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Analysis of heterosis in some bivoltine silkworm hybrids of *Bombyx mori* L

Kritika Sharma and Kamlesh Bali

Abstract
The investigation was carried out during spring 2018, to rear six parents and thirty-one hybrid combinations including control by involving full diallel set of bivoltine breeds in a complete randomized design (CRD) to identify the high yielding bivoltine silkworm hybrids. Thirty-one treatments including control were replicated thrice with 200 worms per replicate post III· Moult. For all the thirty hybrids, estimates for heterosis were worked out as per cent deviation from mid parent value. Different hybrids combinations exhibited significant and desirable heterotic estimate at egg, larval, cocoon and post cocoon stages when compared to check hybrid. Six hybrids *viz.* ND_2 × NSP, ND_2 x U_1, ND_2 ×JD_6, ND_3 × ND_2, ND_3×JD_6 and NSP ×JD_6 recorded positive heterosis for egg traits. For larval traits, eight hybrids *viz.*, ND_2 × CSR_2, ND_3 × NSP, ND_3 × CSR_2, ND_3 × JD_6, U_1 × JD_6, CSR_2 × ND_2, CSR_2 × ND_3 and JD_6 × ND_2 were found to be heterotic. For commercially important cocoon parameters like coon yield by weight, by number, good cocoon and pupation percentage, significant heterosis was observed in twenty-three hybrids. Only one hybrid i.e. CSR_2 ×ND_3 exhibited heterosis above than control for single cocoon weight, single shell weight and shell ratio percentage. At post cocoon stage, only three hybrids *viz.* NSP × ND_3, NSP × U_1 and CSR_2 × ND_2 were significantly heterotic. The perusal of data on the basis of cumulative positive heterosis value of different traits revealed that, hybrid ND_2 × NSP (353.36) ranked at 1st position followed by CSR_2 × ND_2 (333.17) and NSP × ND_3 (333.15) at number 2nd position and 3rd position respectively and were shortlisted and found promising for exploitation at commercial level after validation by having multi location trial before releasing in the field.

Keywords: *Bombyx mori* L., bi × bi hybrids, analysis, heterosis

1. Introduction

Sericulture is rearing of silkworm for the production of cocoons which is the raw material for the production of silk (Kamili *et al.*, 2000) [16]. India has a rich and complex history in silk production and its silk trade dates back to 15th century. Sericulture industry provides employment to approximately 8 million persons in rural and semi-urban areas in India (Masrat and Tripathi, 2017) [30]. India is the second largest producer of raw silk in the world next to China with an annual production of 31,931MT (CSB, 2018) [4] 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. To overcome this drawback, compatible bivoltine breeds/hybrids for rearing under tropical conditions were developed (Lakshmi *et al.*, 2011) [26] and selected for rearing in field conditions.

The bivoltine cocoons are superior in comparison to multivoltine with higher silk content, longer filament, higher neatness, cleanness, low boil off loss ratio, higher tensile strength and less variation in evenness. Hence, these cocoons form suitable raw material for the production of gradable raw silk as compared to multi x bi cocoons (Dandin *et al.*, 2003) [5]. Realizing the importance of bivoltine sericulture, efforts are being made by silkworm breeders of the country to evolve high yielding bivoltine silkworm breeds and hybrids for commercial exploitation which is slowly revolutionizing silk production in India (Moorthy *et al.*, 2007) [33]. Most of the silkworm breeding programmes now-a-days are oriented towards boosting the bivoltine silk yield and fibre performance over the parental performance is practical in biological kingdom. Fusion of new-gene combinations by genetic manipulation is one of the powerful tools in exploiting the commercial qualities of plants and animals. As per available literature, manifestation of heterosis in silkworm has been demonstrated by many breeders (Talebi and

Subramanya, 2009 and Kumar *et al*., 2012) [52, 22]. The F1 hybrids are more productive and robust, which can be reared easily and can trigger a revolutionary change in overall qualitative and quantitative silk output (Hirobe, 1957; Harada, 1961; Kobayashi *et al*., 1968; Gamo, 1976; Nagaraju *et al*., 1996) [12, 11, 19, 7, 35]. The F1 hybrids are more productive and robust, which can be easily reared by the farmers by adopting appropriate rearing technology (Ramesha *et al*., 2009; Seshagiri *et al*., 2009; Manohar Reddy *et al*., 2010; Kiran Kumar and Sankar Naik, 2011) [42, 50, 29, 18]. Thus, there is a need to develop and identify highly adaptive indigenous productive hybrids suitable for different rearing seasons (Kumari *et al*., 2011) [24]. Accordingly, the present investigation was carried out to analyze and identify the newly developed bivoltine hybrids for commercialization.

2. Materials and Methods

The experimental research material for the proposed study comprised of six bivoltine breeds namely; ND_2, ND_3, NSP, U_1, CSR_2 and JD_6 evolved at Division of Sericulture, SKUAST-J, Udheywalla. The data was recorded for various traits and subjected to estimation of cumulative heterosis in relation to mid parent value (Shull, 1948). National authorized commercial hybrid $CSR_2 \times CSR_4$ was taken as check hybrid. All the six breeds were crossed in full diallel fashion and F1 seed of thirty hybrid combinations was prepared to develop, evaluate and identify new bi × bivoltine hybrids for achieving the primary objective of establishing bivoltine hybrids as a concept among sericulturists. The hybrids were reared in a Completely Randomized Block Design (CRD) as per the standard rearing techniques of Dandin *et al.* (2003) [5].

The estimation of hybrids was done by the cumulative heterosis on the basis of mid parent value. It was measured as the F1 deviation from mid-parental value by using the following formula-

Relative Heterosis (MP) = H-MP/MP × 100

Where H= Mean performance of F1 hybrid.

MP= Mid parent value $\frac{P1+P2}{2}$

Test of significance of Mid parent value

SE for MP = $\pm\sqrt{3 \times \sigma^2 e/2r}$

CD= SE (d) × t value at error degree of freedom at 5% level of significance

3. Results and Discussion

In sericulture, heterosis has become an important tool in the utilization of hybrids for commercial exploitation and is one of the best illustrations of practical utility of applied genetics next to maize. The mulberry silkworm, *Bombyx mori* L. is one among the few completely domesticated insects that has attracted breeders from time immemorial due to its economic importance. It has been reported that most of the economically important characters are quantitative and polygenic in nature (Kobari and Fujimoto, 1966) [20]. The ultimate goal of breeding efforts is the achievement of genetic improvement or the genetic gain. The existing gene pool provides raw material for combining genes into recombination's from which individuals and desirable gene combination are selected for multiplication and exploitation. A gene may affect many characters at the same time, linked genes on the chromosome tend to segregate simultaneously and group of genes may work together and interact to express a given character exhibiting a correlated change between the interacting traits. It is on the basis of these genetic properties that one can predict possible alteration of one trait while working to improve the other trait.

Selection of parents on the basis of per se performance does not always fulfil the desired results. More diverse the parents more are the chances of heterosis (Gamo, 1976; Talebi and Subramananya, 2009) [7, 52]. Almost all the economic traits of silkworm are reported to exhibit heterosis (Gautam *et al*., 1998) [9]. Systematic procedure developed for the estimation and exploitation of hybrids through hybridization in silkworm for economic traits on the basis of mid-parent value (Relative heterosis) has brought a revolutionary change in overall qualitative and quantitative silk output (Malik *et al*., 2002) [27]. The earnest efforts of silkworm breeders have resulted in the evolution of large number of breeds/ strains expressing well-defined qualitative and quantitative traits (Singh *et al*., 2006) [51]. Efforts to improve the yield potential requires consideration of cumulative effect of major parameters that influence the silk yield. Multiple trait Evaluation Index method (Mano *et al*., 1993) was found to be a useful tool for judging the superiority of the silkworm hybrids impartially.

In the present study, the estimates for heterosis of thirty hybrid combinations at different stages of life cycle exhibited significant and desirable heterosis in groups over the check hybrid. Some hybrids performed better in some characters but exhibited less percentage of heterosis in some other characters because in silkworm, selection for one character may produce a correlated change in other characters (Kobari and Fujimoto, 1966) [20]

From commercial point of view, fecundity is one of the most important parameter of quality seed for harvesting cocoons and it plays a vital role in the survival of silk industry. Fifteen hybrids were relatively more heterotic when compared to control. Highest heterosis for this parameter was recorded in JD_6 × NSP (33.93) closely followed by $ND_2 \times JD_6$ (33.40), $ND_3 \times JD_6$ (32.44), ND_2 × NSP (29.71) and were above the control heterosis (18.04). However, the lowest heterosis was seen in hybrid U_1 × NSP (7.24) (Table 1). According to Tazima (1957) [53], fecundity mainly depends upon the breed/hybrid mother moth and environmental conditions prevailing at the time of oviposition. Hatching of eggs is an important parameter and it has a direct correlation with number of worms brushed and larval population reared which ultimately contributes for cocoon yield. Twenty hybrids were found to be relatively more heterotic than the check hybrid in hatching percentage indicating genetic superiority due to heterotic effect of inter crossing as reported by Nacheva (1980) [34]. Similar trend was observed by Ram (1994) [39] in bivoltine breeds. The results are in concordance with the findings of Reddy *et al*. (2012) [46]. Maximum heterosis was found in $ND_3 \times ND_2$ (9.19) followed by NSP × ND_3 (9.03), $ND_2 \times CSR_2$ (8.00), $ND_2 \times ND_3$ (7.75) whereas the control remained at heterosis of 0.39. Eight hybrids only were superior for brushing percentage character in comparison to check hybrid. Lakshman and Kumar (2012) [22] suggested that the parental breeds utilized for the production of hybrid combinations, not only improves the egg productivity but heterosis manifestation in hybrids also gets exploited for commercial purpose. Six hybrids out of thirty *viz*., ND_2 × NSP, $ND_2 \times U_1$, $ND_2 \times JD_6$, $ND_3 \times ND_2$, $ND_3 \times JD_6$ and NSP × JD_6 were found to be heterotic and had values more than the control hybrid in all the three parameters (fecundity, hatching percentage and brushing percentage) of egg trait (Table 1).

At larval stage, a negative but desirable and better than control heterosis was recorded in twenty-nine hybrids out of thirty in case of total larval duration. Maximum negative heterosis for total larval duration was recorded in NSP × ND_2 (-8.01), followed by ND_3 × NSP (-7.98) indicating a shorter larval duration as well as intake of mulberry leaf. Weight of ten mature larvae is a cocoon and shell contributing parameter. Highlighting the importance of food intake, Horie *et al*. (1978) [13] 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 gets reflected by the weight of 10 mature larvae. In the present study, findings were similar as reported by Rao *et al*. (1998) [44]. Eleven hybrids cross the heterotic value above than check hybrid. Maximum heterosis was observed in CSR_2 x ND_3 (32.20) followed by ND_2 × CSR_2 and CSR_2 × ND_2 (31.03) (Table 2).

Commercially, larval survival from rearer's point of view is important as it contributes to more number of cocoons harvested for better crop production. Twenty five hybrids showed significant and positive heterosis in comparison to control. Ohi *et al*. (1970) [37] worked out multiple correlations between yield components and found that larval survival is directly correlated to number of cocoons harvested. This is in accordance with the findings recorded in the present study and higher heterosis for this parameter was recorded in ND_2 × ND_3 (23.13) followed by NSP × JD_6 (20.71), ND_3 × ND_2 (20.64) whereas the control hybrid remained at negative heterosis of -0.20. The minimum and below control heterosis was recorded in U_1 × CSR_2 (-8.00). For the larval traits (total larval duration, weight of 10 mature larvae and larval survival percentage), eight out of thirty hybrids *viz*., ND_2 × CSR_2, ND_3 × NSP, ND_3 × CSR_2, ND_3 × JD_6, U_1 × JD_6, CSR_2 × ND_2, CSR_2 × ND_3 and JD_6 × ND_2 were found to be heterotic (Table 2)..

Cocoon characters are commercially important and do have close relation with mulberry leaves given as food. Minagava and Otsuka (1975) [32] has reported interrelationship between multiple characters in silkworm. It therefore becomes essential to evaluate hybrids to understand the magnitude of potential and heterosis towards improvement in a cocoon and silk productivity (Bandyopadhyay, 1990; Gowda *et al*., 2013) [2, 10]. Positive correlation for cocoon yield, single cocoon weight with fecundity and hatching parentage has been reported by Jayaswal *et al.* (1990) [14]. Similar results were also recorded by Joge *et al.* (2003) [15] and Kumar *et al.* (2012) [22]. Malik *et al*. (2006) [28] suggested that cocoon yield/10,000 larvae by weight, single cocoon weight, single shell weight and shell ratio percentage are important parameters for quality cocoon crop. In the present study, great deal of variability was observed in the expression of cocoon weight and twenty-eight hybrids displayed positive and significant heterosis over the mid parent value over the control. The findings are in close conformity to that of Kumar *et al*. (2013) [23]. The cocoon yield by number ranged from -16.94 per cent (U_1 × CSR_2) to 20.67 per cent (ND_2 × ND_3). The heterotic values for this parameter were lower than the cocoon yield by weight. The maximum value of heterosis was recorded in ND_2 × ND_3 (20.67) followed by NSP × JD_6 (18.72), ND_3 × ND_2 (17.42), ND_3 × JD_6 (16.11), ND_3 × NSP (15.57) and ND_2 × NSP (15.13). Higher significance of heterosis for cocoon yield by number can be ascribed by the fact that cocoon yield by weight also exhibited significant differences among hybrids. It may be due to the negative correlation of fecundity (Ram *et al*., 2010) [41] (Table 3).

Twenty-three out of thirty hybrids showed positive and significant heterosis over control which remained at 1.82 for good cocoon percentage. The highest value of heterosis was recorded in ND_2 × ND_3 (33.51) followed by ND_2 × CSR_2 (28.84), ND_3 × ND_2 (28.01) whereas the lowest value was observed in U_1 × CSR_2 (-8.42) (Table 3). Pupation rate though an independent character is greatly dependent on rearing environment, food quality and other abiotic factors. The genetic and environmental interaction gets reflected in this character (Gamo and Hirabayashi, 1983) [8]. Twenty four hybrids exhibited positive and significant heterosis in comparison to check hybrid (Table 3). The observations are in accordance with the findings of Kato *et al*. (1989) [17]. Maximum and above control heterosis was observed in hybrid ND_2 × ND_3 (38.95) followed by ND_2 × CSR_2 (35.18), ND_3 × ND_2 (34.26), ND_3 × NSP (33.79). The observations are in accordance with findings of Gowda *et al*. (2013) [10]. Out of thirty hybrids, twenty-three were found to be more heterotic than control hybrid for the cocoon parameters mentioned in Table 3. The hybrids were ND_2 × ND_3, ND_2 × NSP, ND_2 × U_1, ND_2 × CSR_2, ND_3 × ND_2, ND_3 × NSP, ND_3 × U_1, ND_3 × CSR_2, ND_3 × JD_6, NSP x ND_2, NSP x ND_3, NSP × U_1, NSP × CSR_2, NSP x JD_6, U_1 x ND_3, U_1 x NSP, U_1 × JD_6, CSR_2 × ND_2, CSR_2 × ND_3, CSR_2 × NSP, JD_6 × ND_2, JD_6 × NSP, JD_6 × U_1 and JD_6 x CSR_2.

Cocoon weight has a negative correlation with shell ratio but positive correlation with shell weight while as shell weight has a positive correlation with shell ratio. For single cocoon weight parameter, fifteen hybrids out of thirty displayed a positive and significant heterosis over mid-parent value. The highest value of heterosis was observed in ND_2 × JD_6 (42.50) followed by U_1 × CSR_2 (42.27) whereas control hybrid remained at 31.11(Table 3). Ten hybrids were found to be more heterotic than control hybrid CSR_2 × CSR_4 for shell weight parameter. Maximum heterotic value above control was recorded in ND_2 × JD_6 (45.80) followed by ND_2 × NSP (41.81), CSR_2 × U_1 (38.84), JD_6 × ND_2 (38.54) (Table 3). Similar trend with respect to cocoon and shell weight was also observed by Maqbool *et al*. (2005) [31]. Shell ratio is an important parameter for quality, depicting actual silk content of a cocoon. Fourteen out of thirty hybrids displayed heterosis above control which remained at 2.44. Maximum heterosis was recorded in NSP × ND_2 (11.73) followed by ND_2 × CSR_2 (9.56). For shell ratio percentage, higher significance of the hybrids was due to higher ingestion, digestion and conversion factors. The result obtained corroborates with the findings of Chandraju *et al*. (2013) [3] (Table 3). For single cocoon weight, single shell weight and shell ratio percentage, only one (1) hybrid i.e. CSR_2 × ND_3 was found to have more heterosis than the control hybrid (Table 3).

Post cocoon characters have greater significance not only from reeler's point of view but also from industrial point of view. Three post cocoon parameters *viz*. total filament length, non-breakable filament length and filament size mainly contribute for the end product i.e. silk. The increase or decrease in filament length depends on increase or decrease in the thickness of silk filament and cocoon shell weight of hybrid (Kobari and Fujimoto, 1996; Nagaraju and Kumar, 1995) [20, 36]. For total filament length, twenty-two hybrids recorded significantly higher heterosis than control. The maximum heterosis above control (32.55) was exhibited by U_1 × JD_6 (53.32) followed by U_1 × CSR_2 (49.95) (Table 4). The results are in agreement with Rao *et al*. (2004) [45]. The findings can be attributed to longer Vth instar, larval duration and larval weight (Satenahalli *et al*., 1990) [47]. Rajalakshimi *et al*. (1998) [43] opines that the quality of a good hybrid is to have minimum or no break during reeling. For non-breakable filament length, sixteen hybrids were significantly high in heterosis than check hybrid. Maximum heterosis was displayed by hybrid JD_6 × NSP (58.06) followed by U_1 × JD_6 (57.86) whereas minimum heterotic value was recorded in ND_3 × ND_2 (16.30). Filament size being genetically controlled trait generally may not have significant correlation with other post cocoon parameters. The heterosis for filament size ranged from -11.25 (U_1 × ND_3) to JD_6 × ND_3 (9.34). The positive value represents the thick denier whereas; the negative value represents thin denier. The negative heterosis for denier was exhibited by hybrids ND_2 × ND_3 (-7.50), NSP × JD_6 (-2.52), U_1 × ND_3 (-11.25), U_1 × NSP (-1.29), CSR_2 × JD_6 (-7.56), JD_6 × ND_2 (-3.22) and JD6 x U_1(-5.62) whereas, maximum positive heterosis was recorded in JD_6 × ND_3 (9.34) followed by ND_3 × NSP (7.82), CSR_2 × ND_2 (7.75), NSP × ND_3 (6.95), NSP × U_1(6.86). The heterotic value of control hybrid remained at 5.78. Hybrids NSP × ND_3, NSP × $U_1$and CSR_2 × ND_2 out of thirty hybrids were found to be more heterotic than control in all the post cocoon characters (Table 4). Premaltha *et al*. (2000) suggested that low magnitude of heterosis in hybrids for particular traits indicates the presence of partial dominance. In the present study, extremely variable heterosis was depicted by the hybrid combinations studied and the results are closely in accordance with the findings of Dayandanda *et al*. (2011).

Analysis of positive and significant heterosis indicates the genetic makeup of the parental breeds involved in the hybrid combinations and their expressions in a given set of environment and this has been explained by earlier workers also (Allard, 1956; Sengupta *et al*., 1971 and 1974) [1, 48-49]. In silkworm, even though the parental breeds/strains may be superior, they do not have much value if the same is not reflected in hybrids. The ultimate results are judged by the excellence of commercial traits (Reddy *et al*., 2012) [46] therefore, large numbers of hybrids are tested and promising heterotic combinations are selected based on the commercial economic traits (Kumar and Naik, 2011) [18]. Minagawa and Otsuka (1975) [32] have reported interrelationship between multiple characters in silkworm. It therefore becomes essential to understand the magnitude of heterosis towards the improvement of cocoon traits and silk productivity (Bandyopadhyay, 1990) [2]. Ram *et al*. (2003) [40] suggested that the superiority and potential of hybrids mainly depends on the ranking and considerations of all major egg, larval, cocoon and silk contributing characters and as such it is undoubtedly most important to identify cumulative score of all polygenic characters by adopting relative heterosis for giving adequate weightage to all commercial traits (Reddy *et al*., 2012) [46].

The estimates for heterosis worked out for thirty hybrids for commercial parameters for different stages of silkworm life cycle were pooled in groups. Among these groups, only four hybrids; ND_2 × NSP (353.36), CSR_2 × ND_2 (333.17), NSP × ND_3 (333.15) and ND_3 × ND_2 (305.95) excelled in heterosis value for fifteen commercial parameters i.e. fecundity, hatching percentage, brushing percentage, wt. of 10 mature larvae, larval survival percentage, cocoon yield/10,000 larvae(by weight/by number), good cocoon percentage, pupation percentage, single cocoon weight, single shell weight, shell ratio percentage, total filament length, non-breakable filament length and filament size which displayed superiority over other hybrids (Table 5). While the control hybrid CSR_2 × CSR_4 scored 213.41 only. Thus, the perusal of data on the basis of cumulative positive heterosis value of different traits revealed that, hybrid ND_2 × NSP ranked at 1st position followed by CSR_2 × ND_2 and NSP × ND_3 at number 2nd position and 3rd position respectively and were considered superior for further multi locational rearing trials at field level (Table 5).

Table 1: Heterosis percentage of bi x bivoltine silkworm hybrids for egg traits

Hybrids	Fecundity	Hatching percentage	Brushing percentage
CSR_2 × CSR_4*	18.04	00.39	00.58
ND_2 × ND_3	09.86	07.75	-05.33
ND_2 × NSP	29.71	07.67	02.08
ND_2 × U_1	21.06	04.42	04.25
ND_2 × CSR_2	14.50	08.00	-06.39
ND_2 ×JD_6	33.40	04.48	00.61
ND_3 × ND_2	25.00	09.19	03.58
ND_3 × NSP	18.68	05.94	-006.8
ND_3 × U_1	11.18	06.85	03.92
ND_3 × CSR_2	16.05	06.66	-00.05
ND_3 × JD_6	32.44	06.34	03.39
NSP × ND_2	27.27	01.64	-02.39
NSP × ND_3	20.21	09.03	-06.66
NSP × U_1	26.65	06.60	-03.46
NSP × CSR_2	11.49	04.96	01.26
NSP × JD_6	18.20	02.79	00.98
U_1 × ND_2	08.08	-04.13	-12.03
U_1 × ND_3	13.92	-12.76	-17.65
U_1 × NSP	07.24	-12.15	-21.65
U_1 × CSR_2	17.91	-15.43	-17.78
U_1 × JD_6	12.71	-07.72	-09.34
CSR_2 × ND_2	16.88	02.45	-03.17
CSR_2 × ND_3	10.27	01.66	-07.28
CSR_2 × NSP	12.14	-05.37	-16.59
CSR_2 × U_1	12.70	00.92	-05.00

$CSR_2 \times JD_6$	15.13	-04.41	-29.62
$JD_6 \times ND_2$	25.33	-06.35	-12.12
$JD_6 \times ND_3$	23.11	04.61	-02.80
$JD_6 \times NSP$	33.93	01.95	-12.45
$JD_6 \times U_1$	21.98	-01.84	-03.22
$JD_6 \times CSR_2$	18.64	-05.38	-09.52

* Control- $CSR_2 \times CSR_4$

Table 2: Heterosis percentage of bi x bivoltine silkworm hybrids for larval traits

Hybrids	Total larval duration(D:H)	Weight of 10 mature larvae(g)	Larval survival percentage
$CSR_2 \times CSR_4$*	-02.26	22.80	-0.20
$ND_2 \times ND_3$	-06.60	18.03	23.13
$ND_2 \times NSP$	-05.24	06.45	17.47
$ND_2 \times U_1$	-07.95	15.25	17.76
$ND_2 \times CSR_2$	-03.67	31.03	19.65
$ND_2 \times JD_6$	-05.11	15.78	-01.08
$ND_3 \times ND_2$	-06.63	18.03	20.64
$ND_3 \times NSP$	-07.98	23.80	18.95
$ND_3 \times U_1$	-07.92	16.66	08.27
$ND_3 \times CSR_2$	-06.42	28.81	11.34
$ND_3 \times JD_6$	-07.72	24.13	17.70
$NSP \times ND_2$	-08.01	19.35	12.52
$NSP \times ND_3$	-05.20	17.46	15.24
$NSP \times U_1$	-06.60	18.03	06.44
$NSP \times CSR_2$	-05.02	20.00	13.13
$NSP \times JD_6$	-06.39	15.25	20.71
$U_1 \times ND_2$	-07.95	22.03	-0.44
$U_1 \times ND_3$	-05.14	20.00	09.48
$U_1 \times NSP$	-06.42	18.03	13.70
$U_1 \times CSR_2$	-04.89	22.80	-08.00
$U_1 \times JD_6$	-06.40	25.00	17.31
$CSR_2 \times ND_2$	-03.67	31.03	11.11
$CSR_2 \times ND_3$	-03.67	32.20	0.33
$CSR_2 \times NSP$	-02.23	26.66	02.18
$CSR_2 \times U_1$	-04.99	19.29	0.35
$CSR_2 \times JD_6$	-04.85	23.63	-05.12
$JD_6 \times ND_2$	-07.82	22.80	03.85
$JD_6 \times ND_3$	-05.08	24.13	-03.35
$JD_6 \times NSP$	-03.67	22.03	02.24
$JD_6 \times U_1$	-06.40	21.42	10.06
$JD_6 \times CSR_2$	-04.89	20.00	08.25

* Control- $CSR_2 \times CSR_4$

Table 3: Heterosis percentage of bi x bivoltine silkworm hybrids for cocoon traits

Hybrids	Cocoon yield / 10,000 larvae		Good cocoon percentage	Pupation percentage	Single cocoon weight	Single shell weight	Shell ratio percentage
	By weight	By number					
$CSR_2 \times CSR_4$*	26.14	-11.75	01.82	06.66	31.11	34.21	02.44
$ND_2 \times ND_3$	55.13	20.67	33.51	38.95	23.33	30.18	05.51
$ND_2 \times NSP$	50.07	15.13	22.64	30.11	41.60	41.81	-00.04
$ND_2 \times U_1$	39.23	11.70	14.52	21.79	21.34	18.86	-02.17
$ND_2 \times CSR_2$	43.44	13.22	28.84	35.18	19.15	30.71	09.56
$ND_2 \times JD_6$	30.03	-04.98	-03.62	03.60	42.50	45.80	02.23
$ND_3 \times ND_2$	39.17	17.42	28.01	34.26	20.11	30.54	08.64
$ND_3 \times NSP$	39.91	15.57	27.71	33.79	28.80	32.85	03.00
$ND_3 \times U_1$	32.81	00.18	06.60	12.54	19.33	27.34	06.53
$ND_3 \times CSR_2$	39.86	03.25	17.59	24.40	42.06	34.57	-05.40
$ND_3 \times JD_6$	60.08	16.11	22.79	30.55	30.65	32.57	01.32
$NSP \times ND_2$	35.66	08.64	13.20	17.24	17.88	32.00	11.73
$NSP \times ND_3$	39.58	11.94	22.28	29.59	23.35	32.85	07.59
$NSP \times U_1$	47.83	-01.10	00.88	08.28	33.92	31.34	-01.92
$NSP \times CSR_2$	47.44	05.77	19.17	26.42	25.68	33.33	06.12
$NSP \times JD_6$	58.16	18.72	26.88	31.97	28.56	32.83	03.35
$U_1 \times ND_2$	42.30	-06.52	-01.65	02.12	39.78	32.45	-05.39
$U_1 \times ND_3$	44.30	03.27	10.37	16.01	35.20	33.70	-01.26
$U_1 \times NSP$	44.77	06.64	09.49	18.03	32.96	23.88	-06.84
$U_1 \times CSR_2$	36.22	-16.94	-08.42	-03.84	42.27	38.07	-02.94
$U_1 \times JD_6$	37.60	13.14	12.48	21.93	38.13	36.07	-01.46

CSR$_2$ × ND$_2$	51.28	05.46	19.35	23.61	37.19	35.58	-01.29
CSR$_2$ × ND$_3$	34.67	-07.52	05.29	11.26	31.58	37.17	04.08
CSR$_2$ × NSP	42.88	-04.96	04.44	12.63	38.38	30.37	-05.77
CSR$_2$ × U$_1$	41.30	-08.12	-01.00	06.41	30.68	38.84	06.24
CSR$_2$ × JD$_6$	24.42	-10.27	-00.25	01.36	25.36	33.46	06.46
JD$_6$ × ND$_2$	59.56	03.69	07.08	14.15	43.27	38.54	-03.37
JD$_6$ × ND$_3$	23.00	-06.04	-00.14	06.01	25.44	33.71	06.40
JD$_6$ × NSP	39.87	-00.85	04.41	10.20	34.86	36.60	01.32
JD$_6$ × U$_1$	42.10	04.56	06.36	12.65	37.59	31.76	-04.25
JD$_6$ × CSR$_2$	38.36	02.99	11.71	19.17	22.07	29.96	06.46

* Control- CSR$_2$ × CSR$_4$

Table 4: Heterosis percentage of bi x bi silkworm hybrids for post cocoon traits

Hybrids	Total filament length (m)	Non-breakable filament length (m)	Filament size (d)
CSR$_2$ × CSR$_4$*	32.55	39.91	05.78
ND$_2$ × ND$_3$	19.75	28.11	-07.50
ND$_2$ × NSP	35.60	47.38	05.60
ND$_2$ × U$_1$	28.70	33.49	04.52
ND$_2$ × CSR$_2$	35.32	43.09	04.08
ND$_2$ × JD$_6$	39.06	23.70	03.62
ND$_3$ × ND$_2$	30.48	16.30	04.58
ND$_3$ × NSP	28.96	39.52	07.82
ND$_3$ × U$_1$	30.33	34.54	0.00
ND$_3$ × CSR$_2$	39.50	22.33	0.82
ND$_3$ × JD$_6$	35.94	44.51	04.87
NSP × ND$_2$	20.86	31.36	03.44
NSP × ND$_3$	40.35	51.85	06.95
NSP × U$_1$	49.07	56.33	06.86
NSP × CSR$_2$	44.86	54.89	03.40
NSP × JD$_6$	37.22	48.23	-02.52
U$_1$ × ND$_2$	22.64	27.21	04.56
U$_1$ × ND$_3$	39.64	44.15	-11.25
U$_1$ × NSP	41.23	23.42	-01.29
U$_1$ × CSR$_2$	49.95	52.94	04.50
U$_1$ × JD$_6$	53.32	57.86	04.45
CSR$_2$ × ND$_2$	42.25	50.41	07.75
CSR$_2$ × ND$_3$	34.12	41.16	05.34
CSR$_2$ × NSP	29.85	38.85	02.97
CSR$_2$ × U$_1$	47.52	50.45	05.28
CSR$_2$ × JD$_6$	34.19	40.93	-07.56
JD$_6$ × ND$_2$	34.28	43.41	-03.22
JD$_6$ × ND$_3$	35.62	20.17	09.34
JD$_6$ × NSP	46.32	58.06	04.62
JD$_6$ × U$_1$	33.27	37.22	-05.62
JD$_6$ × CSR$_2$	41.97	24.25	02.78

*Control- CSR$_2$ × CSR$_4$

Table 5: Heterosis over mid parent value for fifteen commercial traits among heterotic hybrids

Hybrids		CSR$_2$ × ND$_2$	NSP × ND$_3$	ND$_3$ × ND$_2$	ND$_2$ × NSP	CSR$_2$ × CSR$_4$*	SE	CD at 5%
Fecundity		16.88	20.21	25.00	29.71	18.04	4.08	NS
Hatching Percentage		02.45	09.03	09.19	07.67	00.39	3.18	NS
Brushing percentage		-03.17	-06.66	03.58	02.08	0.580	1.51	3.42
wt. of 10 mature larvae		31.03	17.46	18.03	06.45	22.80	4.08	9.21
Larval survival percentage		11.11	15.24	20.64	17.47	-00.20	3.65	8.24
Cocoon yield/10,000 larvae	By weight	51.28	39.58	39.17	50.07	26.14	4.08	9.21
	By number	1.820	11.94	17.42	15.13	-11.75	4.45	10.05
Good cocoon percentage		19.35	22.28	28.01	22.64	01.82	03.6	8.28
pupation percentage		23.61	27.81	34.26	30.11	06.66	4.08	9.21
Single cocoon weight		37.19	23.35	20.11	41.60	31.11	4.08	9.21
Single shell weight		35.58	32.85	30.54	41.81	34.21	4.08	NS
Shell ratio percentage		01.29	07.59	08.64	-0.04	02.44	2.60	5.88
Total filament length		42.25	40.35	30.48	35.60	32.55	4.08	NS
Non-breakable filament length (NBFL)		50.41	51.85	16.30	47.38	39.91	4.08	9.21
Filament Size		07.75	06.95	04.58	05.60	05.78	3.52	NS
Cumulative heterosis		335.17	333.15	305.95	353.36	213.41	-	-

*Control- CSR$_2$ × CSR$_4$

4. Conclusion
Thus, based on these facts it can be concluded that for the cumulative heterosis for qualitative and quantitative traits, three hybrid combinations *viz*. $ND_2 \times NSP$, $CSR_2 \times ND_2$ and $NSP \times ND_3$ were short listed and found promising among thirty-one hybrids (including control) studied and hence, can be exploited in the field at farmer's level for better prospects of bivoltine sericulture in the country.

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