***Original Research Article***

**Reeling and Raw Silk Assessment of New Bivoltine Silkworm Double Hybrids** **Tolerant to High Temperature and Muscardine Disease**

**ABSTRACT**

 The study was conducted to evaluate the reeling and raw silk quality characteristics of new bivoltine double hybrids of *Bombyx mori* L. tolerant to high temperature and muscardine disease. Three double hybrids (B1 × B2) × FC1, (B1 × B4) × FC1 and FC2 × (B6 × B8) along with the control FC2 × FC1 double hybrid, were assessed across fifteen farmers’ fields. Cocoon and raw silk parameters were evaluated using standard protocols at the Central Silk Technological Research Institute (CSTRI), Bengaluru. (B1 × B4) × FC1 exhibited superior traits for maximum parameters like average and non-breakable filament length (m), renditta, minimum standard size deviation, (B1 × B2) × FC1 excelled in reelability (%), elongation (%) tenacity (g/d), evenness variation, while FC2 × (B6 × B8) in cleanness (%) and neatness (%) with overall grade range 2A-A among the double hybrids. The findings highlight the commercial potential of these hybrids in tropical sericulture, offering enhanced raw silk quality and resilience against climatic and pathogenic stresses, thereby contributing to sustainable silk production.

**Key words:** Quality parameters, raw silk, major tests, auxiliary tests, high temperature, muscardine, double hybrids.

1. **INTRODUCTION**

The mulberry silkworm *B. mori* holds significant cultural, economic and scientific value. India, being a tropical nation, relies primarily on Multivoltine × Bivoltine hybrids which often fall short of international quality standards due to the inferior silk quality. Therefore, shift toward bivoltine sericulture is crucial for producing raw silk that meets global benchmarks (Datta and Pershad, 2002). The bivoltine silkworm breeds are known for producing superior quality silk; however, their performance is often constrained under tropical field conditions due to high temperatures and disease susceptibility. To overcome these limitations, breeding efforts have focused on developing bivoltine double hybrids with enhanced tolerance to high temperature and muscardine disease (Keerthana, 2018; Jayashree *et al*., Sahana *et al*., 2021; Chandrakala *et al*., 2022; Manjunatha *et al*., 2023; Thrilekha *et al*., 2024) and three new bivoltine double hybrids *viz*., (B1 × B2) × FC1, (B1 × B4) × FC1 and FC2 × (B6 × B8) were identified to be high temperature and muscardine disease tolerant. Field evaluation of these hybrids was undertaken and assessed for rearing parameters along with the control FC2 × FC1 double hybrid.

As the success of sericulture depends on the major component that is the quality of silk obtained, raw silk assessment becomes crucial step. The silk quality directly influences the market value and end-use of silk fabrics. The main objective of raw silk testing is to determine the quality of silk and determine the grade for establishing the standard (Kadhar *et al*., 2013). Therefore, reeling performance and raw silk quality assessment was carried out at CSTRI, CSB, Bengaluru with objective of identifying double hybrids with superior commercial characteristics.

1. **MATERIAL AND METHODS**

The study was conducted using thermotolerant bivoltine silkworm breeds *viz*., B1, B2, B4, B6 and B8 procured from Central Sericultural Research and Training Institute, Mysore which were identified as muscardine tolerant from the previous studies. The double hybrids (B1× B2) × FC1, (B1 × B4) × FC1 and FC2 × (B6 × B8) and their control FC2 × FC1 were reared in the fifteen farmers field covering Tumakuru and Chikkaballapura Districts of Karnataka, such that five farmers each were provided with 20 dfls each of one double hybrid and its control. Three and half kilogram cocoons were collected from selected farmers to assess cocoon and raw silk parameters. The cocoons were stifled in hot air oven at 80°C for three hours and shade dried. These cocoons were brought to the Central Silk Technological Research Institute (CSTRI), Central Silk Board, Bengaluru, to assess reeling performance *viz*., average filament length (m), non-breakable filament length (m), filament denier, reelability (%) and renditta and raw silk quality parameters *viz*., standard size deviation, evenness variation-I, II,III (stripes), cleanness (%), average neatness (%), low neatness (%), maximum deviation, tenacity (g/d), elongation (%), cohesion (strokes) and finally the overall grade for assigned to the raw silk. The data on cocoon parameters were statistically analysed using completely randomized design with 15 replications (farmers) and four treatments (Sundarraj *et al*., 1972). Analysis of variance was performed using OPSTAT software (Sheoran *et al*., 1998). The mean values of the experiments were compared by using Duncan’s Multiple Range Test (DMRT) (Duncan, 1955).

1. **RESULTS AND DISCUSSION**
	1. **Cocoon parameters**

The double hybrid (B1 × B4) × FC1 showed higher value for single cocoon weight (2.68 g), shell weight (0.46 g) and shell ratio (21.70 %) followed by (B1 × B2) × FC1 for shell ratio (20.15 %), FC2 × FC1 for single cocoon weight (1.92 g) and shell weight (0.38 g). Similar results were obtained in laboratory performance where (B1 × B4) × FC1 recoded higher single cocoon weight (2.01 g), shell weight (0.42 g) and shell ratio (21.45 %). These results indicate superior cocoon parameters of (B1 × B4) × FC1 and (B1 × B2) × FC1 which can be attributed to more efficient nutrient utilization during the fifth instar stage and their overall genetic potential.

**3.2 Average filament length (AFL) (m)**

Among the tested double hybrids (B1 × B4) × FC1 recorded highest AFL of 1084.50 m followed by FC2 × (B6 × B8) (1046.00 m). The results are in consistent with earlier studies where Thrileka *et al*. (2024) recorded average filament length of 1487.96 and 1476.00 in (B1 × B2) × (FC1) and (B1 × B4) × (FC1) respectively. A new bivoltine double hybrid for sub-optimal conditions, G11 × G19 recorded average filament length of 756-914, 741-810 and 827-1011 m in Karnataka, Tamil Nadu and Andra Pradesh, respectively (Sivaprasad *et al.,* 2018b). Higher average filament length recorded in (B1 × B4) × FC1, can be attributed to higher quantity of silk filament spun by silkworms. A higher shell weight as observed for these double hybrids, often indicates a larger reserve of silk protein, which can result in longer filament lengths during the reeling process. This quality is highly valued in the textile industry for making beautiful and durable clothing and other products.

**Table 1. Reeling performance of high temperature and muscardine disease tolerant bivoltine silkworm double hybrids reared in the farmer’s field**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Double hybrids** | **SCW** | **SW** | **SR** | **AFL** | **NBFL** | **SCFD** | **RL** | **R** |
| (B1 × B2) × FC1 | 1.86 | 0.37 | 20.15 | 898.00 | 798.00 | 2.44 | 89.10 | 6.60 |
| (B1 × B4) × FC1 | 2.01 | 0.42 | 21.45 | 1084.50 | 947.00 | 2.42 | 88.70 | 6.35 |
| FC2 × (B6 × B8) | 1.80 | 0.33 | 18.90 | 1046.00 | 863.00 | 2.22 | 84.60 | 6.90 |
| FC2 × FC1 | 1.92 | 0.38 | 20.02 | 993.25 | 861.25 | 2.65 | 88.30 | 6.55 |

Note: SCW: Single cocoon weight (g); SW: Shell weight (g); SR: Shell ratio (%); AFL: Average Filament Length (m); NBFL: Non-breakable filament length; SCFD: Single Cocoon Filament Denier; RL: Reelability (%) and R: Renditta

**3.3 Non-breakable filament length (m)**

Among the tested double hybrids for non-breakable filament length, (B1 × B4) × FC1 recorded highest value of 947.00 m followed by FC2 × (B6 × B8) (863.00 m). The results align with the previous studies where a new bivoltine double hybrid for sub-optimal conditions, G11 × G19 recorded non-breakable filament length of 504-681, 616-690 and 666-780 m in samples from Karnataka, Tamil Nadu and Andra Pradesh, respectively (Sivaprasad *et al.,* 2018b). Chattopadhyay *et al.* (2018) recorded non-breakable filament length of 521.50 and 451.30 m in (CSR2 × CSR4) and cross breed, respectively. High non-breakable filament length in (B1 × B4) × FC1, indicates optimized expression and function of fibroin and sericin proteins and enhanced enzymatic activity in the silk gland, facilitating the formation of longer and more cohesive silk fibres with reduced risk of breaks. Longer filaments mean fewer breaks and join in the silk thread, leading to better quality and more luxurious fabrics. This strength not only contributes to the fabric's resilience and durability but also allows for the creation of finer, more luxurious textiles with fewer seams or joints.

**3.4 Single cocoon filament denier**

Among the tested double hybrids, FC2 × FC1 recorded highest single cocoon filament denier of 2.65 followed by (B1 × B2) × FC1 (2.44). The results align with the laboratory results where FC2 × FC1 produced significantly highest cocoon denier of 2.94, followed by (B1 × B2) × (B6 × B8) (2.80) (Thrilekha *et al.*,2024). Chattopadhyay *et al.* (2018) recorded denier of 2.4 and 2.5 in (CSR2 × CSR4) and cross breed, respectively. Kalpana *et al.,* (2005) recorded denier of 2.90, 2.45, 2.47 in CSR2 × CSR5, CSR18 × CSR19 and CSR48 × CSR5 hybrids, respectively. Cocoon denier is crucial in silk production as it measures the thickness of the silk threads. FC2 × FC1 recorded higher denier, followed by (B1 × B2) × FC1, (B1 × B4) × FC1, which can be likely due to the increased fibroin production and higher protein concentration within the gland, leading to thicker and denser filaments. This impacts the durability and quality of the silk, making higher denier silk more suitable for robust, high-quality textiles and potentially commanding a higher market price however, finer and higher quality filaments are more preferred ones for most silk fabric.

**Fig. 1. Average filament length and non-breakable filament length of high temperature and muscardine disease tolerant bivoltine silkworm double hybrids**

0

200

400

600

800

1000

1200

(B1 × B2) × FC1

(B1 × B4) × FC1

FC2 × (B6 × B8)

FC2 × FC1

Meters (m)

Double hybrids

Average Filament Length (m)

Non-Broken Filament Length (m)

**3.5 Reelability (%)**

Among the tested double hybrids for (B1 × B2) × FC1 recorded highest value of 89.10 per cent for reelability, followed by (B1 × B4) × FC1 (88.70 %). Reelability percentage of silk cocoons is a critical measure of how effectively the silk can be unwound and processed into usable thread. A high reelability percentage in (B1 × B2) × FC1 indicates that, a large proportion of the silk from the cocoon can be successfully reeled into continuous threads without breakage or significant defects, which enhances the quality and yield of the final silk product. This metric is vital for determining the efficiency and economic viability of silk production, as higher reelability translates to better-quality silk and lower waste during processing. Consequently, it influences both the practical aspects of silk manufacturing and its market value.

**3.6 Renditta**

Among the tested double hybrids (B1 × B4) × FC1 recorded least renditta of 6.35, followed by FC2 × FC1 (6.55) The results are consistence with earlier studies. Sivaprasad *et al.* (2018a) recorded average renditta of 6.0 in TT21 × TT56. Chandrakanth *et al.* (2021) recorded renditta of 6.5-7.0 in WB-DH (WB 1.3 × WB 7.5). Kalpana *et al.* (2005) recorded renditta of 5.13, 6.66 and 5.30 in CSR2 × CSR5, CSR18 × CSR19 and CSR48 × CSR5 hybrids, respectively. Rendita, defined as number of kg of cocoon producing 1 kg of raw silk. A lower renditta in (B1 × B4) × FC1 indicates that, the cocoons are producing greater and higher quality yarn. Therefore, for the success of sericulture industry lower renditta becomes advantageous.

**3.7 Major quality characteristics of raw silk of new bivoltine double hybrids of high temperature and muscardine disease tolerant silkworm breeds reared in the farmers field**

**3.7.1 Standard size deviation**

Among the tested double hybrids standard size deviation of 1.60 was recorded both in (B1 × B2) × FC1 and (B1 × B4) × FC1. Kalpana *et al.* (2005) recorded standard size deviation of 1.10, 1.30 and 0.98 in CSR2 × CSR5, CSR18 × CSR19 and CSR48 × CSR5 hybrids, respectively. The standard size deviation of silk is crucial for assessing the uniformity and quality of silk production. This metric quantifies the variation in fibre diameter, which directly effects the silk's strength, texture and overall appearance. A lower standard deviation of (B1 × B2) × FC1 and (B1 × B4) × FC1 indicates more consistent fibre size, resulting in smoother and more luxurious fabrics with fewer defects.

**3.7.2 Evenness variation-I and II (Stripes)**

The Evenness variation-I measures the intensity of variation greater than the V0 panel but does not exceed V1 panel of the Standard Variation Photographs. (B1 × B2) × FC1 recorded lower value (13.5 stripes), followed by (B1 × B4) × FC1 (16.00 stripes). Evenness variation-II (the intensity of variation greater than the V1 panel but does not exceed the V2 panel of the Standard Variation Photographs) was 1.00 and 2.00 stripes in (B1 × B2) × FC1 and (B1 × B4) × FC1, respectively. Kalpana *et al.* (2005) recorded Evenness variation I of 10, 14 and 17 stripes, Evenness variation II and III as zero stripes in CSR2 × CSR5, CSR18 × CSR19 and CSR48 x CSR5, respectively. Lower values in FC2 × (B6 × B8) and (B1 × B2) × FC1 indicate more uniform fibres, leading to smoother and more aesthetically pleasing fabrics with fewer defects and improved performance.

**3.7.3 Cleanness (%)**

Cleanness test conducted to ascertain super major defects, major defects and minor defects using seriplane. Each defect carries penalty points and the difference of the total penalty points from 100 gives the test result. This pertains to the removal of impurities such as sericin (the natural gum), foreign particles and debris from the raw silk. Among the four double hybrids higher cleanness was recorded in FC2 × (B6 × B8) (99.00 %) followed by (B1 × B4) × FC1, indicates enhanced silk's sheen, softness and overall aesthetic appeal, while also improving its dyeing and finishing processes.

**3.7.4 Average neatness and low neatness (%)**

Imperfection in raw silk yarn, which are smaller than those described as minor cleanness defects are known as neatness defects. Among all the double hybrids FC2 × (B6 × B8) showed 100 per cent average neatness, followed by (B1 × B4) × FC1 (97.50 %). The low neatness also followed same order with highest value in FC2 × (B6 × B8) (98.00 %) and (B1 × B4) × FC1 (94.00 %). Bindroo *et al.* (2014) recorded neatness of 94, 95 and 94 per cent, respectively in Krishnaraja, Jayachamaraja and CSR2 × CSR4, respectively. A new bivoltine double hybrid for sub-optimal conditions, G11 × G19 recorded neatness of 94-96, 91-93 and 90-97 per cent, when tested in Karnataka, Tamil Nadu and Andra Pradesh, respectively (Sivaprasad *et al.,* 2018b). Higher neatness recorded in FC2 × (B6 × B8) and (B1 × B4) × FC1 directly impacts the fabric’s visual appeal and tactile qualities, leading to a smoother, more lustrous surface. It also ensures that, the silk has a consistent feel and drape, which is crucial for high-quality textile products.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Double hybrids** |  |  | **Major tests\*** |  |  |  |  |  **Auxiliary tests\***  |  |  | **Overall grade** |
| **SZD**  | **EV-I**  | **EV-II**  | **CL**  | **ANE**  | **LNE**  | **MD**  | **EV-III**  | **WB**  | **T**  | **E**  | **C**  |
| (B1 × B2) × FC1 | 1.60 | 13.50 | 1 | 96.50 | 96.00 | 91.50 | 3.15 | 0 | 1.50 | 3.85 | 20.00 | 79.00 | 2A |
| (B1 × B4) × FC1 | 1.60 | 16.00 | 2 | 97.00 | 97.50 | 94.00 | 2.60 | 0 | 2.00 | 3.80 | 19.50 | 82.50 | 2A |
| FC2 × (B6 × B8) | 1.70 | 24.00 | 0 | 99.00 | 100.00 | 98.00 | 2.60 | 0 | 4.00 | 3.75 | 19.00 | 77.50 | A |
| FC2 × FC1 | 1.70 | 24.80 | 0 | 96.20 | 94.40 | 90.60 | 2.90 | 0 | 5.00 | 3.70 | 18.80 | 69.00 | 2A |

**Table 2. Quality characteristics of raw silk of high temperature and muscardine disease tolerant bivoltine silkworm double hybrids reared in the farmers field**

\*-Raw silk reeled at CSTRI, Bengaluru

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|  |  |
| --- | --- |
| SZD: Standard size deviation EV-I: Evenness variation-I (Stripes) EV-II: Evenness variation-II (Stripes) CL: Cleanness (%) ANE: Average neatness (%) LNE: Low neatness (%)  | MD: Maximum deviation EV-III: Evenness variation-III (Stripes) WB: Winding breaks/10 Skeins/hr T: Tenacity (g/d) E: Elongation (%) C: Cohesion (Strokes)  |

**3.8 Auxiliary quality characteristics of raw silk of bivoltine double hybrids of high temperature and muscardine disease tolerant silkworm breeds reared in the farmers field**

**3.8.1 Maximum deviation**

Among the double hybrids least maximum deviation was obtained in (B1 × B4) × FC1 and FC2 × (B6 × B8) both with value 2.60 followed by FC2 × FC1 (2.90). Kalpana *et al.,* (2005) recorded maximum deviation of 2.90, 3.00 and 1.32 in CSR2 × CSR5, CSR18 × CSR19 and CSR48 × CSR5 hybrids, respectively. Maximum deviation measures the largest discrepancy in fibre diameter or other properties from the average value, highlighting the extent of variability in the silk batch. A low maximum deviation recorded in (B1 × B2) × FC1 and (B1 × B4) × FC1 indicates that the fibres are more uniform, contributing to a higher quality, smoother and more reliable fabric.

**3.8.2 Evenness variation -III (Stripes)**

Evenness variation-III (EV-III) measures the intensity of variation, which includes all the variations greater than the V2 panel of the Standard Variation Photographs. Kalpana *et al.* (2005) recorded no evenness variation-III in CSR2 × CSR5, CSR18 × CSR19 and CSR48 × CSR5 hybrids, respectively. Unlike Evenness variation-I and II, which examine short range and inter-fibre inconsistencies, EV-III captures broader variations that can affect the overall consistency of the fabric. A lower EV-III value indicates that, the silk fibres have more consistent thickness across extended lengths.

**3.8.3 Winding breaks (No./10 Skeins/h)**

The winding breaks/10 Skeins/hr (recorded using winding frame, wheels and bobbins) was least in (B1 × B2) × FC1 (1.5 breaks/10 Skeins/h) followed by (B1 × B4) × FC1 (2.0 breaks/10 Skeins/h). Nguku *et al.* (2016) recorded winding breaks/10 Skeins/h of 4, 3 and 6 in three strains *viz*. ICIPE I, ICIPE II and (Chun-Lei × Zheng Zhu), respectively. Kalpana *et al.,* (2005) recorded winding breaks of 4, 4 and 6 breaks/40skeins/h in CSR2 × CSR5, CSR18 × CSR19 and CSR48 × CSR5 hybrids, respectively. Low rates of winding break in (B1 × B2) × FC1 result in lower waste and minimise costs for rework, ensuring a high-quality product and a cost-effective, streamlined manufacturing process.

**3.8.4 Tenacity (g/d) and Elongation (%)**

Tenacity and elongation were recorded using serigraph, sizing reel and scale. Among all the hybrids, tenacity was high in (B1 × B2) × FC1 (3.85 g/d), followed by (B1 × B4) × FC1 (3.80 g/d), indicating the fibre's strength, specifically its ability to withstand tensile stress before breaking. The elongation percentage was high in (B1 × B2) × FC1 (20.0 %), followed by (B1 × B4) × FC1 (19.50). Kalpana *et al.,* (2005) recorded elongation 20.50, 20.98 and 22.32 per cent in CSR2 × CSR5, CSR18 × CSR19 and CSR48 × CSR5 hybrids, respectively. Higher elongation value attributes to the fibre's ability to stretch under tensile stress before breaking. This property is significant because it determines the flexibility and resilience of the silk fabric.

**3.8.5 Cohesion (strokes)**

The cohesion test is used to find the number of frictions required to split silk thread for the purpose of examining the state of cocoon filaments sticking together, using Duplan cohesion tester. The result showed that (B1 × B4) × FC1 recorded high value (82.50 strokes) followed by (B1 × B2) × FC1 (79.00 strokes). Kalpana *et al.* (2005) recorded cohesion of 90, 66 and 110 strokes in CSR2 × CSR5, CSR18 × CSR19 and CSR48 × CSR5 hybrids, respectively. Higher strokes as in (B1 × B4) × FC1, refers to the strong internal bonding between individual silk fibres within a filament.

**3.8.6 Overall grade**

The overall grade of 2A was obtained for three double hybrids *viz.,* (B1 × B2) × FC1, (B1 × B4) × FC1 and FC2 × FC1 and grade A for FC2 × (B6 × B8). Bindroo *et al.* (2014) recorded raw silk grade of 2A-3A in Jayachamaraja. A new bivoltine double hybrid for sub-optimal conditions, G11 × G19 recorded raw silk grade of A-2A, 2A and 2A when reared in Karnataka, Tamil Nadu and Andra Pradesh, respectively (Sivaprasad *et al.,* 2018b). The significance of a high silk grade has direct impact on the quality, value and usability of the final product. High silk grade indicates superior fibre characteristics, such as greater fineness, uniformity, strength and lustrous appearance.

1. **CONCLUSION**

The evaluation of bivoltine double hybrids developed for high temperature and muscardine disease tolerance under farmers’ field conditions revealed promising performance in key raw silk quality parameters. Among the tested hybrids, (B1 × B4) × FC1 and (B1 × B2) × FC1 consistently exhibited various superior traits such as longer filament length, reelability, lower standard size deviation, fewer winding breaks, higher tenacity, and better elongation, highlighting their uniformity, strength, and resilience achieving Grade 2A silk. FC2 × (B6 × B8) stood out with excellent cleanness and neatness, which is highly desirable for high-end fabric production. Overall, the hybrids demonstrated good adaptability and raw silk quality under field conditions, making them suitable candidates for commercial exploitation in tropical sericulture regions. The results affirm the potential of these hybrids to meet both the productivity and quality demands of the silk industry while withstanding environmental and pathogenic stresses.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Author(s) hereby declares that NO generative AI technologies such as large language models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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