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RESEARCH ARTICLE
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Performance Assessment of Reciprocal Hybrids between Chinese and Japanese Silkworm Strains (*Bombyx mori* L.) in Indonesian Sericulture

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ABSTRACT

The silkworm (*Bombyx mori* L.) is an economically important species due to its ability to produce valuable silk. This study aimed to assess reciprocal hybrids based on quantitative and qualitative traits to identify the most productive hybrid lines. Genetic materials used were silkworm's strains from China and Japan with accession numbers 804, 102, and 927, 202 respectively. The experimental design used in this study was a completely randomized design (CRD), consisting of 6 crosses with 3 replications of 200 larvae each, resulting in a total of 3,600 larvae. The data were analyzed using ANOVA, mean comparisons were conducted using Duncan's Multiple Range Test (DMRT). The results showed that the best three varieties namely Variety A (804×927), Variety B (927×804), and Variety D (202×927), produced superior performance with a range of cocoon shell percentage (CSP) 21.42–21.87%, cocoon shell weight (CSW) 0.39–0.40g, cocoon weight (CW) 1.82–1.87g, egg hatchability percentage (EHP) 97.96–98.51%, normal cocoon percentage (NCP) 86.00–92.67%, filament length (FL) 1.076–1.137m, and filament weight (FW) 0.31–0.32g. Meanwhile the qualitative parameters showed a intermediate morphology characteristic between the both parents. The accession number of 804 demonstrated the highest general combining ability, indicating its potential as an optimal female parent for hybrid development. Reciprocal crosses between Chinese and Japanese silkworm strains exhibited a performance level comparable to that of the standard Indonesian hybrid. The strategic utilization of underused female pupae through reciprocal crossing could broaden the genetic base and enhance resource efficiency, thereby aligning with the circular economy principles in the advancement of national sericulture.

Keywords: Agriculture, Industry, Reciprocal, Silk Thread.

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INTRODUCTION

Bombyx mori L., commonly known as the silkworm moth, is an insect from the Bombycidae family that has a significant economic value due to its ability to produce silk filaments, an essential raw material for high-end textile products in Indonesia (Muin et al., 2021; Gautam et al., 2022; Sadapotto et al., 2025). These silk filaments play a crucial role in supporting the national silk-textile industry (Agustarini & Heryati 2019; Muin et al., 2021; Agustarini et al., 2022; Fambayun et al., 2022). In recent years, demand for silk fabric has increased sharply, driven by the increasing diversity and popularity of fashion trends, leading to an increase in demand for silk raw materials from silkworm cultivation (Andadari et al., 2022). However, to meet this demand, Indonesia still relies on imports (Ashar et al., 2024). In 2023, Indonesia imported approximately 5,146 tons of woven silk fabrics from China (BPS-Statistics Indonesia, 2023). Based on United Nations COMTRADE (2025) data reported by Trading Economics (2025),

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the value of Indonesia's silk imports in 2024 reached around US$2.36 million, of which nearly US$2 million originated from China. In contrast, domestic cocoon production only makes 70–80 tons of silk thread annually, while national demand is estimated at about 800 tons per year (Sadapotto et al., 2021).

Breeding or hybridizing silkworm (*B. mori* L.) has long been important method to increase cocoon yield and improve silk quality. This improvement mainly comes from hybrid vigor (heterosis), a condition where hybrid offspring perform better than their parent strains in key traits (Ruiz & Almanza, 2018; Andadari et al., 2022). Recent studies from around the world that combined physical, genetic, and protein level analyses have provided strong evidence of this effect in *B. mori* L.. The results show that hybrid silkworms produce more cocoons, have longer filaments, and show higher silk content and productivity. Conde et al. (2025) and Ge et al. (2020) found that traits such as body weight, silk gland size, and cocoon weight are mainly influenced by genes that work in a non-aditive way, making the hybrids stronger. Similarly, Lu et al. (2025) discovered genetic differences between Chinese and Japanese silkworm groups in a specific gene (BmBeta_spc), which helps improve cocoon yield.

Globally, the expression of heterosis in *B. mori* L. has been demonstrated to be influenced not only by genetic distance but also by the direction of crossing (Talebi & Subramanya, 2009; Bukhari et al., 2021; Sharma & Bukhari, 2021; Shinde et al., 2025). In most breeding systems, unidirectional hybridization, typically a fixed female × male combination, remains the common practice. However, reciprocal crosses (♀A × ♂B and ♀B × ♂A) provide a more comprehensive understanding of hybrid performance by elucidating the effects of maternal inheritance, cytoplasmic interactions, and epigenetic mechanisms on larval development, cocoon production, and silk filament quality. Single directional crosses may therefore provide incomplete insights, as they fail to capture the full expression of hybrid vigor and potential maternal contributions (Wang et al., 2015; Andadari et al., 2022).

From a breeding and policy perspective, evaluating both crossing directions is particularly relevant for Indonesia, where commercial silkworm hybrids are typically produced using Chinese-race females and Japanese-race males. This practice results in the underutilization of female pupae from the Japanese line, leading to inefficiencies in broodstock use. Strengthening local parental stocks and adopting reciprocal crossbreeding schemes could therefore enhance the efficiency of breeding programs and support national silk self-sufficiency.

This study was designed to evaluate the performance of reciprocal crosses between Chinese and Japanese race silkworms. It was hypothesized that reciprocal crosses between Chinese and Japanese race silkworms would perform equally or better than the standard unidirectional hybrid, while enhancing the utilization of female broodstock resources. These reciprocal hybridization strategies not only aim to enhance productivity and silk quality but also promote efficient use of biological, time, and labor resources, which are critical in tropical production systems (Ramesha et al., 2012; Fambayun et al., 2022; Prabhu et al., 2024). Reducing import dependency through the development of high-performing reciprocal hybrids further supports the principles of a circular economy by maximizing biological resource use and minimizing production waste.

MATERIALS & METHODS

The experiment was conducted at the Indonesian Natural Silk Research Laboratory, Bogor, Indonesia, located at an altitude of 220m above sea level (Fig. 1). The rearing site experiences an average daily temperature of 26–30°C, relative humidity between 81% and 95%, and a photoperiod of approximately 3–6 hours. Four bivoltine silkworm strains were used, consisting of 2 (two) Chinese strains (804 and 202) and 2 (two) Japanese strains (927 and 102). The experimental procedure comprised several stages, beginning with silkworm rearing following the method described by Andadari et al. (2013).

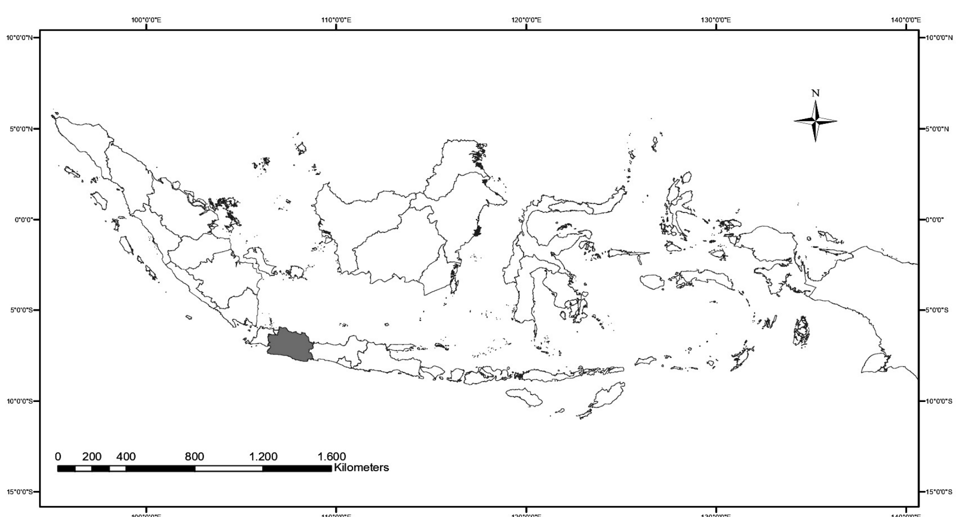

Fig. 1: Research location (Fig. by W. Isnan).

Experimental Design

The experimental design used in this study was a completely randomized design (CRD), consisting of 6 (six) crosses with 3 (three) replications of 200 larvae each, resulting in a total of 3,600 larvae. Table 1 shows the plan for the experimental cross. Each cross combination represented one family group. Sex was not considered during the larval and cocoon stages but was recorded separately at pupation to analyze the sex ratio and utilization rate. While the parameters observed were quantitative and qualitative parameters, including egg hatchability percentage (EHP), cocoon normal percentage (CNP), cocoon weight (CW), cocoon shell weight (CSW), cocoon shell percentage (CSP), filament length (FL) and filament weight (FW).

Table 1: Reciprocal hybridization between the Chinese and Japanese strain silkworm.

♀ \ ♂	804	927	102	202
804	NA	Variety A	NA	NA
927	Variety B	NA	NA	Variety C
102	NA	NA	NA	Variety F
202	NA	Variety D	Variety E	NA

NA: crosses where not applicable.

Quantitative Parameters

Quantitative parameters were evaluated by the productivity level of hybrid silkworms resulting from crossbreeding, through analysis of variance using the following linear model:

$$Y_{ij} = \mu + \tau_j + \varepsilon_{ij}$$

Note: Yij = quantitative measurement value of the i-the individual of the j-the hybrid silkworm variety, μ = overall mean, τj = effect of the j-the hybrid silkworm variety, εij = the residual error.

The quantitative parameters to be observed are described below:

1. Egg quality: total egg number and hatching percentage. eggs hatchability percentage (EHP, %), calculated using the formula:

$$EHP = \frac{\text{Number of hatched eggs}}{\text{Total number of eggs}} \times 100\%$$

2. Rearing yield: ratio of cocoon number to total larvae reared.
3. Cocoon quality: percentage of normal cocoons, cocoon weight, shell weight, and shell ratio (shell weight/whole cocoon weight). We used the method described by Agustarini et al. (2022) to evaluate the quality of the cocoons. We took 20 random cocoons from each hybrid, so that the total sample used was 360 samples (20 × 6 combinations × 3 replicates). We used 12 dried cocoons from each hybrid to test the quality of the filaments, so the total sample was 216 samples (12 × 6 combinations × 3 replicates). To make sure that the results of the filament tests were the same as the results of the cocoon quality tests, all of the cocoons used for filament testing came from the same batches.

- cocoon weight (CW)(g)
- cocoon shell weight (CSW)(g)
- cocoon shell percentage (CSP)(%), calculated using the formula:

$$CSP = \frac{csw}{cw} X\ 100\%$$

- normal cocoon percentage (NCP)(%), calculated using the formula:

$$NCP = \frac{\text{Number of normal cocoons}}{\text{Total number cocoon samples}} \times 100\%$$

- filament length per cocoon (FL)(m)
- filament weight per cocoon (FW)(g).

To observe the abilities and compatibility between the parents that will be crossed, a General Combining Ability (GCA) assessment of the parents is carried out using the following equation (Zobel & Talbert, 1984).

$$gca_i = \bar{Y}_i - \bar{Y}_n$$

Note: gca_i is the estimated GCA effect of parent *i*, $\bar{Y}_i$ is the mean performance of all hybrids involving parent i as one of the parents, $\bar{Y}_n$ is the grand mean (overall mean) of all hybrids in the analysis

Qualitative Characteristics

Qualitative parameters observed included the color and pattern of the silkworm body, as well as the shape and color of the cocoon.

Data Analysis

Data were analyzed using analysis of variance (ANOVA) using SAS software version 9.1. The Percentage data were arc sine-transformed prior to analysis (Gomez & Gomez, 1984). When the analysis of variance revealed a significant differences, Duncan's Multiple Range Test (DMRT) was used for futher analysis to observe the differences between the treatments (Alipanah et al., 2020; Nila & Jones, 2023).

RESULTS

Quantitative Parameters

Quantitative measurement data for this study are presented in Table 2. The egg hatching percentage is calculated as the ratio of the number of fertilized eggs that hatch into silkworm larvae to the total number of eggs produced by the female moth. This parameter is used to assess egg quality and quantity, as well as silkworm health and productivity. Similar to cocoon normal percentage, a high egg hatching percentage indicates higher potential yield and silk production quality (Kumar & Kumar, 2011; Nasirillayev et al., 2025). The results (Table 2) indicate that the average egg hatching percentage ranged from 84.94–98.51%, higher than the range of 85–93% reported in India (Sangle et al., 2022).

Cocoon weight (CW) ranged from 1.70–1.87g, while cocoon shell weight (CSW) was 0.36–0.40g. These values are higher than the cocoon and cocoon shell weights reported for silkworms in India fed various leaf types (Kumar & Kumar, 2011). The percentage of cocoon shells (CSP) was recorded between 20.49–21.87%, while the cocoon normal percentages (CNP) ranged from 86–92.67%. Cocoon weight (CW) is the total mass produced by a single larva and plays a major role in determining the amount of silk that can be spun. Cocoon shell weight (CSW) and cocoon shell percentage (CSP) indicate the proportion of shell mass relative to the total cocoon

Table 2: Quantitative parameters of silkworm hybrids crossbreed between Chinese and Japanese strain.

	Quantitative parameter					
Variety	A	B	C	D	E	F
EHP (%)						
Min	82.73±0.79	80.81±0.79	82.16±0.79	78.48±0.79	80.52±0.79	65.60±0.79
Max	82.78±0.79	82.87±0.79	83.93±0.79	83.13±0.79	80.99±0.79	68.82±0.79
Mean	82.76±0.79[a]	81.82±0.79[a]	83.03±0.79[a]	80.71±0.79[a]	80.75±0.79[a]	67.20±0.79[b]
NCP (%)						
Min	72.86±1.60	60.98±1.60	70.84±1.60	65.56±1.60	68.57±1.60	65.56±1.60
Max	75.52±1.60	67.91±1.60	74.21±1.60	70.84±1.60	74.21±1.60	72.86±1.60
Mean	73.97±1.60[a]	64.82±1.60[b]	72.86±1.60[a]	68.32±1.60[ab]	71.88±1.60[a]	68.56±1.60[b]
CW(g)						
Min	1.84±0.02	1.80±0.02	1.67±0.02	1.76±0.02	1.68±0.02	1.65±0.02
Max	1.87±0.02	1.96±0.02	1.75±0.02	1.89±0.02	1.83±0.02	1.77±0.02
Mean	1.84±0.02[a]	1.87±0.02[a]	1.70±0.02[b]	1.82±0.02[a]	1.77±0.02[a]	1.72±0.02[a]
CSW (g)						
Min	0.40±0.01	0.38±0.01	0.36±0.01	0.38±0.01	0.34±0.01	0.35±0.01
Max	0.41±0.01	0.43±0.01	0.38±0.01	0.40±0.01	0.37±0.01	0.36±0.01
Mean	0.40±0.01[a]	0.40±0.01[a]	0.36±0.01[b]	0.39±0.01[a]	0.36±0.01[b]	0.36±0.01[b]
CSP (%)						
Min	21.68±0.19	20.94±0.19	21.41±0.19	21.31±0.19	20.43±0.19	20.58±0.19
Max	21.99±0.19	22.08±0.19	21.66±0.19	21.66±0.19	20.66±0.19	21.25±0.19
Mean	21.87±0.19[a]	21.42±0.19[b]	21.48±0.19[b]	21.45±0.19[b]	20.49±0.19[b]	20.90±0.19[a]
FL (m)						
Min	1083.5±27.89	1044.3±27.89	1061.5±27.89	1098.8±27.89	900.0±27.89	1086.3±27.89
Max	1183.8±27.89	1125.3±27.89	1125.9±27.89	1188.3±27.89	1125.0±27.89	1125.0±27.89
Mean	1125.5±27.89[a]	1076.7±27.89[a]	1085.9±27.89[a]	1137.3±27.89[a]	991.9±27.89[a]	1103.6±27.89[a]
FW (g)						
Min	0.31±0.01	0.30±0.01	0.28±0.01	0.30±0.01	0.27±0.01	0.25±0.01
Max	0.33±0.01	0.31±0.01	0.33±0.01	0.31±0.01	0.30±0.01	0.28±0.01
Mean	0.32±0.01[a]	0.31±0.01[a]	0.30±0.01[a]	0.31±0.01[a]	0.29±0.01[a]	0.27±0.01[a]

Note: A, B, C, D, E, and F are Hybrıd Varieties, EHP = eggs hatching percentage, NCP = normal cocoon percentage, CW = cocoon weight, CSW = cocoon shell weight, CSP = cocoon shell percentage, FL = filament length, FW = filament weight. Means followed by the same letter are not significantly different (DMRT, P≤0.05).

weight, which is closely related to silk yield potential (Mirhosseini et al., 2005). The CNP is an important indicator of silkworm health and productivity, as well as the effectiveness of rearing and harvesting practices (Zhou et al., 2021). The higher the CNP, the greater the chance of producing silk of optimal quality and quantity (Lee, 1999).

The filament length per cocoon was recorded between 991.9–1,185.9m, while the filament weight ranged from 0.27–0.32g. These values are significantly higher than previously reported values of 415.43–510m for filament length and 0.09–0.13g for filament weight (Ravi & Kumar, 2016). Based on the high CNP, EHP, FL and FW that exceed previous reports, it can be concluded that the tested *B. mori* L. hybrids have high production quality.

To evaluate cocoon quality, the obtained results were compared with the standard cocoon quality parameters specified in Indonesian Nasional Standards No. 7635:2023 (National Standardization Agency, 2023). The corresponding threshold values for cocoon weight (CW), and cocoon shell percentage (CSP) have been listed alongside the performance of the tested hybrids in Table 3.

Based on cocoon quality standards that include cocoon weight and cocoon shell percentage as stipulated by SNI (Table 3), the cocoons produced in this study are included in the A quality category or the best quality (National Standardization Agency, 2023). Reciprocal crosses between Chinese and Japanese silkworm strains exhibited a performance level comparable to that of the standard Indonesian hybrid.

Analysis of variance (ANOVA) was conducted to evaluate the effects of treatments in the measured parameters, and the summary results are presented in Table 4. The results of the analysis showed significant variation in all measured quantitative traits among the silkworm hybrid varieties, reflecting the influence of genetic background and hybrid combinations on trait expression. This finding emphasizes that the importance of selecting appropriate varieties to optimize desired traits in practical applications. Selection of silkworm varieties with high productivity and superior end product quality is the primary objective in silkworm rearing and development programs. Subsequently, Duncan's Multiple Range Test (DMRT) was applied to determine the statistical differences among the silkworm varieties, and the results were presented as a rangking of varieties based on mean values (Table 5).

İt is shown that varieties A and B dominate the best ranking for all quantitative parameters. Based on these results, the best crosses combination can be identified, varieties A and B that showed the female with the highest general combining ability, as listed in Table 6. The female parent with the highest combining ability is accession number 804. The relationships between the quantitative parameters are shown in Table 7, while the results of the correlation analysis presented indicate that CW has a very positive correlation with CSW, CSP, NCP, and FW.

Qualitative Characteristics

The qualitative characteristics of silkworm larvae and cocoons vary among the Chinese, Japanese strains, and their hybrid (Fig. 2). Chinese silkworm larvae exhibit a plain body pattern with a pristine white hue, whereas a pale white shade color with distinct spots around the eyes and the back above the head characterizes Japanese larvae. In terms of cocoon morphology, Chinese cocoons typically possess a rounded shape, while Japanese cocoons tend to

Table 3: Comparison of quantitative parameter values of silkworm hybrids with SNI

Parameter	Quality class based on Indonesian national standards (SNI)			Variety						Quality Class
	1 (A)	2 (B)	3 (C)	A	B	C	D	E	F	
CW (g)	≥1.70	1.30–<1.70	< 1.3	1.84	1.87	1.70	1.82	1.77	1.72	1 (A)
CSP (%)	> 20.00	17.00–<20.00	< 17.00	21.87	21.42	21.48	21.45	20.49	20.90	1 (A)

Note: A, B, C, D, E, and F are Hybrıd Varieties.

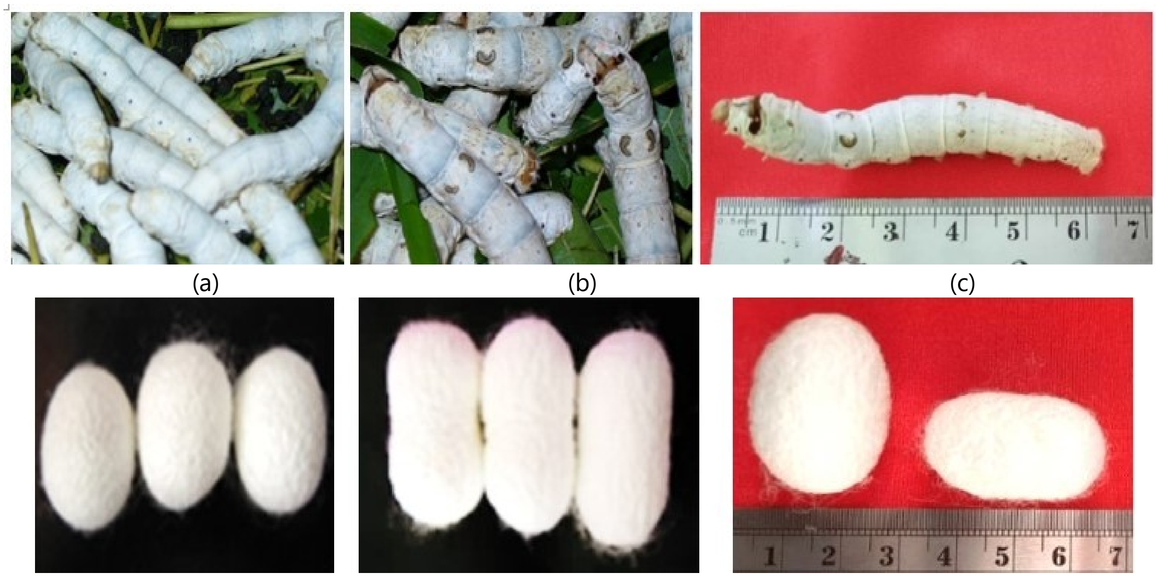

Fig. 2: Characteristic phenotypes: (a) larvae of the Chinese strain, (b) larvae of the Japanese strain, (c) larvae of the Chinese × Japanese hybrid variety, (d) cocoons of the Chinese strain, (e) cocoons of the Japanese strain, and (f) cocoons of the Chinese × Japanese hybrid variety.

Table 4: Mean square and F value of quantitative parameters of crossbreed hybrids between Chinese and Japanese strain

Parameter	EHP	NCP	CW	CSW	CSP	FL	FW
Mean Square	61.71*	149.21*	0.03*	0.00*	1.96*	27,384.2*	0.00*
F value	46.85	10.19	17.20	30.92	18.92	5.38	3.01

Note: * = significant at 1% level (DMRT, P≤0.01), EHP = eggs hatching percentage, NCP = normal cocoon percentage, CW = cocoon weight, CSW = cocoon shell weight, CSP = cocoon shell percentage, FL = filament length, FW = filament weight

Table 5: The rank of quantitative parameters of variety hybrid silkworm resulted from crossing between the Chinese and Japanese strain

Rank	Variety						
	EHP	NCP	CW	CSW	CSP	FL	FW
1	C	A	B	A	A	A	A
2	A	C	A	B	B	C	B
3	B	D	C	C	C	F	C
4	E	B	E	D	D	D	D
5	D	F	F	E	E	B	E
6	F	E	D	F	F	E	F

Note: A, B, C, D, E, and F are Hybrıd Varieties, EHP = eggs hatching percentage, NCP = normal cocoon percentage, CW = cocoon weight, CSW = cocoon shell weight, CSP = cocoon shell percentage, FL = filament length, FW = filament weight.

Table 6: General combining ability (GCA) of silkworm parent for the measurement test of quantitative parameters of Chinese and Japanese strain

Parent	GCA						
	Quantitative parameter						
	EHP	NCP	CW	CSW	CSP	FL	FW
804	0.045	0.091	0.091	0.045	0.973	0.091	0.045
927	0.022	0.040	0.040	0.022	0.554	0.040	0.022
202	0.015	0.051	0.051	0.015	0.074	0.051	0.015
102	-0.002	-0.022	-0.022	-0.00	0.003	-0.022	-0.002

Note: A, B, C, D, E, and F = Hybrıd Varieties, EHP = eggs hatching percentage, NCP = normal cocoon percentage, CW = cocoon weight, CSW = cocoon shell weight, CSP = cocoon shell percentage, FL = filament length, FW = filament weight. A confidence level of 99% (α = 0.01) was applied, with a sample size of six.

Table 7: Pearson correlation between the quantitative parameters

	EHP	CNP	CW	CSW	CSP	FL	FW
EHP	1.0	-	-	-	-	-	-
CNP	0.21	1.0	-	-	-	-	-
CW	0.32	0.60	1.0	-	-	-	-
CSW	0.37	0.66	0.95	1.0	-	-	-
CSP	0.33	0.60	0.67	0.86	1.0	-	-
FL	0.04	0.55	0.52	0.61	0.61	1.0	-
FW	0.46	0.49	0.73	0.78	0.64	0.67	1.0

Note: EHP = eggs hatching percentage, NCP = normal cocoon percentage, CW = cocoon weight, CSW = cocoon shell weight, CSP = cocoon shell percentage, FL = filament length, FW = filament weight. A confidence level of 99% (α = 0.01) was applied, with a sample size of six.

peanut shape. The Hybrid variety silkworms display phenotypic traits that predominantly have an oval shape of the cocoon, which shows the characteristics of an intermediate between both parents' cocoon shapes.

DISCUSSION

Quantitative Parameters

The quantitative parameters measured in this study are important indicators of sericulture success and can also produce superior crossbreeding combinations (Lee, 1999; Andadari et al., 2022). All parameters measured in the offspring resulting from crossbreeding between Chinese and Japanese silkworm strains showed significant variation. Among these combinations, the 927 × 804 cross produced the highest-quality offspring, characterized by superior performance in all quantitative parameters, particularly the highest cocoon weight of 1.96g. This performance is consistent with the positive and high general combining ability values, particularly for cocoon weight percentage (Table 6).

Conversely, the lowest cocoon weight of 1.65g was found in the 102 × 202 crossbreed. However, this value still exceeds the cocoon weight of first-generation silkworms commonly cultivated in tropical regions. Previous studies have shown that the cocoon weight of five *B. mori* L. hybrids in Nigeria ranged from 1.02 to 1.26g (Alebiosu et al., 2014), while research in Central Kalimantan, Indonesia, reported a hybrid cocoon weight of 1.35g (Deni et al., 2019). Differences in cocoon weight are influenced by genetic factors of *B. mori*, such as the type of silkworm and the sex of the pupa, as well as environmental factors, including humidity, room temperature and maintenance methods (Rahmathulla, 2012; Kiplagat, 2022). These findings confirm that selecting appropriate parental lines in hybridization programs is a key strategy for improving key economic traits in silkworms. The superior performance of the 927 × 804 cross reflects the potential for exploiting genetic diversity between Chinese and Japanese strains to produce hybrids with superior characteristics. The observed variation in cocoon weight indicates the important role of combinatory ability in determining hybrid vigor. In addition to improving cocoon quality, appropriate genetic combinations also enhance the hybrid's adaptability to various environmental conditions. Therefore, continuous evaluation and selection of potential crosses are crucial for maintaining the productivity and quality of sericulture in tropical regions.

The correlation between cocoon weight and cocoon shell weight, cocoon shell percentage, and normal cocoon percentage shows a very positive relationship. This means that an increase in cocoon weight will be followed by an increase in cocoon shell weight, cocoon shell percentage, and normal cocoon percentage (Table 7). High cocoon shell productivity, indicated by cocoon shell weight and percentage, is an important benchmark in determining fiber content and cocoon price (Baskoro et al., 2011; Seidavi et al., 2020). The ability to produce filaments is also influenced by genetic factors such as the type of silkworm, as well as environmental factors such as feed type, temperature, and room humidity (Rahmathulla, 2012; Kiplagat, 2022; Kumar et al., 2024).

The strong correlation among these parameters also suggests that selection based on cocoon weight alone could effectively improve overall cocoon quality and economic returns in breeding programs (Neshagaran Hemmatabadi et al., 2016). This interconnectedness of traits simplifies the selection criteria for breeders, allowing them to focus on fewer, more easily measurable indicators without compromising the overall silk yield. Moreover, the categorization of the cocoon quality into group A based on SNI standards confirms the suitability of these hybrids for commercial silk production (Table 3). Such classification not only ensures market competitiveness but also supports efforts to standardize and enhance sericulture practices in tropical regions.

The interesting result was that the observed differences between reciprocal crosses suggest the presence of reciprocal effects, highlighting the interaction between maternal and paternal genetic contributions. Differences in performance based on whether the Chinese or Japanese strain was the female parent may indicate maternal or cytoplasmic inheritance effects. In *B. mori* L., cytoplasmic inheritance is primarily transmitted through the maternal line, involving factors such as mitochondrial function, endosymbiotic components that can influence larval metabolism, developmental rate, or silk production (Takahashi et al., 2006; Zhang et al., 2019; Zhang et al., 2021). Consequently, the enhanced performance of the 927 × 804 hybrid may not be exclusively attributed to beneficial gene combinations, but also to advantageous maternal or cytoplasmic contributions. Variations in hatchability and cocoon quality suggest that maternal lineage may affect hybrid vigor through cytoplasmic inheritance, involving mitochondrial function, yolk composition, or maternally inherited molecules. Similar maternal influences have been reported in transcriptomic and proteomic analyses, where heterosis was linked to non-additive gene action and maternal directional effects (Xiao et al., 2020; Ardehjani et al., 2023; Zhao et al., 2024). Ge et al. (2020) further demonstrated that reciprocal hybrids differ in silk gland gene expression, implying cytoplasmic or maternal regulation of silk protein pathways.

Maternal physiological control also plays a role; Tsuchiya et al. (2020) and Homma et al. (2022) showed that these findings align with recent insights into the maternal to zygotic transition, during which maternal transcripts and proteins direct early embryogenesis (Kojima et al., 2025). Moreover, genomic studies show that structural variations between Chinese and Japanese strains can alter nuclear–cytoplasmic compatibility, explaining direction-dependent hybrid outcomes (Kojima et al., 2025). Overall, these results suggest that reciprocal hybridization effects arise from interactions with maternal cytoplasmic components, providing a genetic basis for the observed asymmetry in hybrid performance (Wang et al., 2015).

Egg hatchability is an important factor in sericulture because it directly influences the success of silk rearing and production (Akinwande, 2022; Bashir et al., 2025). Understanding hatching behavior is key to optimizing this process. The results showed that most cross combinations had high hatchability (≥ 95%), except for the 102 x 202 cross which only achieved ≤85% (Table 2). The low hatchability of this combination indicates the incompatibility of the lines under the environmental conditions used, namely a temperature of 26–30°C, 81–95% humidity, and 3–6 hours of darkness. Environmental factors such as temperature and humidity are known to significantly influence the reproducibility of pure silkworm lines (Nezhad et al., 2010). In addition, the low general combining ability (GCA) of lines 102 and 202 may also contribute to the low hatchability, as reflected by the very low GCA values (Table 5).

The variation in hatchability among different crosses also emphasizes the importance of parental compatibility and environmental adaptability in silkworm breeding. High hatchability not only ensures uniform larval development but also minimizes labor and resource input during the rearing phase. Incompatibility, as seen in the 102 × 202 cross, could lead to asynchronous hatching and reduced larval survival, ultimately affecting cocoon yield and quality. Therefore, selecting parental lines with both strong combining ability and high environmental tolerance is critical for achieving consistent reproductive success and maintaining the efficiency of sericulture operations in tropical climates.

Qualitative Characteristics

The most recognizable phenotypic characteristics of *B. mori* L. silkworms were the body pattern and the shape and color of their cocoon. Chinese strains are characterized by a plain body pattern and a color pristine pure white, in contrast to Japanese strains , which predominantly exhibit a mottled body pattern with a pale white color (Fig. 2a). Additionally. Japanese strains have distinct dark markings around the eyes and on the back of the head (Fig. 2b). Meanwhile, the cocoons of the Chinese and Japanese silkworm strain differ in shape but are almost similar in their white color. The Chinese cocoons are round (Fig. 2d), while the Japanese cocoons tend to resemble the shape of a peanut (Fig. 2e). The body pattern phenotypes of the varieties resulting from the crossing of Chinese and Japanese silkworms exhibit more characteristics of the Japanese body pattern than the Chinese (Fig. 2c). However, the cocoon shapes of all varieties are oval and white, showing an intermediate form between both parents (Fig. 2f). It means that the hybrid varieties inherit a blend of traits from both parental strains , demonstrating a phenomenon known as incomplete dominance or intermediate inheritance. In the case of body pattern phenotypes, the Japanese traits are more dominant, leading to hybrids that resemble the Japanese silkworms more closely. On the other hand, the cocoon shapes exhibit an intermediate form, which indicates that the traits of cocoon shape are inherited in a more balanced manner from both Chinese and Japanese strains .

Similar results were also found in studies showing that hybrids between silkworm strains often combine the traits of their parents, with some characteristics showing dominance and others showing intermediate forms (Nezhad et al., 2010). This pattern of inheritance suggests that certain phenotypic traits are controlled by multiple genes, contributing to the diversity observed in hybrid varieties. This complex pattern of inheritance aligns with the polygenic nature of many morphological traits in *B. mori* L., where gene interactions and epistasis play a significant role in trait expression. For example, body coloration and cocoon shape are influenced by multiple loci, some of which may exhibit dominance or incomplete dominance depending on the genetic background of the parental lines. As a result, hybrids often display novel or intermediate phenotypes not observed in either parent, which can be advantageous for breeding programs aimed at enhancing desirable characteristics (Ruiz & Almanza, 2018).

Implication

The successful hybridization between Chinese and Japanese silkworm strains, specifically between accession numbers 804 and 927, indicates a significant opportunity to produce a superior hybrid silkworm with the high productivity of silk filaments as the main raw material for silk fabric. This is very important for enhancing the silk production in the national silk textile industry in Indonesia. By using the superior hybrid silkworm, silk production could increase, which will support the demand for national silk yarn. Besides the quantity, hopefully, the superior silkworm can produce higher quality silk that will enhance the competitiveness of the Indonesian global market. To fully realize the potential of this superior hybrid, further evaluation under diverse environmental and rearing conditions in Indonesia is essential. Collaboration between breeders, researchers, and silk farmers will be crucial to optimize rearing practices and ensure the consistent performance of the hybrid strain at the field level.

The hybridisation between these two different strains will increase the genetic diversity of silkworm in Indonesia, potentially enhancing their resistance to diseases, improving silk yield and quality, and contributing to the sustainability of the sericulture industry. This genetic diversity may also allow for the development of new silkworm varieties that are better adapted to various environmental conditions. Furthermore, a broader genetic pool can serve as a valuable resource for future breeding programs. It can also reduce the risk of inbreeding depression, which often leads to reduced vitality and productivity in silkworm populations (Bindroo & Moorthy 2014; Ruiz & Almanza, 2018). The establishment of a structured breeding and conservation program becomes imperative to manage and utilize the enriched genetic pool effectively. By maintaining a diverse collection of silkworm germplasm, Indonesia can ensure the availability of resilient and high-performing strains for future breeding objectives. This approach not only supports immediate production goals but also safeguards genetic resources against potential threats such as climate change, emerging pests, and shifting market demands. Moreover, systematic documentation and genetic characterization of these diverse lines will enhance the efficiency of selection processes, allowing breeders to combine desirable traits more precisely to meet specific production and industrial needs.

In Indonesia's current commercial hybridization system, female moths from Chinese strains are typically used as the maternal line, while male moths from Japanese strains serve as the paternal line (Andadari et al., 2022). Under this arrangement, only female pupae from the Chinese line are utilized for hybrid seed production, leaving those from the Japanese line unused. The present study demonstrated that reciprocal crosses using Japanese females and Chinese males, performed equally well across all measured traits, including egg production, hatching rate, rearing yield, percentage of normal cocoons, cocoon weight, shell weight, filament length, and filament weight (Table 2). These comparable results indicate that both crossing directions exhibited similar levels of hybrid vigor, with no apparent maternal or cytoplasmic disadvantages when the Japanese line served as the female parent.

Recognition of these parental influences underscores the importance of evaluating both crossing directions to optimize reproductive outcomes and enhance the efficiency of broodstock utilization in silkworm breeding programs (Gowda et al., 2025). Using female pupae from both parental strains would effectively double breeding resource efficiency and increase potential silk yield at the national level. This approach aligns with circular economy principles by maximizing biological resource use and minimizing broodstock waste (Ellen MacArthur Foundation, 2019), without compromising commercial hybrid performance. To effectively implement this reciprocal crossbreeding strategy on a national scale, institutional support and policy alignment are essential. Government and industry stakeholders should collaborate to update breeding guidelines, provide training for silkworm farmers, and ensure access to high quality parent strains from both Chinese and Japanese lineages. Investment in extension services and technical assistance will help farmers adopt these improved practices and manage reciprocal crosses efficiently. Additionally, integrating this approach into national sericulture development programs can support rural livelihoods, reduce biological waste, and reinforce Indonesia's commitment to sustainable agricultural practices. By maximizing the use of all viable pupae and improving silk output per production cycle, this strategy represents a significant step toward achieving both economic growth and environmental sustainability in the Indonesian silk industry.

Conclusion

In conclusion, the evaluation of mulberry hybrid silkworms demonstrates substantial variability in both quantitative and qualitative traits across different cross combinations. The cross between accessions 927 and 804 exhibited the most promising results, showing superior performance in cocoon weight and other key production parameters, which reflects a strong general combining ability. In contrast, the 102 × 202 cross combinations yielded the lowest cocoon weight and hatchability, indicating lower compatibility and adaptability under the tested environmental conditions. Qualitative observations further revealed that hybrid offspring expressed a mixture of parental characteristics, body patterns tended to resemble the Japanese strain more closely, while cocoon shapes appeared as intermediates between the two parental lines. This study was performed at a single site and within a single rearing season, which indicates that the results may be influenced by specific local environmental factors. Moreover, the tests were performed on a healthy population devoid of disease pressure or fluctuations in feed quality, thus failing to accurately represent field variability. There has also been no economic study of the costs and benefits of crossbreeding. Further research is needed, such as trials conducted across different seasons and locations, evaluations of disease resistance, and studies assessing the economic feasibility of large-scale application.

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