinivasababu, G. K. and Kamble1e, C. K. 2010. A review of the implications of heterozygosity and inbreeding on germplasm biodiversity and its conservation in the silkworm, *Bombyx mori* L. *Journal of Insect Science*, **11**(8): 1-16.
37. Jolly, M. S., Noamani, M. K. R., Iyengar, M. N. S., Basavaraja, H. K., Parthasarathy, B. S. and Ramamohan Rao, P. 1986. Introduction of PCN: A New Breed suited for rain-fed Conditions. *Indian Silk*, **25** (9): 13-16.
38. Joshi, S.L. and Sisodiya, M. K. 2013. Development of hybrid seeds of silkworm *Bombyx mori* L. suitable for Malwa region of Madhya Pradesh, (India). *Asian Journal of Biochemical and Pharmaceutical Research*, **2** (3): 123-128.
39. Kamili, A. S., Masoodi, M. A., Sofi, A. M., Malik, G. N. and Malik, F. A. 1996. Nature and degree of association between various economic attributes of bivoltine silkworm, *Bombyx mori* L. *Oriental Science*, **1**(2): 105-108.
40. Kalpana, G.V., Suresh Kumar, N., Basavaraja, H.K., Mal Reddy, N. and Palit, A.K., 2005. Development of Fine Denier Silkworm Hybrid, CSR-48 X CSR-5 of *Bombyx mori* L. For Superior Quality of Silk. *International Journal of Industrial Entomology*,**10** (2):147-151.
41. Kalpana, G.V; Kumar, N.S; Mal Reddy, N; Joge, P.G. and Palit, A.K. 2000. Productive bivoltine silkworm *Bombyx mori* L. hybrids for large filament length and thin denier. *Advances in Indian*

Sericulture Research. In: *Proceedings of the National Conference on Strategies for Sericulture Research and Development*, CSR&TI (CSB). Mysore, pp. 129-133.

42. Khyade, B. V. and Sarwade, P. J. 2013. Utilization of Ratinol through The topical application to the fifth instar larvae of the silkworm, *Bombyx mori* L. *For qualitative Improvement of Economic Parameters*, **6**:532-537.
43. Krishnaprasad, N. K., Sannappa, B. and Varalakshmi, R. 2003. Comparative Performance of newly evolved bivoltine breeds of *Bombyx mori* L. *Bulletin of Indian Academic Sericulture*, **7**(1): 65-69.
44. Kumar, S., Basavaraja, N., Kishore Kumar, H. K., Mal Reddy, C. N. M., and Datta, R. K. 2002. On the Breeding of CSR-18 X CSR-19 -A Robust Bivoltine Hybrid of Silkworm, *Bombyx mori* L. for The Tropics. *International Journal of Industrial Entomology*, **5** (2): 153-162.
45. Kumaresan, P., Sinha, R. K., Sahni, N. K. and Sekar, S. 2000. Genetic variability and selection indices for economic quantitative traits of multivoltine mulberry silkworm, *Bombyx mori* L. genotypes. *Sericologia*, **40**(4): 595-605.
46. Kumaresan, P., Sinha, R. K. S. and Urs, R. 2007. An analysis of genetic variation and divergence in Indian tropical polyvoltine silkworm (*Bombyx mori* L.) genotypes. *Caspian Journal of Environmental Science*, **5**: 11–17.
47. Kumari, A., Tripathi, N. K. and Bano, R. 2015. Agglomerative hierarchical clustering to study the diversity in *Bombyx mori L.* races on the basis of weight gain characteristics. *International Journal of Recent Scientific Research*, **6**(12): 8005-8008.
48. Lakshmi, H. and Chandrashekharaiah, 2008. Evaluation and selection of breeding resources material of bivoltine silkworm *Bombyx mori* L. suitable to tropical conditions. *Indian J. Agric. Res.*, **42** (4): 235-243.
49. Lakshmi, H., Chandrashekharaiah., Babu, M.R., Raju, P.J., Saha, A.K. and Bajpai, A.K. 2011. HTO_5 x HTP_5: The new bivoltine silkworm *Bombyx mori* L. hybrid with thermotolerence for tropical areas. *International Journal of Plant, Animal and Environmental Sciences*, **1**(2): 88-104.
50. Lakshmi, H. and Chandrashekharaiah, R. 2008. Evaluation and selection of breeding resources material of bivoltine silkworm *Bombyx mori* L. suitable to tropical conditions. *Indian Journal of Agricultural Resources*, **42** (4): 235-243.
51. Mano, Y., Nirmal Kumar, S., Basavaraja, H. K., Mai Reddy, N. and Datta, R. K. 1993. A new method to select promising silkworm breeds/combinations. *Indian Silk*, **31**(10):53-58.
52. Masarat, B., Afifa. S. K. and Sharma, R. K. 2014. Assessment of variability between growth and yield attributes of bivoltine silkworm *Bombyx mori* L. under temperate climatic conditions. *International Journal of Advanced Biological Research*, **4**(3): 374-379.
53. Malik, G.N., Kamili, A.S., Wani Shafiq, A., Munshi, N.A. and Tariq, A. 2001. Performance of some bivoltine silkworm *Bombyx mori* L. hybrids. *Sericologia*, **6**:105-111.
54. Malik, G.N., Kamili, A.S.,Wani, S.A., Dar, H.L., Ahmed, R. and Sofi, A.M. 2002. Evaluation of some bivoltine silkworm, *Bombyx mori* L. genotypes. *SKAUST Journal of Research*. **4**: 83-87.
55. Malik, G.N., Masoodi, M.A., Kamili,A.S. and Sofi, A.M. 1998. Studies on heterosis in some bivoltine silkworm (*Bombyx mori* L.) crosses. *Indian Journal of Sericulture*, **6** (2): 47:49.
56. Maqbool, A., Dar, H. U., Ahmad, M., Malik G. N., Zaffar, G., Mir, S. A. and Mir, M. A. 2015. Comparative performance of some bivoltine silkworm *Bombyx mori* L. genotypes during different seasons. *Academic Journals*, **10**(12): 407-410.
57. Maribashetty, V.G. and Aftab Ahamed, C. A. 2002. Breeding of Hardy Bivoltine Line KSD_2 of Silkworm, *Bombyx Mori* L. for Tropical Climate. *Mysore Journal of Agricultural Sci*ences, **36**: 154-161.
58. Mirhosieni, S.Z., Seidevi, A.R., Ghanipoor, M., and Etebari, K. 2004. Estimation of general and specific combining ability and heterosis in new varieties of silkworm, *Bombyx mori* L. *Journal of Biological Sciences*, **4** (6): 725-730.
59. Mirhosseini, S. Z., Nematollahian, S., Ghanipoor, M. and Seidavi, A. R. 2010 a. Comparison of phenotypic and genetic performance of local silkworm groups and two commercial lines. *Biological Resources*, **43**:411–416.
60. Mohandas, T. P., Sethuraman, B. N., Saratchandra, B. and Chatterjee, S. N. 2004. Molecular genetic approach for identifying markers associated with yield traits in silkworm *Bombyx mori* L. using RFLP-STS primers. *Genetics*, **122**:185-97.
61. Moorthy, S.M., Das, S.K., Kar, N.B. and RajeUrs, S. 2007. Breeding of bivoltine breeds of *Bombyx mori* L. suitable for variable climatic conditions of the tropics. *International Journal of Industrial Entomology*, **14** (2): 99-105.

62. Moorthy, S. M., Das, S. K., Rao, P. R. T., Raje Urs, S. and Sarkar, A. 2007. Evaluation and selection of potential parents based on selection indices and isozyme variability in silkworm, *Bombyx mori* L. *International Journal of Industrial Entomology*, **14**:1–7.
63. Nagaraju, J. 2002. Application of genetic principles for improving silk production. *Current Science*, **83**:409-414.
64. Nezhad, M. S., Mirhosseini, S. Z. S., Gharahveysi, M., Mavvajpour, M. and Seidavi, A. R. 2010. Investigation on intera-specific biodiversity of 51 peanut cocoon strains of Iran silkworm (*Bombyx mori* L.) germplasm based on reproductive traits. *Biotechnology*, **9**: 149–156.
65. Nezhad, S. M., Mirhosseini, Z. M., Gharahveysi, S., Mavvajpour, M. and Seidavi, R. A. 2010. Evaluation of 37 economically important traits from 51 strains of the silkworm *Bombyx mori* L. and their relationships. *Journal of Food, Agriculture and Environmental*, **8**(2): 924-929.
66. Pal, N. B. and Moorthy, S. M. 2011. Assessment of variability in larval and cocoon traits in some genotypes of bivoltine silkworm, *Bombyx mori* L. *International Journal of Research in Biological Sciences*, **1**(4): 59–65.
67. Panday, R.K., Raina, K.S. and Sahaf, A.K. 2012. Impact of sub-tropical environment on silkworm survival in Kandi belt of Jammu province. *The Ecoscan*: *An International Quartely Journal of Environmental Sciences*, (Special Issue) **1**: 337-342.
68. Pallavi, S.N. and Basavaraja, H.K. 2007. Selection of Suitable Foundation Crosses for Utilization in Double Hybrid Bivoltine Silkworm, *Bombyx mori* L. *Indain Journal of Sericulture*, **46**:109-116.
69. Petkov, N., Petkov. Z., Vasileva, Y., Nacheva, Y., Matei, T.D. and Dineta. G. 2006. Analysis of main productive characters variability in genetically sex-limited silkworm (*Bombyx mori* L.) lines and F_t S. *Genetics and Breeding*, **35** (1): 33-36.
70. Rayar, S.G., Kallimari, C.S., Laxmikant, R. and Patil, R.R. 2000. Evaluation of few traditional multivoltine x bivoltine single hybrids of silkworm, *Bombyx mori* L. In: *National Conference on Strategies for Sericulture Research and Development*, pp. 24.
71. Ram, K., Bali, R. K. and Koul, A. 2003. Seasonal evaluation of various cross combinations in bivoltine silkworm *Bombyx mori* L. *Journal of Research Sher- e- Kashmir University of agricultural sciences and technology- Jammu*, **2**(2):169-177.
72. Ram, K., Bali, R. K. and Koul, A. 2006. Identification of bivoltine breeds and their hybrids suitable for subtropical climate of Jammu. *Geobios*, **33**(4): 265-270.
73. Ramesh Babu, C. M., Lakshmi, H., Prasad, J. and Goel, A. K. 2005 b. Combining ability of diallel crosses of bivoltine silkworm, *Bombyx mori* L. *International Journal of Industrial Entomology*, **10**(1): 61-64.
74. Ravinder, S. 2002. *Studies on Rearing Performance of New Bivoltine Breeds of Silkworm, Bombyx Mori* L. *on Improved Mulberry Varieties*. M.Sc. (Agri.) thesis. University of Agricultural Sciences, Dharwad, pp.83.
75. Rao, P. S., Basavaraja, H. K., Kalpana, G.V., Nishitha Naik, V., Mahalingappa, K. C. and Pallavi, S. N. 2004 a. Evolution of a productive bivoltine hybrid of silkworm, *Bombyx mori* L. (Sd-7 X Sd-12) with shorter larval duration. *International Journal of Industrial Entomology*, **8**(1): 27-32.
76. Rao, P. S., Datta, R. K., Palit, A. K. and Haque Rufaie, S. Z. 2004 b. Seasonal effects on the performance of newly evolved bivoltine hybrids of the silkworm (*Bombyx mori* L.) under tropics. *International Journal of Industrial Entomology*, **9**(2): 193-198.
77. Rao, P., Datta, R.K., Basavaraja, H.K., Vijaya Kumari, K.M. and Rekha. 2005. Evaluation of combining ability of certain quantitative traits through diallel crosses in the silkworm (*Bombyx mori* L.). *Indian Journal of Sericulture*, **44**: 75-81.
78. Rao, P.S., Datta, R.K. and Basavaraja, H.K. 2006. Evolution of new thermotolerent bivoltine hybrid of the silkworm *Bombyx mori* L. *Indian Journal of Sericulture*, **45** (1): 15-20.
79. Rayar, S. G. 1987. Performance of Single and Three Way Cross Hybrids of Silkworm, *Bombyx mori* L. M.Sc. (Agriculture) thesis. *University of Agricultural Sciences, Dharwad*, 119.
80. Reddy, M.N., Begum, N.A. and Bindroo, B.B. 2014. CSR_2 x CSR_4 Productive bivoltine hybrids. *Technical Bulletin* no.13.
81. Reddy, N.M., Begum, A.N., Shekar, K.B.C., Kumar, S.N. and Qadri, S.M.H. 2012. Expresssion of hybrid vigour in different crossing pattern involving the bivoltine silkworm *Bombyx mori* L. parents. *Indian Journal of Sericulture*, **51**(1):2631
82. Reddy, N.M., Kumar, S.N., Begum, A.R.N., Moorthy, S.N. and Qadri, S.M.H. 2012. Performance of bivoltine silkworm hybrids of *Bombyx mori* L. involving parental foundation crosses of different generation. *International Journal of Research in Zoology*, **2** (1): 1-5.

83. Reddy, N., Basavaraja, H. K., Suresh Kumar, N., Joge, P. G., Kalpana, G. V., Dandin, S. B. and Datta, R. K. 2004. Breeding of productive bivoltine hybrid, CSR16 x CSR17 of silkworm *Bombyx mori* L. *International Journal of Industrial Entomology,* **8**(2):129-133.
84. Sajgotra, M. and Bali, R. 2016 a. Evaluation and identification of potential bivoltine silkworm hybrids of *Bombyx mori* L. *Indian journal of ecology,* **43**(1):396-399.
85. Sajgotra, M. and Bali, R. 2016 b. Expression of heterosis in bivoltine hybrids of *Bombyx mori* L. for silk yield contributing traits under sub tropical conditions. *International Journal of Bio- resource and stress management,* **7**(2): 258-262.
86. Sajgotra, M., Bali, R. K. and Sharma, R. 2017. Heterosis studies on thermotolerant hybrids of bivoltine silkworm (*Bombyx mori* L). *Journal of pharmacognosy and phytochemistry,* **6**(5): 921-928.
87. Sonwalkar, T. N. 2001. Hand Book of Silk Technology. *New Age International Private Limited*, New Delhi. 14-21.
88. Thiagarajan, V., Bhargava, S. K., Ramesh Babu, M. and Nagaraj, B. 1992. Differences in seasonal performance of twenty six strains of silkworm, *Bombyx mori* L. (Bombycidae). *Journal of Lepidopteron Society*, **47**: 321-337.
89. Trag, A. R., Kamili, A. S., Malik, G. N. and Kukiloo, F. A. 1992. Evolution of High Yielding Bivoltine Silkworm (*Bombyx mori* L.) Genotypes. *Sericologia*, **32**: 321-324.
90. Tribhuwan, Singh, K.P. and Sahaf, A.K. 2012. The Heterosis Phenomenon in Mulberry Silkworm, *Bombyx mori* L. Scholars Research Library. *Annals of Biological Research*, **3** (9):4330-4336.
91. Vijaya Kumari, K.N., Rajan, R.K. and Mal Reddy, N. 2003. Performance of New Productive Bivoltine Hybrids with Recommended Feed and Bed Space. In: *Proc. Natl. Conf. Trop. Seric. Global Compt.,* Central Sericultural Research and Training Institute, Mysore, pp. 280-283.
92. Vidyunmala, S., Narasimha Murthy, B. and Sivarami Reddy, M. (1998). Evaluation of new mulberry silkworm (*Bombyx mori* L.) hybrids (multivoltine x bivoltine) through multiple trait evaluation index. *Journal of Entomology Research*, **22**: 49-53.
93. Zhong, B. 1988. A study on correlation between the activity of ALKP in egg stage and quantitative characters of F, hybrid of *Bombyx mori* L. *Acta Sericologica Sinica,* **14**(1):17-20.