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Review Article

Evaluation of Indigenous and Introduced Bivoltine Silkworm Breeds Along With Identification of Promising Heterotic and Hybrids

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ABSTRACT

The major aims of the breeding program are bespoke hybrids of mulberry silkworm to rearers which produce higher and sustain crops in different climate conditions. Moreover, silkworm breeds/hybrids which perform consistently good under adverse climatic conditions are considered as stable. In order to introduce bivoltine races in a temperate country, it is necessary to have stability in cocoon crop under high-temperature environments. Silkworm breeding is a continuous process to achieve a goal by bringing genetic improvement through recombination of genes by crossing two pure stocks. Cross breeding is extensively used in silkworm improvement as a mean of exploiting heterosis. Heterosis breeding has been recognized as the most suitable methodology for augmenting cocoon yield in silkworm. The required goal of increasing cocoon productivity in quickest possible time can be achieved through heterosis only. The phenomenon of heterosis and its utility in silkworm studies are widely popular and the estimates of heterosis over mid-parent value will be useful in measuring the genetic potential of hybrid combinations.

Keywords: *Bombyx mori L., Heterosis, Bivoltine breeds, Hybrid vigour, Crop improvement*

INTRODUCTION

India is the second largest producer of raw silk in the world next to China with an annual production of 36,152 MT (2020) (CSB, 2020) but the raw silk yarn is of low standard due to multivoltine nature. Besides this, other reason behind low standard of silk is the tropical climatic conditions of the country with marginal sub-tropical and temperate sericultural areas. In tropical areas of the country, multi x bi hybrids are reared and the silk produced is not of superior quality and as such is not sold at International market. Thus, there is a great need and scope for improving bivoltine sericulture in India which is possible only in sub-tropical and temperate areas of the country (Datta, 1984).

The major aims of the breeding program are bespoke hybrids of mulberry silkworm to rearers which produce higher and sustain crops in different climate conditions.

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Moreover, silkworm breeds/hybrids which perform consistently good under adverse climatic conditions are considered as stable. In order to introduce bivoltine races in a temperate country, it is necessary to have stability in cocoon crop under high-temperature environments. The prerequisite of summer hybrid is healthiness and adaptability to adverse conditions of high temperature, low food quality, relatively higher economic traits, with the potential for increased cocoon production (Kumar et al., 2011). A significant impact of silkworm hybrids through the exploitation of hybrid vigour where introduce through several scientists across the sericulture countries to increased quantitative and qualitative silk productivity besides crop stability on a commercial scale and succeeded in the development bivoltine silkworm hybrids (Harada, 1961; Mano et al., 1982; He et al., 1991; Chen et al., 1994; Basavaraja et al., 1995; Rajalakshmi et al., 1998; Datta et al., 2000; Rao et al., 2001; Kumar et al., 2004, Jalali et al., 2011; Khan, 2015 and Ghazy et al., 2017).

The state of Jammu and Kashmir with diverse climatic conditions *viz.,* sub-tropical in Jammu plains, warm temperate in Jammu hills and cool humid in Kashmir valley makes it ideally suitable to rear bivoltine races for the production of quality bivoltine silk. It being a traditional bivoltine silk producing state produces around 25 per cent of the total bivoltine raw silk of the country (Naik et al., 1996). From time to time, various bivoltine silkworm hybrids evolved by the southern states of the country have been recommended by 'Central Silk Board' for commercial exploitation (Rajalakshmi et al., 1998) and have been tried in J&K state also but the performance at state level has not yielded much results. The required goal of increasing the bivoltine cocoon productivity in the quickest possible time frame can be achieved through identification of heterotic season and region specific bivoltine hybrids. To achieve the target, fusion of new gene combinations by genetic manipulation is one of the powerful tools in exploiting the commercial qualities of bi x bi hybrids. As per available literature, manifestation of heterosis in silkworm has been demonstrated by many breeders (Tayade, 1987; Stuber, 1994; Nagaraju, 2002; Talebi & Subramanya, 2009).

Therefore, heterosis breeding has been recognized as the most suitable methodology for augmenting cocoon yield in silkworm. The required goal of increasing cocoon productivity in quickest possible time can be achieved through heterosis only. The phenomenon of heterosis and its utility in silkworm studies are widely popular and the estimates of heterosis over mid-parent value will be useful in measuring the genetic potential of hybrid combinations. Keeping this background in mind the present literature pertaining to evaluate and identify highly adaptive indigenous bivoltine silkworm breeds and to develop productive hybrids through heterosis have been reviewed and presented as follows:

Exploitation of heterosis through hybridization proved revolutionary in silkworm for economic traits and triggered changes in quantitative and qualitative silk output for maximize the cocoon yield, decrease in larval mortality, increase in filament length and lowering of renditta. A brief account of available literature that has direct/indirect bearing on the present topic is as under:

Singh et al. (1994) found that the degree of heterosis varied considerably for several quantitative characters of F1 hybrids in two rearing seasons. During July-August hybird BL-43 × NB_4D_2 exhibited significantly positive heterosis over mid parent values for fecundity and yield /10,000 larvae (by no. and wt.) and cocoon shell weight during Nov-Dec.

Thangavelu (1997) studied the economic characters of popular bivoltine races NB_7, NB_{18}, NB_4D_2, KA, CC_1 and CA_2. Races CC_1 performed better in comparison to other races in respect of fecundity (500-600), survival (90-95 %), cocoon weight (1.70-2.0 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.

Kumar et al. (1999) tested double hybrids on the basis of heterosis for pupation rate and fecundity. Twenty one promising foundation crosses involving productive bivoltine pure breeds were identified and tested for double cross combinations. A total number of hundred and ten, double cross hybrid combinations were evaluated on the basis of their performance, cocoon uniformity test and post cocoon parameters by applying multiple trait evaluation index method. Six double cross hybrid combinations were short listed and two double cross hybrids *viz.*, (CSR_6 × CSR_2) × (CSR_2 × CSR_{27}) and (CSR_6 ×CSR_{20}) × (CSR_{21} × CSR_{29}) were found suitable on the basis of high evaluation index for four major economic traits viz; pupation rate, cocoon yield, silk recovery and filament length.

Singh et al. (2000) studied hybrid vigour in twenty seven crosses over mid parent value. High heterosis was observed in B_{104} × KA (16.47%) followed by A_{104} × NB_4D_2 (14.94%) and A_{101} x NB_4D_2 (11.28%). Highly significant hybrid vigour for cocoon shell weight was observed in B103 × KA (32.75%) followed by B_{102} x CC_1 (27.86%) and B_{104} × KA (14.71). Heterosis effect for cocoon shell ratio was higher in B_{103} × KA (18.50%) followed by B_{104} x KA (8.37%) and B_{102} x CC_1 (5.49%).

Kumar et al. (2000) selected CSR bivoltine hybrid material for estimation of heterobeltosis at 25 ± 1^0C and 36 ± 1^0C temperature. At 36 ± 1^0C the parental breeds CSR_2, CSR_3, CSR_4, CSR_5, and CSR_6 did not pupate. On the other hand, parents viz. CSR_{18} and CSR_{19}, survived at 36 ± 1^0C and its heterosis and heterobeltosis could be calculated both at and 36 ± 1^0C and 25 ± 1^0C.

Begum et al. (2000) analyzed forty-four hybrids of silkworm *Bombyx mori* L. for eight economic traits in respect of mid parent value (heterosis) and better parent value (heterobeltiosis) and percentage improvement over control hybrid KA × NB_4D_2. Five hybrids A × CSR_5, A x J_2, A × 935A, B × 935E and G × A_1 were identified. Among these hybrids, A x J_2, A × 935A and GxA1 showed higher heterosis for most of the quantitative traits during spring season. However two hybrids A × CSR_6 and A × 935A showed significant improvement for yield by weight through least significant improvement for yield by weight through least significant difference (l.s.d.) value ($P<0.05$).

Kalpana et al. (2000) made an attempt to identify productive thin denier hybrids with longer filament length by utilizing thin denier breeds along with productive breeds. A total of 42 hybrids were studied for combining ability. Majority of the hybrids expressed positive heterosis for both filament length and denier, however hybrid JPN_8 × CSR_5 exhibited positive heterosis for filament length (1420m & vigour-6.010) but negative heterosis for denier (2.53d and hybrid vigour – 4.887).

Kumar et al. (2000) estimated heterosis and heterobeltiosis of high yielding and robust CSR bivoltine parents and their hybrids. It was found that hybrids exceeded their parents in many characters with significant positive heterosis over mid parent value (MPV) and better parent value (BPV). Among the three productive hybrids, increased hybrid vigor over MPV was well manifested in CSR_3 × CSR_6 for pupation rate, cocoon weight, shell weight and shell ratio indicating its superiority.

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Babu et al. (2001) studied thirty different crosses of silkworm and evaluated them for their mid and better parent heterosis for silk productivity. Hybrid APS_{13} × APS_8 and APS_5 × APS_8 showed higher heterosis for silk productivity and were identified for commercial exploitation.

Malik et al. (2001) made heterotic studies on the combination of the bivoltine strains for six economic traits. Two combinations B_{38} × C_{108} and J_{122} × B_{38} were found heterotic for four economic traits.

Farooq et al. (2002) made heterotic studies on ten selected divergent bivoltine silkworm *Bombyx mori* L. genotypes; C_{108}, Gonkomonrie, Hualak, J_{112}, Sanish, M_{42}, Jam_{10}, KA, NB_4D_2 and P_5. The mean square of treatments of parents and hybrids were found highly significant indicating considerable variability. Most of the F1 crosses made from these silkworm breeds exhibited significant and desirable heterosis over mid parent value (MPV) and better parent value (BPV).

Narayanaswamy et al. (2002) selected 28 F1 hybrids developed form seven multivoltines and four bivoltines silkworm breeds in a line × tester fashion through heterosis breeding. Hybrid P_2D_1 × NB_{18} recorded highest negative stand and heterosis for fifth instar and total larval duration. They also recorded superiority in ERR for hybrids P_2D_1 × NB_{18} and KJ × KA.

Boyko et al. (2004) studied heterosis in several quantitative traits of cloned breeds, the inter breed silkworm hybrids were exposed to electromagnetic irradiation during post diapause embryonic development. The authors found that resistance to low intensity and high frequency irradiation in hybrids was higher than parental forms.

Rao et al. (2004a) evolved SD_7 and SD_{12} breeds for shorter larval duration. SD_7 and SD_{12} recorded 516 and 511 hr of total larval duration; 152 and 146 hr fifth instar larval duration; 91.00 and 90.93 per cent pupation; 1.810 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/laying. While as, CSR2 and CSR5 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.

Rao et al. (2004b) 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 performed better over KA and NB4D2 in respect of pupation rate, cocoon yield, cocoon weight, cocoon shell ratio and filament length.

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 × 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 where as filament

length and cocoon yield characters exhibited higher values.

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

Pallavi & 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 × CSR_5, CSR_{17} × CSR_{21}, CSR_{17} × CSR_{46}, CSR_{27} × CSR_{46}, CSR_{46} × CSR_2 and CSR_{46} × CSR_{21} (oval type) and CSR_4 × CSR_{26}, CSR_6 × Gen_2, CSR_{26} × CSR_{47}, CSR_{26} × Gen_2, CSR_{47} × CSR_{26} and Gen_2 × Gen_{26} (dumbbell type) were short listed for the preparation of double hybrids.

Zhao et al. (2007) evaluated *Bombyx mori* L. hybrids 873 × 874 for spring and autumn seasons. Breeding results showed that, silkworm reared in temperature above 32^0C affected the quality of cocoons and silk contributing characters decreased markedly. Temperature beyond 32^0 C had marked effect on number of nonviable eggs which increased drastically.

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.

Seshagiri et al. (2009) studied hybrid vigour in thirty crosses over mid parent value and better value. High heterosis was recorded in six combinations, $APMG_1$ × APS_8, $APMG_1$ × APS_{45}, $APMG_3$ × APS_{12}, $APMW_1$ × APS_8, $APMW_2$ × APS_8 and $APMW_4$ × APS_{45} for all the economic traits over mid parent value. The hybrid combinations $APMW_2$ × APS_{45} with seven traits and $APMG_1$ × APS_8, $APMG_1$ × APS_{12}, $APMG_3$ × APS_{12} and $APMW_1$ × APS_8 exhibited positive heterosis for six out of nine traits over better parent heterosis. Further for EI values, two new hybrids, $APMW_1$ × APS_8 (59.58) and $APMG_1$ × APS_8 (58.68) were adjudicated as superior heterotic hybrid combinations.

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 × CSR_4. Among the hybrids evaluated, two hybrids viz., CSR_{50} × CSR_{51} (67.25) and D_2 × 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} × 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 × KB, P_5 × KPG-B, $NB4D_2$ × NB_{18}, P_5 × NB_{18}, KPG-B × NB_7 for spring KPG-B × NB_{18}, NB_{18} × P_5, NB_{18} × NB_7, SH_6 × NB_{18} and KA × 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 × NB_{18} and KA ×NB_{18} were found to be better for spring and summer seasons of Uttar Pradesh.

Kumar et al. (2011) studied the magnitude of heterosis over mid and better parents in fifty bivoltine hybrids of silkworm *Bombyx mori* L. for eight important economic traits under varying environmental conditions. The expression of both relative heterosis and heterobeltiosis was higher in summer (8.97 and 6.71%), followed by rainy (5.87 and 3.42%) and winter (2.13 and 0.03%) seasons. Differential behaviour of various hybrids in different environments for the expression of heterosis was also recorded. This study was carried out in three environments and it was found that four hybrids depicted consistent superior performance under all the environments and hybrid $CSR_{17} \times CSR_{16}$ was suggested for commercial exploitation. The authors further suggested the superiority of identified hybrid, particularly over the better parent as useful in determining the feasibility for the commercial exploitation of heterosis as well as in identifying the parental combinations for producing the highest level of transgressive segregants.

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.

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 × 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 × CSR_2. Growth rate was best in $CSR_{16} \times CSR_1$. Weight of mature larva was highest in CSR_{16}×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 were 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 crossing 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} × 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} × CSR_{17} reared on mulberry variety V_1 is the most suitable for rearing under Marathwada conditions.

Mukherjee et al. (2013) carried out study on heterosis over mid and better parent value for some important commercial characters of 15 hybrids. The hybrids were reared during unfavourable seasons. Hybrids N × M9A, N × M_6M_{81}, N × O, and N × M_6DPC, showed significant mid parent heterosis for various traits. Significant values for ERR, single cocoon weight and single shell weight was observed for better parent value. Among the hybrids, N × M_6DPC and M × M_6M_{81} were significant for various economic traits and were found to be superior over both mid and better parent values.

Ahmad et al. (2013) evaluated 50 F1 hybrids and short listed five hybrids *viz.*, NB_4D_2 × CSR_2; CSR4 × Chaung Naung; Chaung Naung × APS_8; Pam_{106} × Chaung Naung and NB_4D_2 × 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 & 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.

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 × CSR_4, CSR_2 × CSRS, and CSR_{16} × 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 & Singh (2015) analyzed the seasonal rearing performance of bivoltine hybrids viz., SH_6 × NB_4D_2, APS_{12} × APS_{45}, and FC_1 × FC_2 at farmers' level under sub-tropical conditions of Jammu (J&K) and obtained that hybrids, FC_1 × FC_2 and APS_{12} × APS_{45} showed better performance with respect to single cocoon, shell weight and shell percentage.

Wang et al. (2015) analyzed the differential gene expression in different hybrids and parents of *Bombyx mori* L. The results revealed significant changes in gene expression in the fat body involving biological regulation, cellular and metabolic processes. Consistent trends in expression patterns covering different hybrid combinations in 74 genes. Most of the heterosis rates showed that crosses F_1 offspring had more favorable economic traits than those of the reciprocal cross F_1 (including the length and diameter of silk fiber and F_1 females had higher heterosis

for cocoon shell, whole cocoon, pupal weights and diameter of silk fiber than males. It was also seen that heterosis of males for cocoon shell percentage and length of fiber was higher than females.

Maqbool et al. (2015) reared twenty-eight bivoltine silkworm lines viz., 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}, $NB4D_2$, CSR_2, CSR_4, SH_6, SRC, JBEL during spring and summer seasons. The results showed that the breeds J2M, A and NCD were supremefor several traits during spring while as, breeds $CSGRC_5$, New race, JA_1 and Jam $_{21}$ surpassed the check breeds ($NB4D_2$ and SH_6) in number of metric traits during summer. The breeds Sheiki II, $Pampore_5$, J_{122}, Meigitsu, 14M, NJ_3, NB_{18}, CSR_2 and CSR_4 were significantly superior to the check breeds in several traits in both spring and summer seasons.

Bhat et al. (2017) evaluated eight newly evolved silkworm, *Bombyx mori* L. hybrids SK_{28} × $SBNP_1$, SK_{30} × $SBNP_1$, SK_6 × $SBNP_1$, SH_6 × KA, SH_6 × NB_7, NB_{18} × KA, NB_4D_2 × 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} × $SBNP_1$, SK_6 × $SBNP_1$, NB_4D_2 × SH_6 and SK_{30} × $SBNP_1$, 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 where as the remaining 5 accessions (BBE_{0197}, BBE_{0222}, BBE_{0187}, BBE_{0186} and BBI_{0235}) were found performing better in 7 economic parameters only.

Sajgotra et al. (2017) carried out evaluation of the twenty-eight silkworm bivoltine hybrids raised by involving half (8 × 8) diallel set of bivoltine breeds in order to identify the thermotolerant, adaptable, high yielding hybrids suited for sub-tropical climate. The evaluation of hybrids was done on heterosis worked at mid parent value. Maximum heterosis was depicted by non-breakable filament length (37.75) followed by filament length (35.62), cocoon yield (by weight) (35.22), larval weight (28.21), single shell weight (24.46) and cocoon weight (17.10). On the basis of significant heterosis displayed for thirteen important commercial parameters, four hybrid combinations ND_5 × PO_1 (Cumulative heterosis 362.83), ND_5 × PO_3 (Cumulative heterosis 323.17), PO_1 × $Udhey_6$ (Cumulative heterosis 291.31) and PO_1 × $Udhey_3$ (Cumulative heterosis 250.42) were identified to be heterotic.

CONCLUSION

The existing tropical and sub – tropical situation provides scope for exploiting multivoltine x bivoltine hybrid at commercial venture as they are hardy and have tremendous ability to survive and reproduce under varied or fluctuating environmental climatic conditions. Improvement of breeds necessarily means selection of desirable genes in appropriate combinations, which contribute to the overall genetic worth of the population.

With respect to the economic value, the focus should be on all the genes affecting the traits thereby contributing to the viability and productivity. Therefore, selection of hybrid combinations emphasizes the need to organize the genetic material in a way that helps to improve the manifestation of commercially important traits. This can be achieved precisely by adopting a strategy by setting up a common index giving adequate weightage to all the component traits manifested among an array of hybrids. In view of this, all the major traits have been considered together to obtain the aggregate index value, since exclusion of any one trait can result in negative situation.

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