

Comprehensive assessment of pivotal silkworm races for economic traits in Jammu and Kashmir, India

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ABSTRACT: The present study aims for a comparative study including performance and stability of parental lines Shogetsu Hosho, Shunrei Shogetsu and N124xC124. The economic traits of the three selected silkworm races evaluated revealed that fecundity in Shogetsu Hosho ranged from 424 to 600 eggs, in Shunrei Shogetsu it was 478–611 and in N124xC124 it ranged 438–565. The effective rate of rearing (ERR) in Shogetsu Hosho ranged from 11.74 to 15.64 kg, while in Shunrei Shogetsu it was 13.16–17.57 and in N124xC124 it ranged 11.99–16.65 kg. Single cocoon weight (SCW) was in the range of 1.38–1.62, 1.50–1.98, 1.44–1.95 g, respectively for Shogetsu Hosho, Shunrei Shogetsu and N124xC124 races. The single shell weight (SSW) ranged from 0.28 to 0.34 g in Shogetsu Hosho, 0.30–0.38 g in Shunrei Shogetsu and 0.27–0.31 g in N124xC124 races. The silk ratio percentage (SR%) was in the range of 18.18–22.37, 17.51–20.65, 14.36–20.96, respectively for Shogetsu Hosho, Shunrei Shogetsu and N124xC124 races. All races exhibited a moderate range of egg-laying capacity, with Shunrei Shogetsu showing the highest potential (up to 611 eggs per month), followed by Shogetsu Hosho (up to 600) and N124xC124 (up to 565). Multiple trait evaluation index (MTEI) values of the three races were found to be in the order of Shunrei Shogetsu followed by Shogetsu Hosho and N124xC124. Stability varied among traits and silkworm races. N124xC124 was found to be stable (value close to one) for fecundity (0.81) and SCW (1.06), while Shogetsu Hosho showed stability for ERR (0.99). The Francis coefficient of variation for fecundity placed Shunrei Shogetsu in the fourth quadrant, indicating a higher mean with low variation, followed by Shogetsu Hosho in the third quadrant (high mean and high variation) and N124xC124 in the first quadrant (low mean and low variation), indicating comparatively greater stability in Shunrei Shogetsu. Similarly, for ERR, N124xC124 appeared in the fourth quadrant, followed by Shunrei shogetsu (third quadrant) and Shogetsu Hosho (second quadrant). For SCW, the order was Shunrei Shogetsu (third quadrant) and both N124xC124 and Shogetsu Hosho in the first quadrant. In the case of SSW, Shunrei Shogetsu occupied the third quadrant, Shogetsu Hosho spanned the second and third quadrants and N124xC124 was in the first quadrant. For SR, Shunrei Shogetsu was in the fourth quadrant, followed by Shogetsu Hosho (third quadrant) and N124xC124 (second quadrant). Overall, Shunrei Shogetsu showed better stability across most traits, followed by Shogetsu Hosho and N124xC124. However, when all three methods used are ranked according to the traits, ranked according to Shogetsu Hosho, followed by Shunrei Shogetsu and N124XC124. © 2025 Association for Advancement of Entomology

KEY WORDS: Silkworm, bivoltine, evaluation, traits, stability

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INTRODUCTION

Sericulture, a vital agro-based industry, significantly boosts many economies. This is largely because silk holds major commercial importance in textiles and mulberry silkworms, which produce over 95 per cent of the world's silk. India currently stands in second position in silk production where an increase in the bivoltine silk has made a huge impact on the economic growth. In financial year 2024-25 alone, India produced about 10,160 MT of bivoltine silk. The raw silk production of bivoltine silk 1995-96 was about 475 MT. The CAGR growth year by year from 1995, stands at 11.14 per cent. The remarkable growth of the bivoltine silk was influenced by the various mulberry, silkworm breeding programmes and extensive extension programmes bringing awareness among the farmers who previously preferred multivoltine or cross breed (GoI, 2013, 2024; Bavachikar *et al.*, 2023; Londhe and Chougale 2022; CSB 2024, NAAS 2024).

The strategic utilization of three pivotal parental races, namely Shogetsu Hosho, Shunrei Shogetsu and N124xC124, has played a pivotal role in propelling India to a dominant position in bivoltine silk production. The subsequent development of bivoltine single hybrids, such as SH6xNB4D2 in the northern states and CSR double hybrids in the southern states, has further bolstered India's standing in the global silk industry. These three foundational parental races were instrumental in the creation of highly promising breeds like SH6 (Shogetsu Hosho), CSR2, CSR5, CSR6 (Shunrei Shogetsu), NB4D2, NB18 and KA (N124xC124). Moreover, these foundational breeds were employed in the development of advanced races, including CSR4, CSR8 (SL), CSR12 and the most recent Gen2 and Gen3, where NB4D2, KA, CSR5 and CSR2 played vital roles as parental components (Bindroo *et al.*, 2014). The impact of these evolved races has extended to hybrid evaluation programs, culminating in the release of influential hybrids such as CSR double hybrids, SH6xNB4D2 and CSR2xCSR4 into the field. These identified hybrids have significantly contributed to the sustained growth of bivoltine silk production for over two decades, marking a substantial stride in India's silk industry.

In general, use of three parental lines has brought a remarkable growth to bivoltine sericulture industry of the country which was previously known for multivoltine silk. Currently, the usage of the three parental races is restricted to germ plasm programmes. Economic traits stability analysis in breeding refers to the evaluation of the stability of economically important traits over time and across different environments. This analysis helps breeders understand how well the genetic makeup of a population will persist and remain consistent over time and in different environments. The changed environmental variables due to climate change pose a challenge to breeders in order to identify a stable breed/ hybrid for a stable crop. The present study aims for a comparative study including performance and stability of the three parental lines discussed above.

MATERIALS AND METHODS

The three silkworm races were reared during five spring seasonal rearing under recommended rearing conditions (Krishnaswami 1978; 1983). First to third instar larvae were fed KNG and Ichinose mulberry varieties (27- 28°C; 85-90% RH) and fourth and fifth instars with Goshierami leaves (24-26 °C; 70-80% RH). The three races were reared in three replications, with 250 larvae retained after the third moult. At the end of fifth instar, mature larvae were manually collected and transferred to collapsible plastic mountages for spinning. Rearing parameters were subsequently assessed using the following equations.

Fecundity: Number of late born larva+ number of unfertilized eggs + number of dead eggs + number of colors changed eggs+ number of larvae brushed

$$\text{ERR (kg)} = \frac{\text{Weight of cocoon harvested/}}{\text{Number of worms retained after 3rd moult}} \times 10,000$$

$$\text{SCW (g)} = \frac{\text{Weight of 10 cocoons (g)}}{10}$$

$$\text{SSW (g)} = \frac{\text{Weight of 10 cocoon shells (g)}}{10}$$

$$\text{SR\%} = \frac{\text{Single cocoon shell weight (g)}}{\text{Single cocoon weight (g)}} \times 100$$

The multi trait evaluation index (MTEI) was computed using the formula specified by Mano et al. (1993).

$$\text{MTEI} = \frac{(A-B)}{(C \times 10)} + 50$$

Where: *A*: value obtained for a specific trait of a given race; *B*: mean value of the same trait across all the considered race; *C*: standard deviation of the particular trait across all the considered race; 10 and 50: standard unit and fixed value.

Stability parameters were measured using three parameters: Francis variation coefficient (CV_i), Eberhart and Russell regression coefficient (B_i) by following equations (1966).

Eberhart and Russell (Regression coefficient): When the regression coefficient of a hybrid is one (B_i = 1), it is considered stable and exhibits a unit response. Eberhart and Russell proposed a model to assess the behavior of cultivars, which was utilized for the evaluation in this case. The model is described as follows:

$$B_i = \frac{\sum_j (Y_{ij} - \bar{Y}_i - \bar{Y}_j + \bar{Y}_{..})(\bar{Y}_j - \bar{Y}_{..})}{\sum_j (\bar{Y}_j - \bar{Y}_{..})^2}$$

Francis variation coefficient: The stability dataset was evaluated as per the Francis and Kannenberg based on the coefficient of variation, mean yield and environmental variance. The stability model by Francis and Kannenberg expressed by the following equation. A race is considered stable if it has a large mean yield and a small coefficient of variation.

$$CV_i = \left(\frac{\sum_j (Y_{ij} - \bar{Y}_i)^2}{\frac{s-1}{\bar{Y}_i}} \right) \times 100$$

RESULTS AND DISCUSSION

The economic traits of the three selected silkworm races evaluated in the present study revealed that fecundity in Shogetsu Hosho ranged from 424 to

600 eggs, in Shunrei Shogetsu it was 478–611 and in N124xC124 it ranged 438–565 (Fig. 1). The yield per 10,000 larvae by weight in Shogetsu Hosho ranged from 11.74 to 15.64 kg, while in Shunrei Shogetsu it was 13.16–17.57 kg and in N124xC124 it ranged 11.99–16.65 kg (Fig. 2). SCW was in the range of 1.38–1.62, 1.50–1.98, 1.44–1.95g, respectively for Shogetsu Hosho, Shunrei Shogetsu and N124xC124 races (Fig. 3). The SSW ranged from 0.28 to 0.34g in Shogetsu Hosho, 0.30–0.38g in Shunrei Shogetsu and 0.27–0.31g in N124xC124 races (Fig. 4). The SR percentage was in the range of 18.18–22.37, 17.51–20.65, 14.36–20.96, respectively for Shogetsu Hosho, Shunrei Shogetsu and N124xC124 races (Fig. 5). All races exhibited a moderate range of egg-laying capacity, with Shunrei Shogetsu showing the highest potential (up to 611 eggs per month), followed by Shogetsu Hosho (up to 600) and N124xC124 (up to 565). As with fecundity, a range of cocoon yield was observed across all races. Shunrei Shogetsu again exhibited the highest potential, indicating its suitability for higher production, followed by N124xC124 and Shogetsu Hosho. Considerable variation was also recorded in cocoon characters, with the highest average values for single cocoon weight, shell weight and shell ratio observed in Shunrei Shogetsu, followed by Shogetsu Hosho and N124xC124 (Figs. 1–5).

This study focused on five key economic traits of silkworms: fecundity, cocoon weight, shell weight and shell ratio. These traits significantly impact various micro-industries within sericulture. In silkworm breeding programs, a well-established approach involves employing a MTEI. This index considers the combined value of multiple traits, providing a more comprehensive picture of a silkworm race's performance. MTEI is a widely used methodology in Japan and elsewhere (Mano et al., 1993; Singh and Subba Rao 1993). The evaluation index values calculated as per Mano index among the traits varied considerably where, the cumulative evaluation index values of the three races were found to be in the order of Shunrei Shogetsu followed by Shogetsu Hosho and N124xC124 (Table 1).

Shunrei Shogetsu demonstrated a balanced performance across different metrics in fecundity, ERR, SCW, SSW and SR, while in Shogetsu Hosho. It's important to note that MTEI assigns a single index value based on a pre-determined weighting system for each trait tailored to the specific breeding goals. However, in general silkworm breeders refrain from using the evaluation index since use of evaluation index for negative traits is a major problem. By incorporating additional relevant indices, we can create a more nuanced picture of a race's suitability for different breeding objectives within the sericulture industry.

The riddle for a silkworm breeder resides in the management of important economic traits as there are several economic traits where some are positively correlated with each other while some are negatively correlated. Economic traits related to fecundity includes important interconnected traits such as number of larvae hatched and number larvae brushed, late born larvae. These associated economic traits concern with the industry involving silkworm egg production and chawki rearing centres where high fecundity is a desirable trait to maximise the egg production (Ullal and Narashimhanna, 1981; Mirhosseini *et al.*, 2005; Singh *et al.*, 2011; Neshagaran *et al.*, 2014).

Similarly, cocoon weight and its associated traits concern sericulture famers, where higher number of cocoons and weight defines the economy of farmer. The cocoon weight represents several associated economic traits such as pupation rate indicating survivability, cocoon weight comprising weight of pupa and shell (Ksham *et al.*, 1995; Mirhosseini *et al.*, 2005; Neshagaran *et al.*, 2014). Further, the shell weight has an association with post cocoon sector which has a correlation with the associated traits such as length of silk spun by the larva and denier indicating thickness of the filament. Thus, the economic traits selected under in the present study was an attempt to compare performance of the three important races along with stability of the same as these individual economic trait has a direct correlation with diverse sectors such as egg production centres and chawki rearing centers (fecundity and associated traits), sericulture farming community (cocoon weight and associated

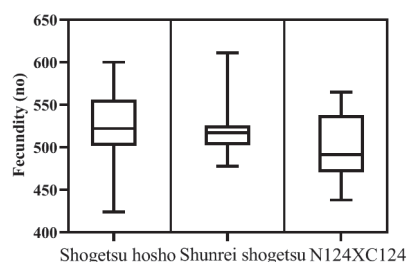


Fig. 1 Range of fecundity from Shunrei Shogetsu, Shogetsu Hosho, N124XC124 reared in five different environments.

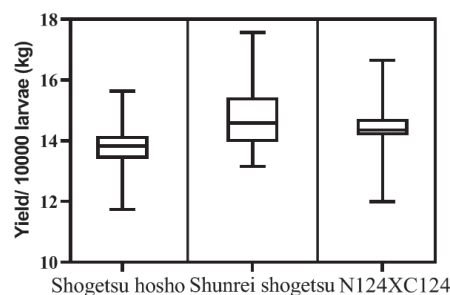


Fig. 2 Range of ERR from Shunrei Shogetsu, Shogetsu Hosho, N124XC124 reared in five different environments

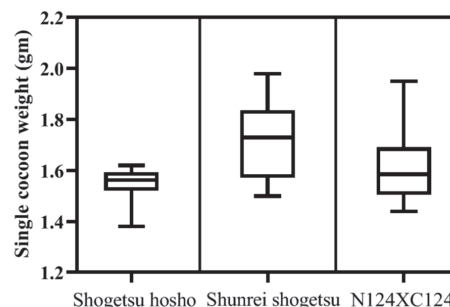


Fig. 3 Graph depicting the range of SCW from Shunrei Shogetsu, Shogetsu Hosho, N124XC124 reared in five different environments.

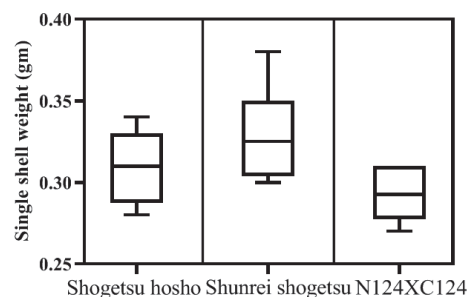


Fig. 4 Graph depicting the range of SSW from Shunrei Shogetsu, Shogetsu Hosho, N124XC124 reared in five different environments.

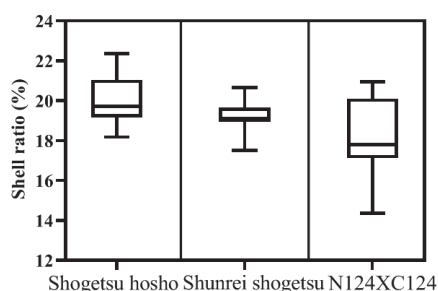


Fig. 5 Graph depicting the range of SR percentage from Shunrei Shogetsu, Shogetsu Hosho, N124XC124 reared in five different environments.

traits) and post cocoon sector (shell weight and associated traits) with significant impact on the economy.

The stability analysis evaluates the variance of the traits, providing an indication of trait variation within the population. The stability of a trait is determined by the correlation between the mean of the trait and the mean of the environment. A stable trait remains constant over time and across different environments, while an unstable trait may vary greatly. According to the Eberhart and Russell model, stable varieties are defined as those with a regression coefficient of one and a regression deviation that isn't significantly different from zero. In the present study, as expected, stability varied among traits and silkworm races. N124xC124 was found to be stable (value close to one) for fecundity (0.81) and SCW (1.06), while Shogetsu Hosho showed stability for ERR (0.99). Results for the other traits are varying (Table 2). The stability of a trait can be assessed by examining the correlation between the average trait value and the average environmental conditions. Genes, as internal factors, play a crucial role in trait expression. However, environmental factors can significantly influence gene expression and, consequently, the resulting phenotype. Even with identical genetic makeup, organisms can develop different observable traits depending on their environment. A stable trait is one that remains constant over time and in different environments, while an unstable trait may vary greatly (Reza and Rahman, 2005; Zhao *et al.*, 2007; Ahsan and Rahman, 2008; Rahmathulla, 2012; Muniraju and Mundkur, 2018). For instance, in silkworm breeding various economic traits such as

fecundity, cocoon weight, silk quality are considered. Identification of a breed with stable performance in all the economic parameters is essential as each economic traits confer to different micro industries within the field of sericulture. Overall, stability analysis of economic traits is a critical component of breeding programs as it helps breeders to make informed decisions about the development of a stable breed or hybrid (Pour-Aboughadareh *et al.*, 2022; Lee *et al.*, 2023; Khandelwal *et al.*, 2024).

The Francis coefficient of variation for fecundity placed Shunrei Shogetsu in the fourth quadrant, indicating a higher mean with low variation, followed by Shogetsu Hosho in the third quadrant (high mean and high variation) and N124xC124 in the first quadrant (low mean and low variation), indicating comparatively greater stability in Shunrei Shogetsu. Similarly, for ERR, N124xC124 appeared in the fourth quadrant, followed by Shunrei shogetsu (third quadrant) and Shogetsu Hosho (second quadrant). For SCW, the order was Shunrei Shogetsu (third quadrant) and both N124xC124 and Shogetsu Hosho in the first quadrant. In the case of SSW, Shunrei Shogetsu occupied the third quadrant, Shogetsu Hosho spanned the second and third quadrants and N124xC124 was in the first quadrant. For SR (%), Shunrei Shogetsu was in the fourth quadrant, followed by Shogetsu Hosho (third quadrant) and N124xC124 (second quadrant). Overall, Shunrei Shogetsu showed better stability across most traits, followed by Shogetsu Hosho and N124xC124 (Figs. 6–10).

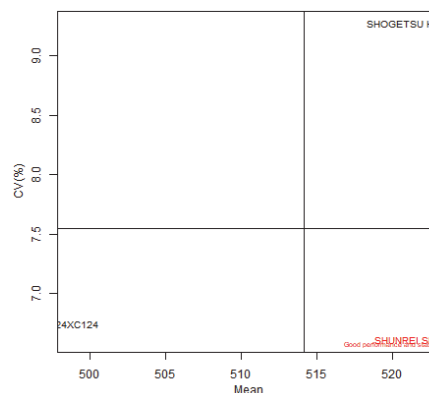


Fig. 6 Graph depicting the coefficient of variation and mean fecundity of Shunrei Shogetsu, Shogetsu Hosho, N124XC124 averaged over five environments.

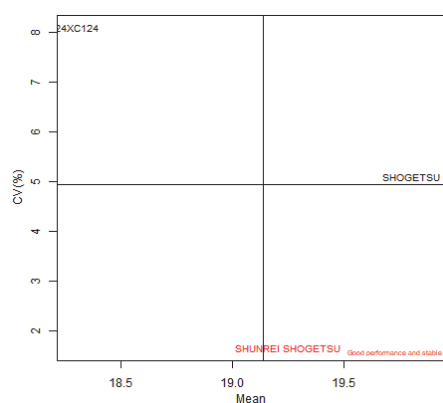


Fig. 7 Graph depicting the coefficient of variation and mean SR percentage of Shunrei Shogetsu, Shogetsu Hosho, N124XC124 averaged over five environments.

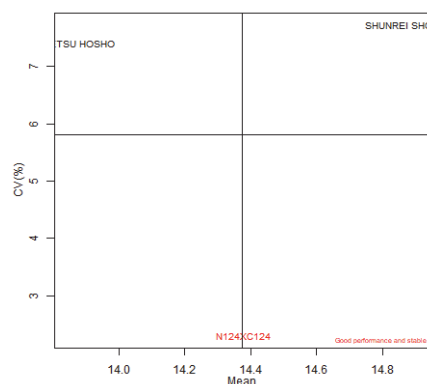


Fig. 10: Graph depicting the coefficient of variation and ERR of Shunrei Shogetsu, Shogetsu Hosho, N124XC124 averaged over five environments.

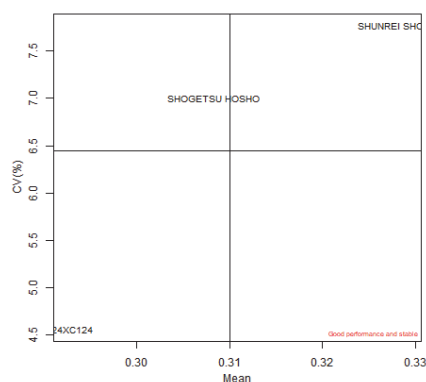


Fig. 8 Graph depicting the coefficient of variation and mean SSW of Shunrei Shogetsu, Shogetsu Hosho, N124XC124 averaged over five environments.

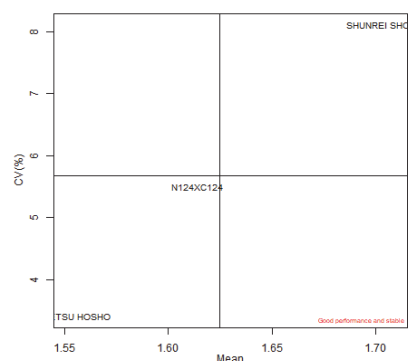


Fig. 9: Graph depicting the coefficient of variation and mean SCW of Shunrei Shogetsu, Shogetsu Hosho, N124XC124 averaged over five environments.

In the present study, stability analysis of the three pivotal parental races Shogetsu Hosho, Shunrei Shogetsu and N124×C124 revealed their distinct

adaptive responses and genetic buffering capacities against environmental fluctuations. Since these three races played a pivotal role in the evolution of the majority of bivoltine breeds in India, maintaining a comprehensive, environment-specific database of their performance parameters becomes crucial. Such a repository would be invaluable if breeders need backcross with the original parental lines in cases of degeneration or loss of key genetic traits. Moreover, this information could serve as a reference framework for future breeding programs, enabling breeders to select parental races based on documented stability indices and adaptive performance across environments. Furthermore, the present study demonstrates that stability analysis is a valuable tool for shortlisting breeds or hybrids, as it provides insights into performance variation across diverse environments and serves as a complementary tool to the widely used Mano evaluation index, which considers only economic trait performance.

These three foundational parental races were instrumental in the creation of highly promising breeds like SH6 (Shogetsu Hosho), CSR2, CSR5, CSR6 (Shunrei Shogetsu), NB4D2, NB18 and KA (N124×C124). Moreover, these foundational breeds were employed in the development of advanced races, including CSR4, CSR8 (SL), CSR12 and the most recent Gen2 and Gen3, where NB4D2, KA, CSR5 and CSR2 played vital roles as parental components. The impact of these evolved races has extended to hybrid evaluation programs,

Table 1 Evaluation index values of N124XC124, Shogetsu Hosho, Shunrei Shogetsu in the selected traits

Race	Fecundity	Yield per 10,000 larvae	Single cocoon weight	Single shell weight	Silk Ratio (%)
Shogetsu Hosho	55	40	41	49	59
Shunrei Shogetsu	56	60	61	60	51
N124XC124	38	50	49	40	39

Table 2. Stability values of the three silkworm races N124XC124, Shogetsu Hosho, Shunrei Shogetsu using Eberhart and Russel's model

Race	Fecundity	ERR	SCW	SSW	SR
N124XC124	0.81	0.43	1.06	0.13	2.02
Shogetsu Hosho	1.57	0.99	-0.05	1.55	0.55
Shunrei Shogetsu	0.62	1.58	1.99	1.33	0.43

culminating in the release of influential hybrids such as CSR double hybrids and CSR2xCSR4 in the southern states and SH6xNB4D2 in the northern states. These hybrids have become dominant in bivoltine silk production, further bolstering India's standing in the global silk industry. In conclusion, evaluating all traits collectively provides a nuanced picture of the economic potential of each race, making them valuable for future breeding programs.

A stable trait is one that remains constant over time and in different environments, while an unstable trait may vary greatly (Reza and Rahman, 2005; Zhao *et al.*, 2007; Ahsan and Rahman, 2008; Rahmathulla, 2012; Muniraju and Mundkur, 2018). For instance, in silkworm breeding various economic traits such as fecundity, cocoon weight, silk quality are considered. Identification of a breed with stable performance in all the economic parameters is essential as each economic traits confer to different micro industries within the field of sericulture. Overall, stability analysis of economic traits is a critical component of breeding programs as it helps breeders to make informed decisions about the development of a stable breed or hybrid (Pour-Aboughadareh *et al.*, 2022; Lee *et al.*, 2023; Khandelwal *et al.*, 2024). In the three models tested, a considerable variation was observed with each performing better in few traits which

increases the complexity of the breeder while catering to the different micro industries within the sericulture as discussed before. However, when all three methods used are ranked according to the traits, ranked according to Shogetsu Hosho, followed by Shunrei Shogetsu and N124XC124. Although the aim of the study was not to identify or shortlist a breed, the comparative performance of the three breeds with historical pivotal parental races, propelling India to a dominant position in bivoltine silk production.

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