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Evaluation of High Temperature and Muscardine Disease Tolerant Foundation Crosses in Farmers' Field Conditions

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Abstract

Evaluation of foundation crosses *viz*., B1 × B2, B1 × B4 and B6 × B8 of high temperature and muscardine disease tolerant silkworm breeds *viz*., B1, B2, B4, B6 and B8 was done in the farmers field, covering Tumakuru District. Parental rearing was carried out in the Department of Sericulture, University of Agricultural Sciences, GKVK, Bengaluru, to obtain 50 dfls each of B1 × B2, B1 × B4 and B6 × B8 foundation crosses. These dfls were distributed to fifteen farmers of Tumakuru district. Total 16 traits were assessed along with the control FC1 for B6 × B8 and FC2 for B1 × B2, B1 × B4. Rearing parameters of F1's *viz*., total larval duration (hours), effective rearing rate (%), fifth instar larval weight (g/10 larvae), cocoon yield by number (No./ 10,000 larvae), cocoon yield by weight (kg/ 10,000 larvae), single cocoon weight (g), pupal weight (g), shell weight (g) and shell ratio (%) were assessed at the farmers field. Further, F1's reared in the farmers field were procured and recorded to assess the grainage parameters namely pupation rate (%), moth emergence (%), fecundity (No.), hatching (%), dead eggs (%), egg retention in ovary (%) and egg recovery (g/kg of cocoons). The results have shown that, the performance of the single hybrids B1 × B2 and B1 × B4 was superior for majority of the parameters compared to control indicating their advantage to be used as foundation cross to develop new double hybrids with dual advantage of high temperature and muscardine disease tolerance.

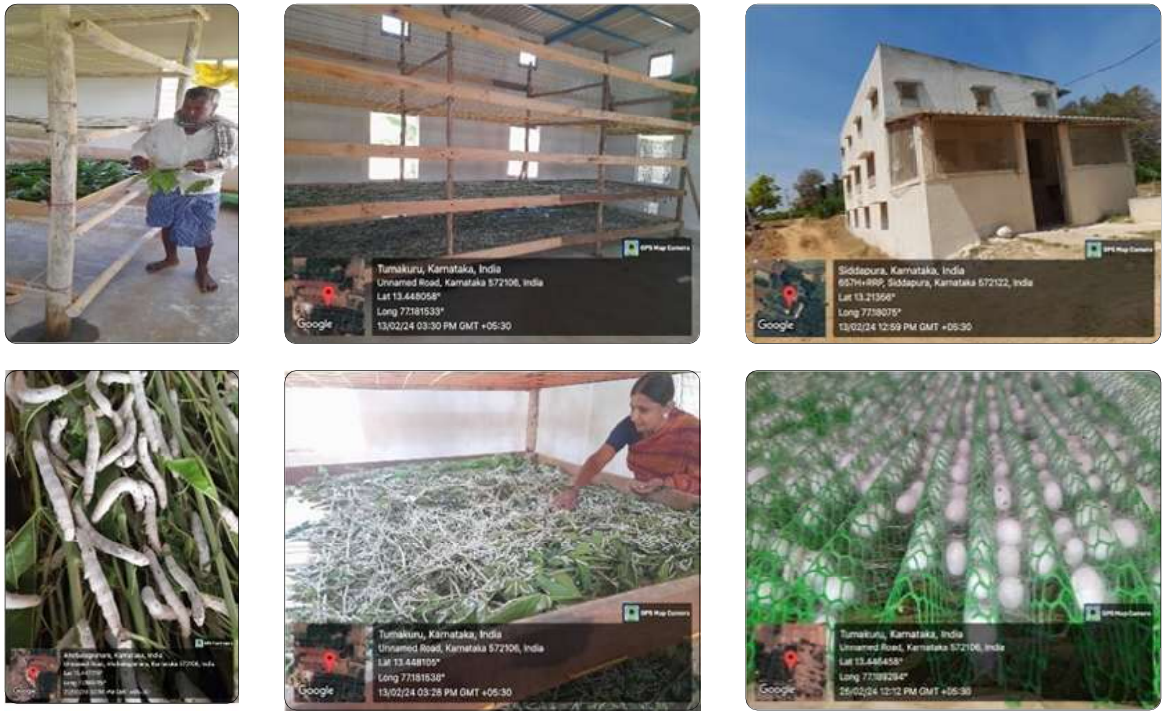
Keywords : High temperature, Muscardine disease, Foundation crosses, Double hybrids

Sericulture is an agro-based cottage industry that holds unique cultural, economic and scientific benifits, *viz.,* creating job opportunities, supporting sustainable rural development, preserving cultural heritage, generating employment, fostering research and innovation and producing eco-friendly goods. The monophagous silkworm, *Bombyx mori* L. feeding only on mulberry plant has a remarkable influence on the sericulture market. India, being tropical nation, has been primarily using Multivoltine × Bivoltine hybrids. However, these hybrids often produce low quality silk with least competitiveness in the international markets than bivoltine silkworm breeds and hybrids. Therefore, focusing on bivoltine sericulture is essential to produce raw silk that meets global quality benchmarks (Datta and Pershad, 2002). Indian sericulture faces various problems like, poor leaf quality, high temperature and inadequate management practices in summer leading to crop losses due to both environment conditions and disease incidence. Cocoon crop losses due to diseases range from 15-47 per cent. Among the diseases, the white muscardine disease caused by the fungus, *Beauveria bassiana* (Bals.-Criv.) Vuill., is devastating, particularly during the rainy and winter seasons, when the humidity and temperature conditions promote its proliferation, leading to significant losses upto 40 per cent (Sreedhar and Reddy, 2017).

The recent studies on multi-stress tolerant silkworm breeds have identified a few thermotolerant breeds viz., B1, B2, B4, B6, B8 (Keerthana, 2018; Sahana *et al.,* 2021; Chandrakala *et al.,* 2022; Manjunatha *et al.,* 2023 and Thrilekha *et al.,* 2024) and hybrids *viz.,* B1 × B4 and B1 × B8 which have shown better overall performance, while B4 × B6, B6 × B4 and B1 × B6 hybrids have demonstrated superior heterotic performance under muscardine infection (Jayashree, 2019). Similarly, the laboratory assessment of three foundation crosses, B1 × B2, B1 × B4 and B6 × B8 and their double hybrids *viz.,* (B1× B2) × FC1, (B1 × B4) × FC1 and FC2 × (B6 × B8) has revealed to be promising (Thrilekha *et al.,* 2024). In this background, field evaluation of three foundation crosses B1 × B2, B1 × B4 and B6 × B8 which have shown promising performance in the earlier studies was carried out to check their adaptability.

Material and Methods

Five silkworm breeds *viz.,* B1, B2, B4, B6 and B8, identified to be tolerant to high temperature and muscardine disease, from previous studies (Keerthana *et al.,* 2019), were procured from Central Sericultural Research and Training Institute, Mysuru. Parental rearing was carried out in the Department of Sericulture, University of Agricultural Sciences, GKVK, Bengaluru from November to December, 2023 by following recommended rearing practices (Dandin and Giridhar, 2014) to obtain oval cocoon spinning hybrid *viz.,* B1 × B2, B1 × B4 and peanut cocoon spinning hybrid, B6 × B8. Further, 50 dfls of each hybrid *viz.,* B1 × B2, B1 × B4 and B6 × B8 were selected and black boxed at pin head stage. The study was conducted in the Eastern Dry Zone of Karnataka. A total of 150 dfls were provided to Shri Manjunatha Chawki Rearing Centre, Beladhara village of Tumakuru district and the observations on fecundity (%), hatching (%) and dead eggs (%) were recorded. The worms were reared upto 2nd moult by feeding thrice a day and maintaining proper spacing and rearing environment. They were then distributed to the farmers of Chinnivaranahalli, Buchanahalli and Tamadihalli villages such that 10 dfls each of B1 × B2 and FC2, B1 × B4 and FC2 and B6 × B8 and FC1 hybrids were provided to five farmers each and



Plates 1 : Rearing of foundation crosses of high temperature and muscardine disease tolerant bivoltine silkworm breeds in the farmers field

assessed for total larval duration (hours), effective rearing rate (%), fifth instar larval weight (g/10 larvae), cocoon yield by number (No./10,000 larvae), cocoon yield by weight (kg/10,000 larvae), single cocoon weight (g), pupal weight (g), shell weight (g) and shell ratio (%). Regular field visits, *i.e.,* twice a week to individual rearing houses and phone calls were made to monitor the crop and collect data.

Further, F1 cocoons raised in the farmers field were procured and the observations on pupation rate (%), moth emergence (%), fecundity (No.), hatching (%), dead eggs (%), egg retention in ovary (%) and egg recovery (g/kg of cocoons), were recorded to assess the grainage performance of the foundation crosses. The data was statistically analysed using completely randomized design (Sundarraj *et al.,* 1972). The mean values of the experiments were compared by using Duncan's Multiple Range Test (DMRT) (Duncan, 1955).

Results and Discussion

Fecundity (No.)

Among five foundation crosses, B1 × B4 recorded significantly higher fecundity of 557.86 eggs, followed by FC2 (544.46 eggs) (Table 1). While B6 × B8 recorded significantly lowest fecundity of 515.86 eggs followed by FC1 (521.66 eggs) and B1 × B2 (530.26 eggs) (Table 1).

The present findings align with previous studies where, Thrilekha *et al*. (2024) recorded significantly highest fecundity of 562.00 eggs in B1 × B4, followed by FC2 (550.00 eggs). While B6 × B8 recorded significantly lowest fecundity (510.67 eggs).

The variations in temperature and RH can cause incomplete fecundity and prolongation in oviposition and extreme conditions result in poor development of embryo and increase in sterility. High fecundity recorded in B1 × B4 hybrid may be due to a combination of favorable genetic traits, optimal environmental conditions, proper nutrition and good parental rearing practices, making it a promising choice for silkworm breeding programme which aim at improving the egg-laying efficiency.

Hatching (%)

Significant differences were observed for the hatching percentage in all the foundation crosses (Table 1). B1 × B4 foundation cross recorded significantly highest hatching percentage of 98.00 followed by B1 × B2 (97.20 %) and FC2 (96.43 %). On the other hand, FC1 showed significantly lowest hatching percentage of 95.08, followed by B6 × B8 (95.28 %) (Table 1).

Table 1

Egg and larval characteristics of high temperature and muscardine disease tolerant bivoltine silkworm foundation crosses reared in the farmers field

Foundation crosses	Fecundity (No.)	Hatching (%)	Dead eggs (%)	Total larval duration (h)	Fifth instar larval weight (g/10 larvae)	Effective rate of rearing (%)
B1 × B2	530.26 ^{bc}	97.20 ^{ab}	2.07 ^{ab}	634.03 ^{a}	36.11 ^{b}	94.22 ^{ab}
B1 × B4	557.86 ^{a}	98.00 ^{a}	1.44 ^{d}	612.47 ^{bc}	37.37 ^{a}	96.50 ^{a}
FC2	544.46 ^{ab}	96.43 ^{b}	2.17 ^{a}	642.19 ^{a}	35.62 ^{b}	91.20 ^{c}
B6 × B8	515.86 ^{c}	95.28 ^{c}	2.01 ^{b}	601.09 ^{c}	33.09 ^{c}	93.40 ^{bc}
FC1	521.66 ^{c}	95.08 ^{c}	1.88 ^{c}	624.73 ^{ab}	32.88 ^{c}	95.20 ^{ab}
F test	*	*	*	*	*	*
S. Em ±	6.61	0.35	0.04	6.46	0.41	0.89
CD @5%	18.74	1.00	0.10	18.29	1.15	2.52
CV (%)	5.73	1.71	8.95	4.83	6.81	4.41

*-Significant at 5 %; Figures with same superscript are statistically on par

These results corroborate with the previous studies wherein, Thrilekha *et al.* (2024) reported highest hatching percentage of 98.20 in B1 × B4 followed by B1 × B2 (97.70 %) under laboratory conditions. Hatching percentage is a crucial commercial indicator for validating hybrids, as it directly reflects egg viability. A higher hatching percentage indicates favourable genetic and physiological conditions of the female moth (Buhroo *et al*., 2017). In this study, the hybrids B1 × B4 and B1 × B2 exhibited higher hatching percentage compared to others, suggesting their enhanced suitability. This increased viability can likely be linked to their genetic characteristics, which supports improved egg viability, embryonic development and overall health of the female moth supported by optimum egg incubation conditions.

Dead Eggs (%)

Dead eggs percentage exhibited significant differences among the foundation crosses (Table 1). Among five foundation crosses, B1 × B4 showed significantly least dead egg percentage of 1.44 whereas, highest dead egg percentage was found in FC2 (2.17 %) followed by B1 × B2 (2.07 %), B6 × B8 (2.01 %) and FC1 (1.88 %) (Table 1).

In the laboratory study, lowest dead egg per cent was reported in case of B1 × B4 (1.80 %) (Thrilekha *et al.*, 2024). The percentage of dead eggs reflects egg quality and can reveal potential issues with the health of the female moth, mating or rearing conditions. In this study, the foundation cross B1 × B4 recorded lowest percentage of dead eggs, which may be due to genetic characters and indicating that female parent has got better adaptation to rearing environmental conditions. Higher hatching percentage in B1 × B4 foundation cross as observed, contributes to reduced dead eggs percentage.

Total Larval Duration (h)

Total larval duration was calculated starting from the first day of the first instar until 50 per cent spinning. Significant differences in total larval duration were observed among the various foundation crosses examined.

The results showed that FC2 exhibited longest total larval duration of 642.19 hours followed by B1 × B2 (634.03 h), which were statistically on par. Whereas, B6 × B8 showed significantly shortest total larval duration (601.09 h) followed by B1 × B4 (612.47 h) and FC1 (624.73 h) (Table 1 and Fig.1).

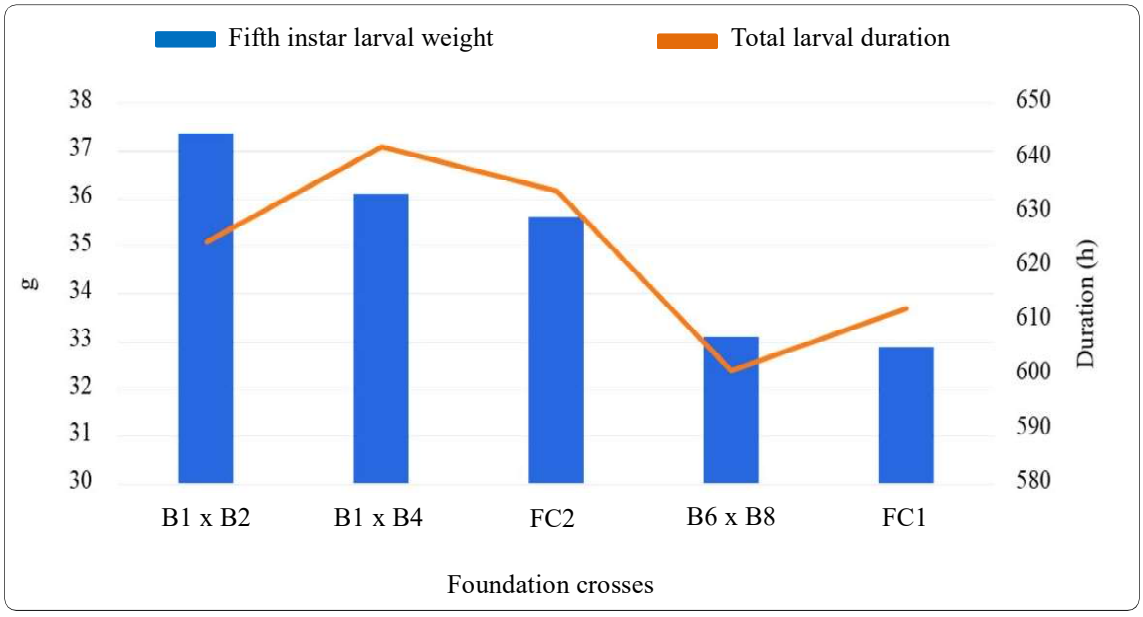


Fig. 1 : Fifth instar larval weight and total larval duration of high temperature and muscardine disease tolerant bivoltine silkworm foundation crosses reared in the farmers field

Thore *et al.* (2023) reported that CSR50 × CSR51, CSR16 × CSR17 and S8 × CSR16 showed larval duration of 22.10, 22.93 days and 23.19 days, respectively. Thrilekha *et al.* (2024) reported significantly prolonged fifth instar duration with regard to B1 × B4 followed by B1 × B2 and FC2.

The short larval duration observed in B6 × B8 and B1 × B4 which might be likely due to higher feed consumption and faster metabolic rate, which plays a crucial in sericulture as it leads to faster growth and cocoon production, thereby increasing the efficiency of silk farming. This shorter duration reduces rearing costs, optimizes resource use and enables more frequent harvests, which can improve overall productivity and profitability. Additionally, it helps in better disease management and more predictable harvest cycles, contributing to a more sustainable and economically viable silk production process.

Fifth Instar Larval Weight (g/10 larvae)

Significant variations in fifth instar larval weight were observed across different foundation crosses (Table 1 and Fig. 1). The highest fifth instar larval weight was observed in B1 × B4 (37.37 g) followed by B1 × B2 (36.11 g) and least was observed in FC1 (32.88 g) followed by B6 × B8 (33.09g) and FC2 (35.62 g).

The present findings align with previous studies, where Thrilekha *et al.* (2024) reported that the hybrid B1 × B2 and FC2 were statistically on par with each other exhibited significantly highest fifth instar larval weight of 35.56 g/10 larvae and 35.24 g/10 larvae, respectively, followed by B1 × B4 (33.49 g/10 larvae). In contrast, B6 × B8 showed significantly least larval weight of 30.47 g/10 larvae, followed by FC1 (31.81 g/10 larvae). Bahar *et al*. (2011) who reported larval weight in the range 35-38 g for silkworms fed with different mulberry varieties and that of Keerthana (2018) and Sahana *et al*. (2021), where breeds B1, B2, B4 and hybrids B1 × B4, B4 × B1 and B1 × B8 (Jayashree, 2019) exhibited higher larval weight. Keerthana (2018), Sahana *et al*. (2021) and Chandrakala *et al*. (2022) found that the breeds B4, B2 and B1 showed improved fifth instar larval weight under laboratory conditions.

In the present study, the foundation crosses, B1 × B4 and B1 × B2 were found to perform better with respect to fifth instar larval weight in field conditions. This might be caused due to optimized genetic traits which enhanced nutrient assimilation and increased growth efficiency. The observed higher weight in high temperature and muscardine disease tolerant hybrids under field conditions.

Effective Rate of Rearing (%)

Highest ERR of 96.50 per cent was obtained in B1 × B4 followed by FC1 (95.20%) and B1 × B2 (94.22%) (Table 1). Least ERR was observed in FC2 (91.23%) followed by B6 × B8 (93.41%).

The results are consistent with earlier studies done by Simon *et al*. (2024) observed ERR of 58 and 62 per cent in FC1 and FC2, respectively. Naga Jyothi *et al.* (2010) recorded ERR of 77.6 per cent in Pure Mysore × NB_4D_2. Maske *et al.* (2020) observed ERR of 86.93, 89.47, 87.20 and 93.72 per cent in CSR2 × CSR4, S8 × CSR16, CSR50 × CSR5 and CSR16 × CSR17, respectively.

The effective rate of rearing was high in B1 × B2 and B1 × B4 suggesting that they excel in with standing high temperatures in the field. ERR is crucial for optimizing silk production, as it directly impacts the quantity and quality of silk harvested. A higher effective rearing rate means more silkworms reach the cocoon stage, enhancing yield and quality while improving resource use and reducing waste. It may be due to enhanced survivability and growth performance of B1 × B2 and B1 × B4 under specific environmental conditions. Enhanced performance of these hybrids indicates a potential pathway for developing hybrids with dual stress resistance capabilities.

Cocoon Yield by Number (No./10,000 larvae)

Among the five foundation crosses highest cocoon yield (No./10,000 larvae) was obtained in B1 × B4 (9633.33) followed by B1 × B2 (9200.00) and FC2 (9065.00) (Table 2). Least number of cocoons was

found in B6 × B8 (8060.00/10,000 larvae) followed by FC1 (8813.33/10,000 larvae).

In laboratory experiments significantly highest cocoon yield was exhibited by B1 × B2 (5,933.33/10,000 larvae) and B1 × B4 (5866.67/10,000 larvae) under muscardine infection (Thrilekha *et al.*, 2024). A higher cocoon yield by number in B1 × B4 and B1 × B2 under field rearing indicates the efficiency and productivity of silkworms in producing cocoons. Increased cocoon yield may also be due to higher ERR as observed in B1 × B4 and B1 × B2 foundation crosses, suggesting that the silkworms are well-suited to produce double hybrids with dual tolerance to temperature and muscardine disease tolerance.

Cocoon Yield by Weight (kg/10,000 larvae)

Cocoon yield in high temperature and muscardine disease tolerant silkworm foundation crosses exhibited significant variations under field conditions (Table 2). B1 × B4 produced significantly highest cocoon yield by weight of 17.43 kg per 10,000 larvae followed by FC2 (16.37 kg). The least cocoon yield by weight was observed in B6 × B8 (12.84 kg) followed by FC1 (14.29 kg) and B1 × B2 (16.32 kg). The results obtained align with the previous results. Under field conditions CSR18 × CSR19, CSR46 × CSR47 and CSR50 × CSR51 showed cocoon yield of 16.9, 18.6 and 20.9 kg/10,000 larvae, respectively (Naseema Begum *et al.*, 2014), CSR2 × CSR4 and CSR2 × CSR5 showed 19.14 and 18.26 kg/10,000 larvae, respectively (Mal Reddy *et al.*, 2014b) and S8 × CSR16 recorded 21 kg/10,000 larvae (Meenal *et al*., 2020).

The variation in cocoon yield observed among Thermotolerant bivoltine silkworm hybrids under field conditions can be linked to several factors, including breed-specific traits, genetic factors and innate immune responses. The consistent high cocoon yield (kg/10,000 larvae) recorded for hybrids B1 × B2 and B1 × B4 is likely due to enhanced genetic traits which optimize silk production, including the increased larval weight and size of silk gland, as well as overall larval health and growth, highlighting their potential to be used to produce double hybrids to manage dual stress factors effectively.

Single Cocoon Weight (g)

Single cocoon weight showed significant differences among foundation crosses under field conditions

Table 2

Cocoon yield and cocoon parameters of high temperature and muscardine disease tolerant bivoltine silkworm foundation crosses reared in the farmers field

Foundation crosses	Cocoon yield by number (Per 10,000 larvae)	Cocoon yield by weight (kg/ 10,000 larvae)	Single cocoon weight (g)	Shell weight (g)	Pupal weight (g)	Shell ratio (%)
B1 × B2	9200.00 ^{b}	16.32 ^{b}	1.77 ^{b}	0.36 ^{ab}	1.37 ^{b}	20.35 ^{a}
B1 × B4	9633.33 ^{a}	17.43 ^{a}	1.82 ^{a}	0.37 ^{a}	1.41 ^{ab}	20.59 ^{a}
FC2	9065.60 ^{b}	16.37 ^{b}	1.81 ^{a}	0.31 ^{c}	1.43 ^{a}	19.38 ^{b}
B6 × B8	8060.00 ^{d}	12.84 ^{d}	1.57 ^{d}	0.35 ^{b}	1.27 ^{c}	19.29 ^{b}
FC1	8813.33 ^{c}	14.29 ^{c}	1.62 ^{c}	0.31 ^{c}	1.29 ^{c}	19.10 ^{b}
F test	*	*	*	*	*	*
S. Em ±	72.42	0.24	0.02	0.004	0.02	0.10
CD @5%	204.26	0.67	0.05	0.01	0.05	0.28
CV (%)	4.70	8.95	5.04	6.05	6.51	2.96

*-Significant at 5 %; Figures with same superscript are statistically on par

(Table 2, Fig. 2 and Plate 2). Among the five foundation crosses highest single cocoon weight was observed in B1 × B4. (1.82 g) followed by FC2 (1.81 g) and B1 × B2 (1.77 g). Least value of 1.57 g was recorded in B6 × B8 followed by FC1 (1.62 g).

The results align with the laboratory performance of these breeds where B1 × B4 (1.89 g) and FC2 (1.85 g) were statistically on par with each other, followed by B1 × B2 (1.72 g). Whereas, significantly least cocoon weight of 1.34 g has obtained in B6 × B8 followed by FC1 (1.43 g) (Thrilekha *et al*., 2024).

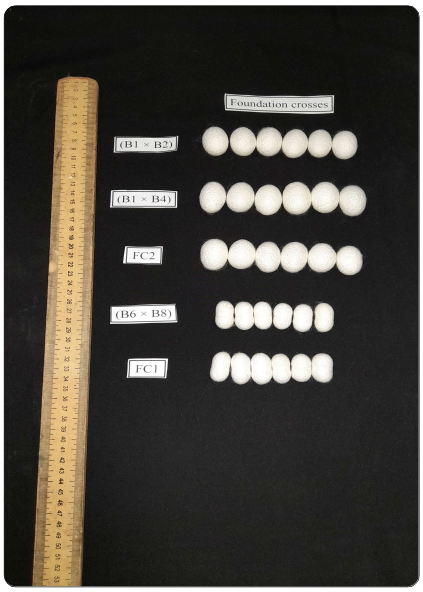


Plate 2 : Cocoons of foundation crosses of high temperature and muscardine disease tolerant bivoltine silkworm breeds in the farmers field

Field evaluation of CSR18 × CSR19, CSR46 × CSR47 and CSR50 × CSR51 (Naseema Begum *et al.*, 2014), CSR2 × CSR4 and CSR2 × CSR5 (Mal Reddy *et al.*,2014a) and CSR50 × CSR51, CSR16 × CSR17 and S8 × CSR16 (Thore *et al.* 2023) showed single cocoon weight of 1.853, 1.986, 2.170, 2.01, 1.99, 1.38, 1.31 and 1.20 g, respectively. Better performance exhibited by hybrids B1 × B4 and B1 × B2 is attributable to the genetic traits which lead to increased silk filament length and thickness, as well as enhanced silk gland development and overall larval growth. The higher single cocoon weight may also be due to increased larval weight of these foundation crosses that has contributed to spin heavier and denser cocoons. This emphasizes their potential to be used as promising foundation crosses to be used for producing double hybrids with dual advantage of thermotolerance and muscardine disease tolerance trait.

Shell Weight (g)

Significant differences were observed in shell weight under field conditions (Table 2 and Fig. 2). Among

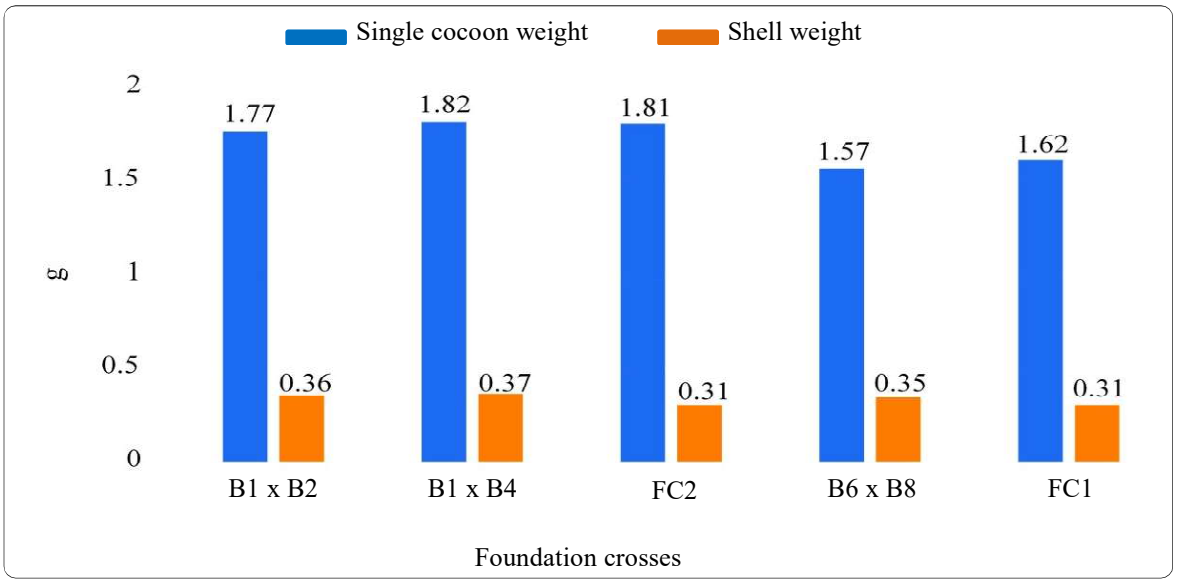


Fig. 2 : Single cocoon weight and shell weight of high temperature and muscardine disease tolerant bivoltine silkworm foundation crosses reared in the farmers field

the five foundation crosses highest shell weight was observed in B1 × B4. (0.37g) followed by B1 × B2 (0.36g) and B6 × B8 (0.35g). Least shell weight of 0.31g was recorded in both the hybrids *viz*., FC1 and FC2. The findings align with the laboratory studies conducted by Thrilekha *et al*. (2024) who recorded significantly highest shell weight of 0.37g in B1 × B4, followed by B1 × B2 (0.34) and FC2 (0.33 g) which were statistically on par with each other.

Field studies have shown shell weight of 0.393, 0.465 and 0.523g in CSR18 × CSR19, CSR46 × CSR47 and CSR50 × CSR51, respectively (Naseema Begum *et al.*, 2014), 0.472 and 0.474 g in CSR2 × CSR4 and CSR2 × CSR5, respectively (Mal Reddy *et al.*, 2014b) and 0.28, 0.30 and 0.26g in CSR50 × CSR51, CSR16 × CSR17 and S8 × CSR16, respectively. The hybrid CSR16 × CSR17 showed highest single shell weight of 0.312g (Bobade *et al*., 2019).

The variation in shell weight observed in field conditions can be linked to genetic differences, adaptability and the physiological responses of silkworm hybrids. Heavier larvae like, B1 × B4 and B1 × B2 have more stored nutrients and energy, enabling them to produce more silk. Notably, these hybrids, which exhibit the highest shell weight, highlight their potential as effective candidates for producing double hybrids.

Pupal Weight (g)

Significant differences were observed in pupal weight under field conditions (Table 2). Among five foundation crosses, FC2 recorded highest pupal weight of 1.43g followed by B1 × B4 (1.41g) and B1 × B2 (1.37g). Significantly least pupal weight was observed in B6 × B8 (1.27g) followed by FC1 (1.29g) wherein, both were statistically on par with each other.

The findings align with the laboratory performance of these foundation crosses. FC2 and B1 × B4 which were statistically on par with each other, recorded pupal weight of 1.49 g and 1.46 g, respectively, followed by B1 × B2 (1.32 g). Whereas, significantly least pupal weight was recorded in B6 × B8 (1.02g) followed by FC1 (1.08g) (Thrilekha *et al*., 2024). Akarsha *et al*. (2023) recorded pupal weight of 1.182, 1.272 and 1.407 g from three farmers' fields, respectively for CSR2 × CSR5.

High pupal weight as observed in FC2, B1 × B4 and B1 × B2 is a crucial factor in silk production due to its association with enhanced larval health and silk yield. Higher pupal weight of these foundation crosses is a consequence of heavier pupae, typically resulted from heavier larvae of FC2, B1 × B4 and B1 × B2, that have grown well, indicating they have had adequate nutrition during larval stage. In the present study higher pupal weight of FC2, B1 × B4 and B1 × B2 in the field rearing suggests greater resilience to environmental stresses and diseases, making it a valuable trait for using to produce double hybrids.

Shell Ratio (%)

Significant differences in the shell ratio were obtained among the various foundation crosses under field rearing (Table 2). Among the five foundation crosses B1 × B4 and B1 × B2 were statistically on par with each other, recorded significantly highest shell ratio of 20.59 and 20.35 per cent respectively, followed by FC2 (19.38 %), B6 × B8 (19.29%) and FC1 (19.10 %) which were all statistically on par.

The results are consistent with the laboratory performance of these foundation crosses, where B1 × B4 recorded significantly highest shell ratio of 23.60 per cent and significantly least shell ratio of 18.01 per cent in B6 × B8 (Thrilekha *et al*., 2024). Field evaluation of CSR18 × CSR19, CSR46 × CSR47 and CSR50 × CSR51 (Naseema Begum *et al.*, 2014), CSR2 × CSR4 and CSR2 × CSR5 (Mal Reddy *et al.*, 2014b) and CSR50 × CSR51, CSR16 × CSR17 and S8 × CSR16 (Thore *et al.*, 2023) showed shell ratio of 21.2, 23.4, 24.1, 23.5, 23.8, 21.84, 21.36 and 21.32 per cent, respectively. S8 × CSR16 performance in different locations of Karnataka, Andra Pradesh, Tamil Nadu showed higher shell ratio of 22.1, 22.2 and 21.7 per cent as against control CSR2 × CSR4 (20.6 %) (Meenal *et al*., 2020).

In the present study, high shell ratio was obtained in B1 × B4 and B1 × B2 which means more silk can be harvested from each cocoon. This can be probably attributed to genetic improvements in the silk gland function further, resulting in increased deposition of silk proteins. Economically, a higher shell ratio enhances the return on investment, making sericulture more profitable.

Pupation Rate (%)

Among the five foundation crosses, significantly high pupation rate of 97.31 per cent was observed in B1 × B4 followed by FC2 (96.79 %) and B1 × B2 (96.35 %) (Table 3). Least pupation rate was observed in B6 × B8 (95.16 %) followed by FC1 (95.36 %), which are statistically on par with each other.

In the field conditions pupation rate of 95.10, 95.60 and 96.30 per cent were obtained in CSR18 × CSR19, CSR46 × CSR47 and CSR50 × CSR51, respectively (Naseema Begum *et al*., 2014). Bhat *et al*. (2017) obtained pupation rate of 74.00, 92.30, 80.00, 83.00, 77.30, 74.30 and 76.00 per cent in SK3, SK6, CSR2, CSR4, CSR6, CSR18, CSR19 and CSR26, respectively.

High pupation per cent indicates that a large proportion of the larvae successfully transition from the larval stage to the pupal stage, reflecting effective rearing conditions and overall health of the silkworms. Higher pupation rate in B1 × B4 suggests that the silkworms are well-nourished and less stressed, which can lead to better-quality silk. Therefore, this foundation cross can be utilized for double hybrids production.

Moth Emergence (%)

Significant variation was observed in moth emergence per cent in the foundation crosses. (Table 3). Among the five foundation crosses significantly high moth emergence per cent of 94.60 was obtained in B1 × B4 followed by B1 × B2 (93.66%), FC2 (93.26%) and FC1 (91.93%), which were all statistically on par with each other. Least moth emergence per cent was obtained in B6 × B8 (88.86%).

In the present study higher moth emergence rate was observed in B1 × B4 followed by B1 × B2. This is likely attributable to the superior nutrient utilization and metabolic efficiency, that support robust growth and a higher success of metamorphosis of larvae and pupae, finally reaching the adult moth stage. A higher moth emergence rate suggests that these hybrids are well adapted to environmental conditions during rearing, such as temperature and humidity and

TABLE 3

Grainage performance of high temperature and muscardine disease tolerant bivoltine silkworm foundation crosses reared in the farmers field

Foundation crosses	Pupation rate (%)	Moth emergence (%)	Egg recovery (g/kg of cocoons)	Egg retention in ovary (%)
B1 × B2	96.35 ^{b}	93.66 ^{a}	51.11 ^{c}	5.19 ^{c}
B1 × B4	97.31 ^{a}	94.60 ^{a}	52.76 ^{b}	7.22 ^{b}
FC2	96.79 ^{ab}	93.26 ^{a}	52.33 ^{b}	6.35 ^{bc}
B6 × B8	95.16 ^{c}	88.86 ^{b}	55.24 ^{a}	10.49 ^{a}
FC1	95.36 ^{c}	91.93 ^{a}	54.56 ^{a}	9.61 ^{a}
F test	*	*	*	*
S. Em ±	0.33	1.03	0.24	0.52
CD @5%	0.94	2.93	0.68	1.48
CV (%)	1.57	5.13	2.62	8.60

*-Significant at 5 %; Figures with same superscript are statistically on par

efficiently metamorphosed. Therefore, these foundation crosses can be used to produce double hybrids to exploit various other traits.

Egg Recovery (g/kg of cocoons)

Among all the foundation crosses significantly highest egg recovery of 55.24 g/kg of cocoons was obtained in B6 × B8 followed by FC1 (54.56 g/kg of cocoons) (Table 3). Egg recovery of B1 × B4 (52.76 g/kg of cocoons) and FC2 (52.33 g/kg of cocoons) were statistically on par with each other. Least egg recovery was obtained in B1 × B2 (51.11 g/kg of cocoons). Jayappa and Dutta (2012) recorded egg recovery between 63.87 g to 69.32 g per kg of CSR2 silkworm seed cocoons.

High egg recovery in B6 × B8 followed by FC1 was obtained which is the consequence of a larger number of viable eggs available for hatching, leading to more larvae and potentially greater silk yield. Economically, higher egg recovery reduces losses and enhances profitability by ensuring a stable supply of larvae for cocoon production.

Egg Retention in Ovary (%)

Among all foundation crosses, the egg retention was significantly low in B1 × B2 (5.19 %), followed by FC2 (6.35%) and B1 × B4 (7.22 %) (Table 3). Highest egg retention was observed in B6 × B8 (10.49) followed by FC1 (9.61). Mathur *et al*. (1995) recorded egg retention of 2.22, 2.20 and 1.49 per cent during October - November, January - February and December - January, respectively in Nistari.

Low egg retention in the ovary as observed in B1 × B2, FC2 and B1 × B4 is typically owing to better reproductive efficiency and health in female moths. When egg retention is low, it means that the moths are effectively laying eggs rather than retaining them in the ovaries, leading to more efficient egg production and fewer issues related to egg quality or fertility. This results in a higher number of viable eggs available for hatching, which can improve overall silk yield and productivity.

The foundation crosses in sericulture are vital for establishing a genetically diverse base population of silkworms, which enhances adaptability, disease resistance and overall productivity. By selecting desirable foundation crosses for higher cocoon and raw silk yield, it is easy to contribute to the development of specific breeding lines tailored to local conditions. The current study has shown that two foundation crosses B1 × B2 and B1 × B4 have performed better in farmers field. Further, on station and large-scale trials will prove their adaptability in field conditions. Using these foundation crosses new double hybrids with dual advantage of high temperature and muscardine disease tolerance can be obtained, helping farmers with easy rearing thoughout the year.

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