INTERNATIONAL JOURNAL OF ADVANCED BIOLOGICAL RESEARCH

www.scienceandnature.org

EVALUATION OF HETEROSIS IN BIVOLTINE DOUBLE HYBRID CROSSES OF SILKWORM *BOMBYX MORI* L. UNDER SUB-TROPICAL CONDITIONS

[a*]Mokshe Sajgotra, [b]Smaili Mehra and [b]Bali, R.K.
[1] Department of Sericulture, Government Degree College, Udhampur - 182101, J&K, India
[2]Division of Sericulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Udheywalla - 180 001, J&K, India
*Corresponding author email: mokshesajgotra@gmail.com

ABSTRACT
Selection, evaluation and synthesis of productive breeds/hybrids are an important component in the development of sericulture. The main objective of any breeding programme is to develop new breeds/hybrids as well as to identify promising hybrids for commercial exploitation with consistent performance over desired environmental conditions. In the present investigation, an attempt was made to develop and evaluate ten double bivoltine hybrids raised by involving eleven hypersericigenous (Z, ZZ, PO_1, PO_3, SPO, ND_2, ND_5, NSP, CSR2, CSR4 and CSR5) and four thermotolerant (U-1, U-3, U-4 and U-6) breeds along with ruling bivoltine double hybrid, $FC_1 \times FC_2$ in order to identify the adaptable double silkworm hybrids suited for sub-tropical climate. Observations were made on fourteen economically important traits namely, fecundity, hatching, brushing, weight of 10 mature larvae, larval survival, cocoon yield per 10,000 larvae (by weight and by number), pupation, single cocoon weight, single shell weight, shell ratio, average filament length, non-breakable filament length and denier. The data was analyzed using Evaluation index (E.I.) method. Eight hybrid combinations recorded mean evaluation index (E.I.) values of >50 ranging from 50.36 to 54.89, whereas, control scored E.I. value of 38.35 only. Three double hybrid combinations, ($PO_1 \times ND_2$) × (CSR5 × CSR4) (54.89), (U-3 × U-6) × ($PO_3 \times ND_2$) (54.24), and ($PO_3 \times ND_5$) × (CSR4 × CSR2) (54.20) recorded Average E.I. value >54 for all the characters under sub-tropical conditions.

KEYWORDS: Bivoltine, Double hybrids, Heterosis, Adaptable, Evaluation

INTRODUCTION
India is a vast country where majority of the rural population is associated with the various agricultural ventures such as sericulture, which is an important component of the diversified agriculture and plays a vital role in generating gainful employment opportunities for the masses of the farming community including women and the farmers with small land holdings to land less in the rural areas for livelihood. The trend of sericulture development in India has shown a quantum jump in mulberry silk production with an annual production of 20,000 MT during the last three decades (Lakshmanan and Kumar, 2012) and it enjoys the comfortable second position for the production of silk in the world next only to China, in which silkworm breeding and development of bivoltine hybrids have played a vital role. India being predominantly a tropical country with marginal sub-tropical and temperate sericulture zones. Mostly multi x bivoltine hybrids are reared in tropical areas of the country which do not meet the international standards, thus, there is great need and scope for improving the bivoltine sericulture of the country (Moorthy *et al.*, 2007). As a result, more emphasis needs to be given to bivoltine sericulture, which is the need of the hour if India has to produce international silk grade. Realizing the importance of bivoltine sericulture, efforts are being made by silkworm breeders of the country to evolve high yielding bivoltine silkworm breeds for commercial purpose. Most of the silkworm breeding programmes now-a-days are oriented towards boosting the bivoltine silk yield and fiber quality. The northern states of India, such as Jammu & Kashmir, Himachal Pradesh, Uttrakhand and some pockets of Punjab assumes special significance due to its salubrious climate congenial for rearing of bivoltine silkworms and these states have observed an increasing trend in cocoon production and has a high potential for bivoltine sericulture activities (Datta, 2001). However, this production is limited to spring season (March/April) as only one commercial rearing is conducted throughout the year, though enough of mulberry leaf is available for second rearing (September/October). It is in recent years that an attempt for second commercial rearing during autumn season (September/October) has also been initiated, though the percentage of success in this period is imperatively less due to certain reasons such as poor leaf quality, high temperature, high relative humidity, and incidence of diseases besides lack of autumn specific productive silkworm breeds and hybrids (Ram *et al.*, 2010). These factors combinedly act as main constraints in boosting the silk production of the sub-tropical regions. To overcome this, the development of indigenous adaptable thermotolerant silkworm breeds/hybrids is imperative for

introducing additional crop in autumn season for commercial exploitation in this region. Considering the economic importance of silkworm rearing as an employment and income generating activity, therefore, the present investigation was aimed to develop and evaluate silkworm double hybrids for autumn season that can withstand high temperature and humidity and results in better yield, adaptability and quality for successful commercial exploitation of bivoltine crop.

MATERIALS & METHODS

The present investigation was conducted during autumn 2015 at Division of Sericulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu with an intention to develop, evaluate and identify new bivoltine double hybrid combinations suitable for rearing during autumn season in sub-tropical conditions of northern India. For this purpose, eleven hypersericigenous (Z, ZZ, PO_1, PO_3, SPO, ND_2, ND_5, NSP, CSR2, CSR4 and CSR5) and four thermotolerant (U-1, U-3, U-4 and U-6) breeds were crossed in autumn season of 2014 to obtain F_1 hybrids and single cross hybrids were again reared in spring season of 2015 for preparation of ten double cross hybrids i.e. (PO_3 × ND_5) × (CSR_4 × CSR_2), (PO_1 × ND_2) × (CSR_5 × CSR_4), (U-6 × ND_5) × (U-4 × ND_2), (U-6 × ND_2) × (U-3 × PO_1), (U-6 × PO_1) × (U-3 × ND_2), (U-3 × U-6) × (PO_3 × ND_2), (U-1 × ND_2) × (NSP × SPO), (NSP × ZZ) × (SPO × Z) and (NSP × Z) × (SPO × ZZ). The rearing of all the double hybrids along with the ruling bivoltine double hybrid, FC_1 × FC_2 (control) was carried out in a completely randomized block design (CRD) with three replications each during autumn 2015 (i.e. September to October). Standard rearing techniques as suggested by Dandin *et al*. (2003) were followed. Data was recorded replication-wise for all the treatments viz., fecundity, hatching, brushing, weight of 10 mature larvae, larval survival, cocoon yield per 10,000 larvae (by weight and by number), pupation, single cocoon weight, single shell weight, shell ratio, average filament length, non-breakable filament length and denier and the data was then analyzed using multiple trait index (Evaluation index) method.

The Evaluation Index method developed by Mano *et al.* (1993) was found to be very useful in selecting potential hybrids. Data on the economically important traits was collected, pooled and analyzed. The Evaluation Index (E.I.) was calculated as per the procedure:

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

Where, A=Value obtained for a particular trait of a particular hybrid combination.
B=Mean values of a particular trait of all the hybrid combinations.
C=Stand deviation of a particular trait of all the hybrid combinations.
10=Standard Unit.
50=Fixed Value.
The E.I. value fixed for the selection of hybrids is 50 or >50 for the traits. The hybrid, which scored above the limit, is considered to possess greater economic value.

RESULTS & DISCUSSION

Mulberry silkworm, *Bombyx mori* L. is an insect of economic importance, which is commercially exploited for silk. Ultimate objective of silkworm breeding is not only to synthesize new genotypes but also to identify sustainable silkworm hybrids for commercial purpose. In order to improve the yield and quality of silk, it is pertinent to characterize the potential of available genetic resources for transferring the desirable components in hybrids. Selection of parents on the basis of per se performance does not always lead to fruitful results. More diverse the parents more are the chances of heterosis (Talebi and Subramanya, 2009). The earnest efforts of silkworm breeders have resulted in the evolution of large number of silkworm strains expressing well-defined qualitative and quantitative traits (Singh *et al*., 2006).

The introduction of hybrid concept for greater productivity and evaluation of hybrids derived from the selected pure lines is undoubtedly the most widely tested method for identifying the superiority of the hybrid. Superiority of single, three way and double hybrids over their parental races was initially worked out by Harada (1961) and Pannegpet and Jaroonchai, (1975). With the increase in demand for F_1 hybrids, now a days double cross hybrid are also being popularized because of their obvious advantages like easy rearing of foundation crosses and more egg yield. Moreover, the polygenic expression in double hybrids is more stable than single hybrids in unfavorable environments because of their flexibility in gene constitution within the population (Watanabe, 2002). Double hybrids of bivoltine silkworm are essentially preferred to overcome deleterious environmental effect expected in widely varying agro-climatic conditions (Lakshmanan and Kumar, 2012).

Fecundity is an important trait for variability of a commercial grainage. Variation in fecundity was found in different breeds and hybrids, which resulted in fluctuation of egg number per brood. Overall Evaluation Index value of 61.88 for fecundity was recorded for U-6 where as lowest value of 28.53 was recorded for CSR2 (Table 1). Amongst eleven double cross hybrid combinations studies including control, six hybrids viz. (PO_3 × ND_5) × (CSR4 ×CSR2), (PO_1 × ND_2) × (CSR5 × CSR4), (Z × NSP) × (Z × SPO), (NSP × ZZ) × (SPO × Z), (NSP × Z) × (SPO × ZZ) and (U-3 × U-6) × (PO_3 × ND_2) scored E.I. value >50 for fecundity which may be due to more accumulation of pupal weight. (Table 2). Lakshmanam and Kumar, 2012 suggested that when parental breed are utilized for the production of hybrid combination for foundational crosses (FCs) it not only helps in high egg recovery but heterosis manifestation in hybrids of FCs also gets exploited for commercial purpose.

According to Tazima (1957), fecundity mainly depends upon genotype of mother moth and environmental conditions at the time of oviposition. Higher fecundity registered in F_1 hybrids can be attributed to heterotic effect prevailing in hybrids. However, Ullal (1964) observed that the silkworm seed produced from autumn cocoon crop resulted in better fecundity than seed produced from spring reared cocoons. Hatching and brushing being two important seed parameters, commercially show direct co-relation to number of worms brushed and larval population reared that ultimately contribute for cocoon yield. High percentage of hatching and brushing generally results into more cocoon production. The Evaluation Index value for hatching was highest in U-1 (75.94) followed by U-4 (64.46) and lowest (39.48) in U-6 (Table 1). Hybrids, (PO_3 × ND_5) × (CSR4 x CSR2), (PO_1 × ND_2) × (CSR5 × CSR4), (U-6 × ND_5) × (U-4 × ND_2), (U-6 × ND_2) × (U-3 × PO_1), (U-3 × U-6) × (PO_3 × ND_2), (U-1 × ND_2) × (NSP × SPO) and (NSP × ZZ) × (SPO × Z) obtained higher E.I. value (>50) for hatching and brushing (Table 2), thus indicating genetic superiority due to the heterotic effect of inter crossing as reported by Nacheva (1980).. Similar trend was observed by Ram (1994) in bivoltine breeds. High hatching percentage observed in bivoltine breeds also reflects the high value for number of eggs hatched, number of worms brushed and brushing percentage which are important characters of quality silkworm seed and breed. This observation is in concordance with the findings of Reddy *et al*. (2012). Silkworms are voracious eaters of mulberry during its larval stages and around 80 percent leaf is consumed in last two instars (Fukuda, 1960). Highlighting the importance of food intake Horie *et al.* (1978) reported that for the production of 1 g larval dry weight, requirement of ingestion and digestion of food is 4.2 mg and 1.8 mg respectively. The intake of food during total larval life is also reflected by the weight of 10 mature larvae and is a cocoon and shell contributing parameter. The maximum E.I. value of 67.17 for weight of 10 mature larvae was observed in breed CSR4 whereas minimum E.I. value of 31.81 was found in U-4 (Table 1). For hybrids, maximum E.I. value of 65.52 was recorded in hybrid (PO_1 × ND_2) × (CSR5 × CSR4) followed by (NSP × Z) × (SPO ×ZZ) (62.02) and control hybrid, (FC_1 × FC_2) recorded E.I of 60.83. Minimum E.I. of 37.55 was found in (U-3 × U-6) × (PO_3 × ND_2) followed by (Z × NSP) × (Z × SPO) (39.86) (Table 2). The present study reveals that bivoltine double cross hybrids consume more mulberry leaves for attaining good growth and development at larval stage resulting in the higher larval weight which gets reflected in cocoon weight, shell weight and raw silk production. The significant E.I. values observed in double cross hybrids indicates their superiority and thus parallels the observations of Rayar (2007). Commercially larval survival constitutes an important character for rearer's point of view that contributes to produce more number of cocoons for better crop production. Breed ND_5 qualified for highest E.I. value 67.11 for larval survival parameter followed by PO_3 (65.46) while as lowest E.I. value of 30.30 was recorded in breed U-4 (Table 1). Among hybrids, (NSP × Z) × (SPO × ZZ) and (Z × NSP) × (Z × SPO) displayed maximum E.I. value of 60.53 followed by (U-3 × U-6) × (PO_3 × ND_2) (58.30) and (NSP × ZZ) × (SPO × Z) (57.56), whereas, minimum E.I. of 33.09 was displayed by hybrid (U-6 × PO_1) × (U-3 × ND_2). Control hybrid FC_1 × FC_2 scored E.I of 32.95 only (Table 2). The insignificant variation for larval survival can be attributed to uniform rearing condition and non-occurrence of disease or may be due to the better adaptability to autumn conditions. Ohi *et al*. (1970) also worked out multiple co-relations between yield components and found that larval survival is directly correlated to number of cocoons harvested. This is in accordance with the findings observed in the present study.

Minagava and Otsuka (1975) has reported interrelationship between multiple characters in silkworm. It therefore becomes essential to evaluate the breeds and their hybrids to understand the magnitude of potential and hetorosis towards improvement in cocoon and silk productivity as suggested by Bandopady (1990). Malik *et al*. (2006) suggested that cocoon yield/10,000 larvae by weight and by number, good cocoon percentage, pupation percentage, single cocoon weight, shell weight and shell ration percentage are important parameter for quality cocoon crop as well as potential hybrid. Cocoon yield for 10,000 larvae brushed; by weight and by number showed significant differences among hybrids studies. Cocoon yield by number is an important parameter for contributing viability. The highest E.I. value of 72.91 was recorded in breed PO_3 followed by SPO (55.94) whereas, lowest E.I. value of 32.17 was depicted by breed NSP (Table 1). In hybrids, (PO_1 × ND_2) × (CSR5 × CSR4) recorded highest E.I. value of 64.46 for cocoon yield/10,000 larvae (by weight) followed by hybrid (NSP × Z) × (SPO × ZZ) with a value of 60.20 and (U-3 × U-6) × (PO_3 × ND_2) (58.93). The lowest E.I. value of 36.17 was achieved in control hybrid FC_1 × FC_2 (Table 2). Maximum E.I. value for cocoon yield per 10,000 larvae by number was recorded in breed ND_5 (66.94) followed by PO_3 (65.30) while as breed U-4 scored minimum E.I value of 30.39 (Table 1). In two hybrids, (NSP × Z) × (SPO × ZZ) and (Z × NSP) × (Z × SPO) maximum E.I. of 60.52 followed by (U-3 × U-6) × (PO_3 × ND_2) (58.30) was recorded. Minimum E.I value was obtained in (U-6 × PO_1) × (U-3 × ND_2) (33.10) followed by control hybrid, FC_1 × FC_2 (32.97) (Table 2). The higher yield by weight and number in bivoltine hybrids may be due to the higher brushing percentage, larval survival percentage and their adaptability for autumn season. Positive correlation for cocoon yield, single cocoon weight with fecundity and hatching parentage has been reported by Jayaswal *et al*. (1990). Similar results were also recorded by Kumar *et al*. (2011). Pupation rate though an independent character is greatly depended on rearing environment, food quality and other abiotic factors. The genetic and environment gets more reflected in this character. In the present study, breeds, PO_3 and ND_5 scored highest E.I. value of 66.15 for pupation and a low E.I. of 33.18 was recorded for breed U-1 and U-4 (Table 1). A maximum E.I. value of 60.68 was exhibited by hybrid (Z × NSP) × (Z × SPO) followed by hybrid (U-3 × U-6) × (PO_3 × ND_2) (60.70).

Minimum E.I value was recorded for hybrid (U-6 × PO_1) x (U-3 × ND_2) (34.50), whereas, control hybrid FC_1 × FC_2 recorded E.I. of 32.37 for pupation character (Table 2). The observations are in accordance with the findings of Gowda *et al*. (2013). The cocoon weight, shell weight and shell ratio are important commercial parameters of cocoon for yield and silk reeling performance. The cocoon weight has a negative correlation with shell ratio but positive correlation with shell weight whereas, shell weight has positive correlation with shell ratio. Breed PO_3 scored highest E.I. value of 86.33 where as breed NSP recorded a lowest value of 33.66 (Table 1). Maximum E.I. value of 67.40 was recorded in hybrid (PO_1 × ND_2) × (CSR5 × CSR4) for single cocoon weight followed by (PO_3 × ND_5) × (CSR4 × CSR2) (61.80), while as hybrid (U-6 × ND_2) × (U-3 × PO_1) obtained minimum E.I. of 34.40 only. Control hybrid FC_1 × FC_2 recorded E.I. of 47.00 (Table 2). This character depicts the superiority of hybrids and indicates that phenomenon of heterosis could be either due to additive gene action or due to dominance as reported by Petkov (1989). Single shell weight contributes for silk content. The maximum E.I. value of 70.00 was recorded by breed PO_3 and ND_5. Breeds PO_1, SPO, ND_2, NSP and CSR5 scored a E.I. value of 60.00 while as U-4 scored a minimum E.I value of 20.00 (Table 1). Among the hybrids studied, maximum E.I. value of 71.00 was achieved by (PO_3 × ND_5) × (CSR4 × CSR2) followed by (U-1 × ND_2) × (NSP × SPO) (58.00). The control hybrid could not qualify the index value of 50 for single shell weight (Table 2). Shell ratio is an important parameter of quality depicting actual silk content of a cocoon. For shell ratio, maximum E.I. value of 68.09 was depicted in breed ND_5 followed by NSP (64.36) and a minimum value of 29.36 was recorded in breed U-4 (Table 1). In hybrids, maximum E.I value of 68.00 was depicted by hybrid (U-6 × ND_2) × (U-4 × ND_2) followed by (PO_3 × ND_5) × (CSR4 × CSR2) (63.06) and a minimum value of 35.90 was recorded in hybrid (PO_1 × ND_2) × (CSR5 × CSR4). The control hybrid scored E.I of 41.42 for said trait (Table 2). Saratchandra *et al.* (1992) has reported superior mulberry variety particularly triploids responsible for higher cocooning characters. Similar findings were also recorded by Rao *et al*. (2006).

Post cocoon characters have greater significance not only from reeler's point of view but also from industrial point of view. Three post-cocoon parameter viz. total filament length, non-breakable filament length and denier mainly contribute for silk, the end product. The E.I. for total filament length in breeds ranged from 65.96 to 32.71 with maximum value in CSR4 (65.96) and minimum value in U-1 (32.71) (Table 1). In hybrids, maximum E.I. value for total filament length was achieved in (U-6 × ND_2) × (U-3 × PO_1) (72.47) followed by (U-3 × U-6) × (PO_3 × ND_2) (60.02) and minimum value of 39.08 was recorded in hybrid (Z × NSP) × (Z × SPO). Control hybrid FC_1 × FC_2 recorded E.I. value of 40.73 (Table 2). Increase or decrease in filament length is dependent on increase or decrease in the thickness of silk filament and cocoon shell weight of breeds and hybrids (Basavaraja, 1996). Rajalakshmi *et al* (2000) opines that the quality of a good hybrid is to have minimum or no breaks during reeling. Breeds, CSR2 and CSR5 recorded maximum non-breakable filament length with E.I. value of 61.06 followed by ND_5 (59.99) while as U-1 scored a minimum E.I. value of 29.65 (Table 1). In hybrids, maximum E.I value was scored by hybrid (U-6 × ND_2) × (U-3 × PO_1) to the tune of 73.24 followed by (PO_3 × ND_5) × (CSR4 × CSR2) (56.92) and hybrid (Z × NSP) × (Z × SPO) scored minimum E.I value of 40.72. Control hybrid, FC_1 × FC_2 recorded the E.I. of 35.65 for non-breakable filament length (Table 2). Denier denotes thickness of the filament and an E.I. value of 75.00 was recorded for breed PO_3 followed by U-1, ZZ, PO_1, NSP (66.66). Breed U-4 and CSR2 scored least E.I. of 41.66 (Table 1). In hybrids, maximum E.I value was recorded in (NSP × ZZ) × (SPO × Z) (67.77) followed by (U-3 × U-6) × (PO_3 × ND_2) (59.25). Hybrid (PO3 × ND5) × (CSR4 × CSR2) scored least E.I. value of 35.55 and control hybrid FC_1× FC_2 recorded E.I. of 45.55 (Table 2). Thiagarajan *et al*. (1993) reported that silk yield is the main contributing factor among major twenty characters usually considered by the breeders. Premaltha *et al*. (2000) suggested that low magnitude of heterosis in hybrids for particular traits indicates the presence of partial dominance. The results are in accordance with the findings of Dayananda *et al*. (2011).

Ram *et al*. (2010) suggested that the superiority and the potential of breeds and hybrids among depend on the ranking and considering all the major cocoon yield and silk contributing parameters. In silkworm (*Bombyx mori* L.) even though the parental strains are superior they do not have much value if the same is not refuted in the hybrids. The ultimate results in silk worm breeding are judged by the excellency of commercial traits the appear in the hybrids (Reddy *et al*., 2012). Therefore large numbers of hybrids are tested and promising ones are selected based on the economic traits (Kumar and Naik, 2011). Evaluation of different breed/hybrids is undoubtedly the most important method to identify their superiority. This could be achieved precisely by adopting a common index giving adequate weight age to all the commercially important traits (Reddy *et al*., 2012). Based on the superior index values for fourteen qualitative and quantitative traits eight hybrid combinations were short listed with average E.I. value >50. The hybrids were: (PO_1 × ND_2) × (CSR5 × CSR4) (E.I. 54.89) followed by (U-3 × U-6) × (PO_3 × ND_2) (E.I. 54.24), (PO_3 × ND_5) × (CSR4 × CSR2) (E.I. 54.20), (NSP × ZZ) × (SPO × Z) (E.I. 52.79), (Z × NSP) × (Z × SPO) (E.I. 52.75), (NSP × Z) × (SPO × ZZ) (E.I. 51.52), (U-1 × ND_2) × (NSP × SPO) (E.I. 51.15) and (U-6 × ND_5) × (U-4 × ND_2) (50.36). Control hybrid, FC_1 × FC_2 stood at average E.I. value of 38.35 only. Thus, based on the Evaluation Index values for qualitative and quantitative traits three hybrid combination viz. (PO_1 × ND_2) × (CSR5 × CSR4), (U-3 × U-6) × (PO_3 × ND_2) and (PO_3 × ND×) × (CSR4 × CSR2) were identified as potential combinations both by evaluation and ranking through E.I. values respectively. These hybrids can be commercially exploited for sub-tropics for autumn season after multi locational trials.

REFERENCES

Bandopadyay, A.(1990) Utility of diallel mating designs in breeding. *Workshop on Biometrical Genetics*, Central Sericultural Research and Training Institute, Mysore, India. pp 22-27(Abstracts).

Basavaraja, H.K. (1996) Studies on the synthesis of productive bivoltine strains of *Bombyx mori* L. through hybrid dization, selection and genetic evaluation. *Ph.D. Thesis*, University of Mysore, Mysore, India.

Dandin, S.B., Jayant, J. and Giridhar, K. (2003) *Handbook of Sericulture Technologies*. Central Silk Board, Bangalore.

Datta, R.K., Basavaraja, H.K., Reddy, N.M., Kumar, S.N., Kumar, N.S., Babu, R., Ahsan, M.M., Jayaswal, K.P. (2001) Breeding of new productive bivoltine hybrid, CSR12×CSR6 of silkworm, *Bombyx mori* L. International Journal of Industrial Entomology 3, 127−133.

Dayananda., S.K, Rao, P.R.M., Gopinath, O. and Kumar, S.M.N. (2011) Evaluation and identification of promising bivoltine double hybrid of silkworm *Bombyx mori* L. for tropics through large scale in house testing. *International Journal of Industrial Entomology*. **23**(2): 187-191.

Fukuda, S. (1960) Biochemical studies on the formulation of silk protein. Part IX. The direct and indirect formulations of silk protein during the growth of silkworm larva. *Bulletin Agricultural chemical society, Japan*. **24** (supplement): 296-401.

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.

Harada, C. (1961) On the heterosis of quantative characters in the silkworms. *Bulletin Sericulture Express Station*. **17**(1): 50-52.

Horie, Y., Inokuchi, T. and Watanabe, K. (1978) Quantitative studies of food utilization by the silkworm *Bombyx mori* L. through the life cycle II. Economy of nitrogen and amino acids. *Bulletin sericultural Experimental Station, Japan*. **27** (2):531-578.

Jayaswal, K.P., Singh, T. and Sen, S.K. (1990) Correlation between economic parameters and their application in silkworm breeding. *Indian silk*. 25-27.

Kumar, S.N., Murthy, D.P. and Moorthy, S.M. (2011) Analysis of heterosis over environments in silkworm (*Bombyx mori* L.) *ARPN Journal of Agricultural and Biologic al Science*, **6(1)**: 3.

Kumar, K.P. and Naik, S. (2011) Development of polyvoltine x bivoltine hybrids of mulberry silkworm, *Bombyx mori* L. Tolerant to BmNPV. *International Journal of Zoological Research*, **7**: 300-309.

Lakshmanan ,V. and Suresh Kumar, N. (2012) Analysis of heterosis in new double hybrid combination in bivoltine silkworm *Bombyx mori* L. *International Journal of Sciences and Nature*, **3**(1): 197-204.

Mano, Y., Kumar, N.S., Basavaraja, H.K., Reddy, N.M. and Datta, R.K. (1993) A new method to select promising silkworm breeds/combinations. *Indian Silk*. **31**: 53.

Malik, G.N., Massoodi, M.A., Kamili, A.S. and Sofi, A.M. (2006) Studies on heterosis in some bivoltine silkworm (*Bombyx mori* L.) crosses. *Journal of Sericulture*. **6**(1&2): 47-49.

Minagawa, I. and Otsuka, Y. (1975) Relationships of actual performance of double cross hybrids and predicted value based on the mean value of the single crosses concerned in the silkworm *Bombyx mori* (L). *Japanese Journal of Breeding*. **25**: 251-257.

Moorthy, S.M., Das, S.K., Kar, N.B., Urs, S.R. (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.

Nacheva, I. (1980) Heterosis effect on some technological qualities of cocoons and silk fibres in the silkworm *Bombyx mori*. *Zhivotnov'DNauki*, **17**: 88-94.

Ohi, H., Miyahara, T. and Yamashita, A. (1970) Analysis of various practically important characteristics in the silkworm in early breeding generations of hybrids, variation among strains, correlations between parents and offspring as well as relationship between each character. *Technical Bulletin of Sericultural Experimental Station, Japan*, **93**: 9-49.

Pannegpet, P. and Jarronchai, J. (1995) Survey on the practical characters of double cross hybrids of bivoltine silkworm races (2).*Bulletin of Thai Sericultural Research and Training Center, Thailand*. **5**: 85-86.

Petkov, N. (1989) Influence of colour size and weight on heterosis effect in silkworm *Bombyx mori* L. *Genetic Sciences Bulgaria*, **12** (4): 286-291.

Premalatha, V., Rao, D., Rao, R.P., Mohan, R., Singh, R., Kariappa, B.K., Jayaswal, K.P. and Datta, R.K. (2000) Evaluation of heterosis through combining ability in polyvoltine strains of silkworm, *Bombyx mori* L. National Conference on: *Strategies for Sericulture Research and Development*. pp 25.

Ram, K. (1994) Genetic divergence in silkworm (*Bombyx mori* L.). *Ph.D. thesis* submitted to

Department of Genetics. Punjab Agricultural University, Ludhiana.

Ram, K., Bali, R.K. and Koul, A. (2010) Identification of bivoltine breeds and their hybrids suitable for sub-tropical climate of Jammu. *Geobios*. **33**(4): 265-270.

Rao, P.S., Datta, R.K. and Basavaraja, H.K. (2006) Evolution of a new thermo-tolerent bivoltine hybrid of the silkworm (*Bombyx mori* L.).*Indian Journal of Sericulture*. **45**(1): 15-20.

Rajalakshmi, E., Chauhan, T.P.S., Kamble, S.B.T. and Mahadevaiah, B.M. (2000) Evaluation of newly evolved bivoltine hybrids of *Bombyx mori* L. for silk yield contributing traits under hill conditions. *Indian Journal of Sericulture*. **39**(1): 21-23.

Rayar, S.G. (2007) Use of Evaluation index for selecting potential parents for silkworm breeding. *Karnataka Journal of Agricultural Science,* **20**(1): 420-421.

Reddy, N. M., Kumar, S.N., Begum, A.R.N., Moorthy, S.M. 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.

Saratchandra, B., Rajanna, L., Philomena, K.L., Paramesha, C., Ramesh, S.P., Tayappe, T. and Sabitha, M.G. (1992) An evaluation of elite mulberry varieties for good yield and quality through bioassay. *Sericologia*, **32** (1): 127-134.

Singh, R., Rao, R.D., Sharma, S. D., Chandrashekharan, K., Basavaraja, H. K., Kariappa, B. K. and Dandin, S. B. (2006) Development of robust polyvoltine breed NP1 of the mulberry silkworm, *Bombyx mori* L. *Inernational Journal of Industrial Entomology*, **12**(1): 29-34.

Talebi, E. and Subramanya, G. (2009) Genetic distance and heterosis through Evaluation Index in silkworm *Bombyx mori* L. *World Applied Sciences,* **7** (9):1131-1137.

Tazima, Y. (1957) Report on sericulture. Industry in India, Silk Board, Bombay, India.

Thiagarajan, V., Bhargava, S.K., Ramesh Babu, M. and Nagaraju, B. (1993) Difference in seasonal performance of twenty strains of silkworm *Bombyx mori* L.(Bombycidae). *Journal of Lepidopteran Society*, **47**(4): 321-337.

Ullal, S.R. (1964) Sericulture in USSR – A study report. Silk Board, Bombay, India.

Watanabe, H. (2002) Genetic resistance of the silkworm, *Bombyx mori* L. to viral disease. *Current Science*, **83**: 439-446.

TABLE 1 Evaluation Index values of parental silkworm breeds for commercial traits

Breeds → Parameters ↓		U- 1	U- 3	U- 4	U- 6	Z	ZZ	PO_1	PO_3	SPO	ND_2	ND_5	NSP	CSR2	CSR4	CSR5
Fecundity		56.14	58.65	54.71	61.88	55.06	59.37	51.10	46.46	49.33	52.56	55.42	51.48	28.53	31.04	38.21
Hatching		75.94	55.23	64.46	39.48	51.12	56.41	39.74	45.38	53.12	45.12	44.00	45.69	39.64	45.48	49.69
Brushing		71.65	62.00	63.08	35.31	54.68	52.51	39.82	46.17	54.11	45.48	45.60	38.17	55.66	45.54	52.74
Wt. of 10 mature larvae		46.96	41.90	31.80	36.86	41.90	46.96	52.02	57.07	52.02	57.07	57.07	62.12	61.12	62.12	62.12
Larval Survival		41.85	56.70	30.30	46.80	38.24	46.39	57.11	65.46	52.06	52.98	67.11	38.55	49.48	55.05	52.68
Cocoon yield per 10,000 larvae	By number	39.51	54.25	36.76	47.16	51.92	58.01	49.80	72.91	55.14	55.14	43.35	32.17	52.94	55.85	44.32
	By weight	41.85	56.60	30.39	46.77	38.27	46.36	57.00	65.30	51.99	52.91	66.94	38.58	49.43	54.96	52.60
Pupation		33.18	44.17	33.18	44.17	44.17	44.17	55.16	66.15	55.16	55.16	66.15	44.17	55.16	55.16	55.16
Single cocoon weight		46.00	46.66	49.00	35.00	52.00	48.66	66.00	86.33	53.66	49.66	41.33	33.66	47.66	50.00	46.66
Single shell weight		30.00	40.00	20.00	30.00	40.00	50.00	60.00	70.00	60.00	60.00	70.00	60.00	50.00	50.00	60.00
Shell ratio		37.54	44.45	29.36	41.90	42.27	50.63	50.63	49.45	49.45	57.27	68.09	57.81	51.09	57.18	50.54
Total filament length		32.71	42.62	36.60	39.08	43.68	46.86	55.70	57.47	52.52	43.68	61.01	57.12	61.01	65.96	53.94
Non-breakable filament length		29.65	39.64	43.57	38.21	42.50	48.21	53.92	59.63	59.63	43.21	59.99	55.35	61.06	54.28	61.06
Filament size		66.66	58.33	41.66	50.00	58.33	66.66	66.66	75.00	58.33	50.00	50.00	66.66	41.66	50.00	50.00
Total		649.64	701.21	564.88	592.62	654.15	721.20	754.68	862.78	763.50	720.24	794.00	695.51	687.95	747.67	706.90
Average E.I.		46.40	50.08	40.34	42.33	46.72	51.51	53.90	61.62	54.53	51.44	56.71	49.67	49.13	53.40	50.49

TABLE 2: Evaluation Index values of double bivoltine hybrids crosses for commercial traits

Hybrids → Parameters ↓		$FC_1 \times FC_2$ (control)	$(PO_1 \times ND_2) \times$ (CSR5 × CSR4)	(U-3 × U-6) × (PO_3 × ND2)	$(PO_3 \times ND_5) \times$ (CSR4 × CSR2)	(PO_3 × ND5) × (CSR4 × CSR2)	(Z × NSP) × (Z × SPO)	(NSP × Z) × (SPO × ZZ)	(U-1 × ND2) × (NSP × SPO)	(U-6 × ND_2) × (U-3 × PO_1)	(U-6 × ND_5) × (U-4 × ND_2)	(U-6 × PO_1) × (U-3 × ND_2)
Fecundity		33.98	55.42	60.58	51.80	59.81	58.26	61.62	44.31	41.99	48.70	35.79
Hatching		27.20	54.52	57.37	64.91	51.34	46.48	47.26	54.46	56.25	50.94	39.77
Brushing		29.14	56.66	38.58	61.06	51.56	52.34	46.31	59.43	58.22	55.24	41.91
Wt. of 10 mature larvae		60.83	65.52	37.55	42.16	48.04	39.86	62.02	50.34	58.53	43.36	42.16
Larval Survival		32.95	56.82	58.30	49.41	57.56	60.53	60.53	47.18	45.70	47.93	33.09
Cocoon yield per 10,000 larvae	By weight	36.17	64.46	58.93	47.95	57.41	56.96	60.20	46.55	44.26	40.77	36.33
	By number	32.97	56.82	58.30	49.41	57.55	60.52	60.52	47.18	45.71	47.93	33.10
Pupation		32.37	56.48	60.68	48.10	57.53	60.68	58.58	50.19	43.90	47.05	34.47
Single cocoon weight		47.00	67.40	58.00	61.80	45.20	48.60	43.60	55.60	37.40	34.40	51.80
Single shell weight		41.00	56.00	54.00	71.00	46.00	56.00	39.00	58.00	50.00	33.00	46.00
Shell ratio		41.42	35.91	45.10	63.06	51.02	60.40	43.26	53.67	67.95	47.14	42.04
Total filament length		40.73	50.76	60.02	55.71	43.39	39.08	40.09	46.31	50.63	72.47	50.88
Non-breakable filament length		35.65	52.10	52.72	56.92	44.93	40.72	41.71	47.77	51.17	73.24	52.22
Filament size		45.55	39.62	59.25	35.55	67.77	58.14	56.66	55.18	52.59	41.48	39.62
Total		536.96	768.49	759.38	758.84	739.11	738.57	721.36	716.17	705.09	683.64	579.18
Average E.I.		38..35	54.89	54.24	54.20	52.79	52.75	51.52	51.15	50.36	48.83	41.37